Application Priority Framework for Fixed Mobile Converged Communication Networks

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Abstract

The current prospects in wired and wireless access networks, it is becoming increasingly important to address potential convergence in order to offer integrated broadband services. These systems will need to offer higher data transmission capacities and long battery life, which is the catalyst for an ever-increasing variety of air interface technologies targeting local area to wide area connectivity.

Current integrated industrial networks do not offer application aware context delivery and enhanced services for optimised networks. Application aware services provide value-added functionality to business applications by capturing, integrating, and consolidating intelligence about users and their endpoint devices from various points in the network. This thesis mainly intends to resolve the issues related to ubiquitous application aware service, fair allocation of radio access, reduced energy consumption and improved capacity. A technique that measures and evaluates the data rate demand to reduce application response time and queuing delay for multi radio interfaces is proposed. The technique overcomes the challenges of network integration, requiring no user intervention, saving battery life and selecting the radio access connection for the application requested by the end user.

This study is split in two parts. The first contribution identifies some constraints of the services towards the application layer in terms of e.g. data rate and signal strength. The objectives are achieved by application controlled handover (ACH) mechanism in order to maintain acceptable data rate for real-time application services. It also looks into the impact of the radio link on the application and identifies elements and parameters like wireless link quality and handover that will influence the application type. It also identifies some enhanced traditional mechanisms such as distance controlled multihop and mesh topology required in order to support energy efficient multimedia applications. The second contribution unfolds an intelligent application priority assignment mechanism (IAPAM) for medical applications using wireless sensor networks. IAPAM proposes and evaluates a technique based on prioritising multiple virtual queues for the critical nature of medical data to improve instant transmission. Various mobility patterns (directed, controlled and random waypoint) has been investigated and compared by simulating IAPAM enabled mobile BWSN. The following topics have been studied, modelled, simulated and discussed in this thesis:

1. Application Controlled Handover (ACH) for multi radios over fibre
2. Power Controlled Scheme for mesh multi radios over fibre using ACH
3. IAPAM for Biomedical Wireless Sensor Networks (BWSN) and impact of mobility over IAPAM enabled BWSN

Extensive simulation studies are performed to analyze and to evaluate the proposed techniques. Simulation results demonstrate significant improvements in multi radios over fibre performance in terms of application response delay and power consumption by upto 75% and 15 % respectively, reduction in traffic loss by upto 53% and reduction in delay for real time application by more than 25% in some cases.

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Abbreviations and Acronyms

ABC	Always Best Connected
ACH	Application Controlled Handover
AP	Access Point
BAN	Body Area Network
BB	Baseband
BER	Bit Error Rate
BI	Beacon Interval
BP	Blood Pressure
BS	Base Station
BSS	Basic Service Set
BWA	Broadband Wireless Access
BWSN	Biomedical Wireless Sensor Network
CDMA	Code Division Multiple Access
CFP	Contention Free Period
CO	Central Office
CS	Central Station
CSMA/CA	Carrier Scenes Multiple Access with Collision Avoidance
DAC	Digital to Analogue Convertor
DAS	Distributed Antenna System
DCF	Distributed Coordination Function
DECT	Digital Enhanced Cordless Telecommunications
DFB	Distributed Feedback
DR	Dynamic Range
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplex
ECG	Electrocardiogram
EDFA	Erbium Doped Fibre Amplifier
EDR	Enhanced Data Rate
EEG	Electroencephalograph
EMG	Electromyogram
EMI	ElectroMagnetic Interference
EOG	Electrooculography
FBG	Fibre Bragg Gratings
FCC	Federal Communications Commission
FMC	Fixed Mobile Convergence
FTP	File Transfer Protocol
FWA	Fixed Wireless Access
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communication
GTS	Guaranteed Time Slot
HFR	Hybrid Fibre Radio
HR	High Rate
HSDPA	High-Speed Downlink Packet Access
HTTP	Hyper Transmission Transfer Protocol
IA	Intelligent Algorithm
IAPAM	Intelligent Application Priority Assignment Mechanism

IBSS	Independent Basic Service Set
ICT	Information and Communication Technologies
IETF	Internet Engineering Task Force
IMDD	Intensity Modulation and Direct Detection
IP	Internet Protocol
ISM	The industrial, Scientific and Medical
ISP	Internet Service Provider
JSIM	Java-based simulation system
LAN	Local Area Network
MAC	Media Access Layer
MANET	Mobile Ad hoc Network
MAS	Medium Access Slot
Mbps	Mega Bits Per Second
MBWA	Metropolitan Broadband Wireless Access
MCHO	Mobile-Controlled Handover
MDEV	Mesh Device
MMF	Multi Mode Fibre
MNC	Mesh Network Coordinator
MPNC	Mesh Pico Net Coordinator
MU	Mobile Unit
MUX	Multiplexer
NCHO	Network Controlled Handover
NF	Noise Figure
NIC	Network Interface Card
NS2	Network Simulator 2
OFDM	Orthogonal Frequency-Division Multiplexing
OLT	Optical Line Terminal
ONU	Optical Network Unit
OS	Operating System
OSI	Open System Interconnection.
OTDM	Optical Time Division Multiplexing
PCB	Probability of Blocking Connections
PDA	Personal Digital Assistant
PDF	Probability Distribution Function
PER	Packet Error Rate
PHD	Probability of Dropping Handovers
PHY	Physical Layer
PNC	Piconet Coordinator
POF	Polymer Optical Fibre
PON	Passive Optical Network
Pos	Position
PSRC	Power Source
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAM	Random Access Memory
RAP	Radio Access Point
RAU	Radio Access Unit
RF	Radio Frequency
RFD	Reduced-Function Device
RoF	Radio over Fibre

Rx	Receiver
SCM	Sub-Carrier Multiplexing
SD	Service Discovery
SDR	Software Defined Radio
SEC	Security
SIG	Special Interest Group
SIM	Subscriber Identity Module
SMF	Single Mode Fibre
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TRANS	Transport Layer
Tx	Transmitter
UMTS	Universal Mobile Telecommunication System
UWB	Ultra Wideband
VPN	Virtual Private Network
WDM	Wavelength Division Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WTU	Wireless Terminal Unit
WWIN	Wired Wireless Integration Network

Chapter 1

Introduction

1.1 Wireless Communication Systems

Wireless communication has experienced tremendous growth in the last decade. In 1991 less than 1% of the world's population had access to a mobile phone. By the end of 2001, an estimated one in every six people had a mobile phone [1]. During the same period the number of countries worldwide having a mobile network increased from just three to over 90%. In fact the number of mobile subscribers overtook the number of fixed-line subscribers in 2002. It is predicted that this growth will continue to rise, and by 2016 there will be more than 8 billion mobile subscribers worldwide [2] as shown in Figure 1.1.

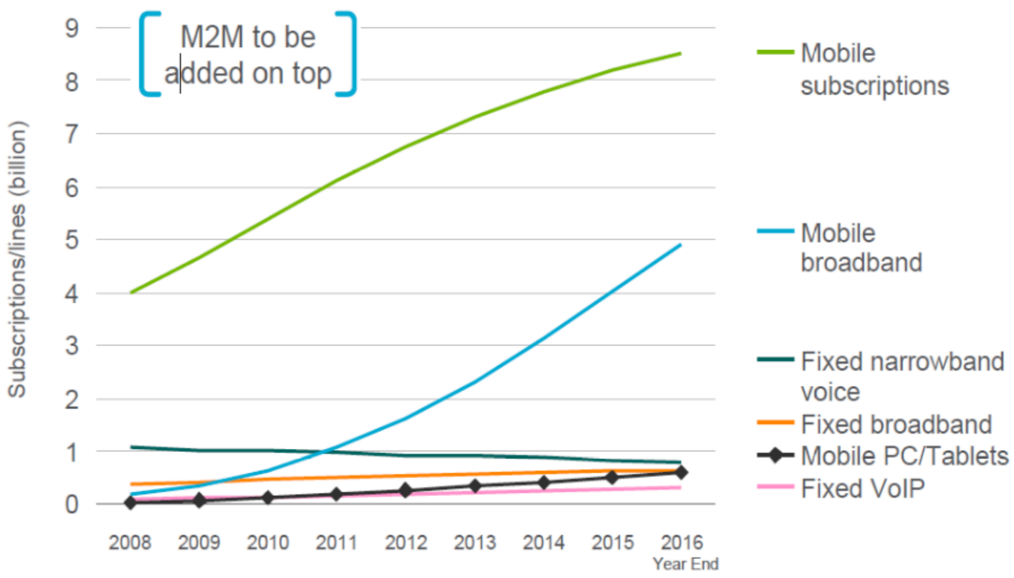

Figure 1.1: Growth of Fixed and Mobile Communications [2].

Apart from mobile telephone communications, Wireless Local Area Networks (WLANs), which came on the scene less than a decade ago (1997), have also experienced phenomenal growth. The rapid proliferation of WLAN hotspots in public places, such as airport terminals has been astounding. In fact WLANs have now made their way into homes, riding on the back of xDSL and cable access modems, which are now integrated with WLAN Radio Access Points (RAPs). As a result, the number of wireless Internet subscribers is expected to overtake the number of wired Internet users quite soon, as shown in Figure 1.1. The growth of wireless data systems is also seen in the many new standards, which have recently been developed or are currently under development as discussed in Section 1.2.

The rapid growth of wireless communications is mainly attributed to their ease of installation in comparison to fixed networks [1]. However, technological advancement, and competition among mobile operators have also contributed to the growth. So far there have been three mobile telephone standards, launched in succession approximately every decade. The first-generation (1G) mobile systems were analogue, and were commissioned in the 1980s. In the 1990s, second-generation (2G) digital mobile systems such as the Global System for Mobile communications (GSM) came on the scene. The GSM standard has been extremely successful, providing not only national, but also international coverage as well. Universal Mobile Telecommunication System (UMTS) is currently the mainstream mobile communication system referred as third-generation (3G).

Table 1.1: WLAN Standards

Year	**WLAN Standard**	**Frequency**	**Modulation**	**Bit Rare (Max)**
1997	IEEE 802.11	2.4 GHz	Frequency Hopping and Direct Spread Spectrum	2 Mbps
1998	Home RF	2.4 GHz	Wideband Frequency Hopping	1.6 Mbps
1999	IEEE 802.11b	2.4 GHz	Direct Sequence Spread Spectrum	11 Mbps
1999	IEEE 802.11a	5GHz	OFDM	54 Mbps
2000	HiperLAN 2	5 GHz	OFDM Connectionoriented	54 Mbps
2003	IEEE 802.11g	2.4 GHz	OFDM compatible with 802.11a	54 Mbps
2007	IEEE 802.11n	2.4/5 GHz	Quadrature Amplitude Modulation	600 Mbps

Both 1G and 2G systems were designed primarily to provide voice applications, and to support circuit-switched services [4]. However, GSM does offer data communication services to users, although the data rates are limited to just a few tens of kbps. In contrast, WLANs originally designed to provide fixed data network extension, support Mbps data transmission rates. The WLAN standard – IEEE 802.11, also known as Wi-Fi, was first commissioned in 1997 and offered 2 Mbps. Since then, the standard has evolved several times responding to the sustained user demand for higher bit-rates as shown in Table 1.1. Currently, WLANs are capable of offering up-to 54 Mbps for the IEEE 802.11a/g, and HiperLAN2 standards operating in the 2.4 GHz and 5 GHz license-free ISM bands. However, WLANs do not offer the kind of mobility, which mobile systems do.

1.2 Broadband Wireless Communication System

The explosive growth of the Internet, and the success of 2G and 3G systems together with WLANs have had a profound impact on our perception of communication. First of all, the vast majority of users now believe in the new notion of "always on" communication. We are now living in the era of ubiquitous connectivity or "communication anytime, anywhere, and with anything".

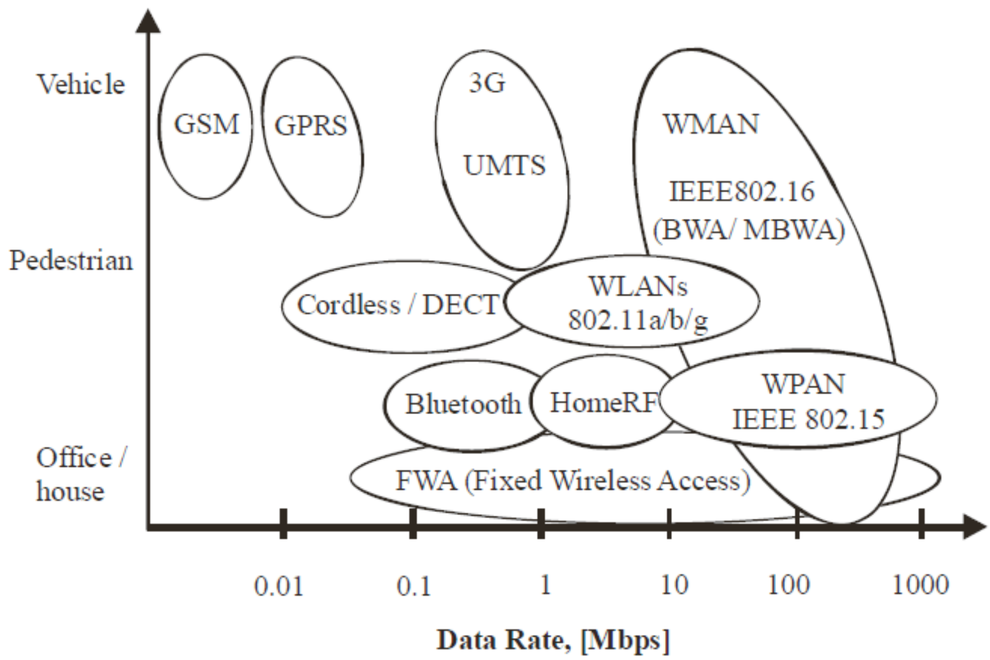

Figure 1.2: Current and Future Wireless Communication Systems [2], [4], [5].

Secondly, the concept of broadband communication has caught on very well. As fibre penetrates closer to the end-user environment (Fibre To The Home/Curb/X, FTTH/C/X), wired transmission speeds will continue to rise. Transmission speeds such at 100 Mbps (Fast Ethernet) are now beginning to reach homes. The demand to have this broadband capacity also wirelessly has put pressure on wireless communication systems to increase both their transmission capacity, as well as their coverage.

In general there is a trade off between coverage and capacity. Figure 1.2 shows the relationship between some of the various standards (present and future), in terms of mobility (coverage), and capacity. For instance, the cell size of Wireless Personal Area Networks (WPANs) is typically a few metres (picocell), while their transmission rates may reach several tens of Mbps. On the other hand 2G (e.g. GSM), and 3G (e.g. Universal Mobile Telecommunication System (UMTS) and the International Mobile Telecommunications (IMT2000)) systems have cells that extend several kilometres, but have data rates limited to less than 2 Mbps. Therefore, as mobile communication systems seek to increase capacity, and wireless data systems seek to increase coverage, they will both move towards convergence. A case in point is the IEEE 802.16, otherwise known as WiMAX, which appears to lend weight to the notion of convergence, as shown in Figure 1.2. WiMAX seeks to provide high-bit rate mobile services using frequencies between 2 – 11 GHz. In addition, WiMAX also aims to provide Fixed Wireless Access (FWA) at bit-rates in the excess of 100 Mbps and at higher frequencies between 10 – 66 GHz [6].

1.3 Challenges of Broadband Wireless Access Network

Figure 1.3 illustrates the configuration of narrowband wireless access systems (e.g. GSM) as we know them today. The central office handles call processing and switching, while the Base Stations (BS) act as the radio interfaces for the Mobile Units (MU) or Wireless Terminal Units (WTU). The BSs may be linked to the central office through either analogue microwave links or digital fibre optic links. Once the baseband signals are received at the BS, they are processed and modulated onto the appropriate carrier. The radius covered by the signal from the BS is the cell radius.

All the MU/WTU within the cell, share the radio frequency spectrum. WLANs are configured in a similar fashion, with the radio interface called the Radio Access Point (RAP).

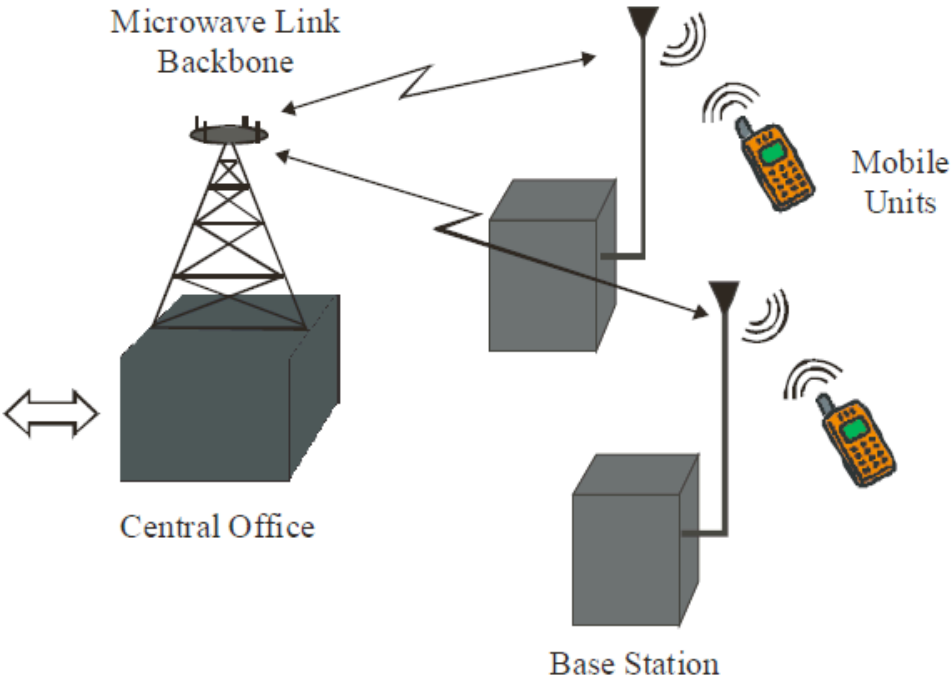

Figure 1.3: Components of Narrowband Wireless Access Network.

In general, low carrier frequencies offer low bandwidth. Therefore, part of the reason why narrowband wireless access systems (e.g. 2G) offer limited capacity is because they operate at low frequencies. For instance GSM operates at frequencies around 900 or 1800 MHz with 200 kHz allocated frequency spectrum. UMTS operates at frequencies around 2 GHz and has 4 MHz allocated bandwidth [7]. However, there is also stiff competition for frequency spectrum among the many wireless communication systems using carrier frequencies below 6 GHz. These include radio and TV broadcasts, and systems for (vital) communication services such as airports, police and fire, amateur radio users, wireless LANs, and many others. Low frequencies allow for low cost radio front-ends (in the BS and the MU/WTU). In addition, the efficiency of RF active devices (transistors) is higher at low frequencies, than at high frequencies. For instance, at millimetre wave frequencies the efficiency of active devices can be as low as 30 % [9]. Therefore, the low-power consumption advantage of systems operating at low frequencies is quite significant. Furthermore, low-frequency RF signals allow for larger cells, due to the longer reach of the radio waves. The larger cells enable high mobility, but lead to poor spectrum efficiency, since the spectrum is shared by all MUs/WTUs operating within the cell [7].

Therefore, one natural way to increase capacity of wireless communication systems is to deploy smaller cells (micro- and pico-cells). This is generally difficult to achieve at low-frequency microwave carriers, but by reducing the radiated power at the antenna, the cell size may be reduced somewhat. Pico-cells are also easier to form inside buildings, where the high losses induced by the building walls help to limit the cell size. In contrast, the high propagation losses, which radio waves experience at mmwave frequencies, together with the line-of-site requirements, help to form small cells. Another way to increase the capacity of wireless communication systems is to increase the carrier frequencies, to avoid the congested ISM band frequencies. Higher carrier frequencies offer greater modulation bandwidth, but may lead to increased costs of radio front-ends in the BSs and the MUs/WTUs.

Smaller cell sizes lead to improved spectral efficiency through increased frequency reuse. But, at the same time, smaller cell sizes mean that large numbers of BSs or RAPs are needed in order to achieve the wide coverage required of ubiquitous communication systems. Furthermore, extensive feeder networks are needed to service the large number of BSs/RAPs. Therefore, unless the cost of the BSs/RAPs, and the feeder network are significantly low, the system-wide installation and maintenance costs of such systems would be rendered prohibitively high. This is where Radio-over-Fibre (RoF) technology comes in. It achieves the simplification of the BSs/RAPs (referred to as Remote Antenna Units – RAUs) through consolidation of radio system functionalities at a centralised headend, which are then shared by multiple RAUs. In addition, a further reduction in system costs may be achieved if low-cost multimode fibres are used in the extensive feeder network [10].

Therefore, for broadband wireless communication systems to offer the needed high capacity, it appears inevitable to increase the carrier frequencies and to reduce cell sizes. This is evident from the new standards in the offing, which are aiming to use mm-waves. For example the recently formed IEEE 802.15 WPAN standard Task Group 3c is aiming to use the unlicensed mm-wave bands between 57 - 64 GHz for very-high-speed short-range communication offering up-to 2 Gbps [7]. The IEEE 802.16 (WiMAX) standard specifies frequencies between 10–66 GHz for the first/last mile Fixed Wireless Access (FWA). A summary of the operating frequencies for some of the current and future (broadband) wireless systems is given in Table 1.2.

Table 1.2: Frequencies for Wireless Broadband Communications

Frequency	Wireless Systems
2 GHz	UMTS / 3G Systems
2.4 GHz	IEEE 802.11 b/g WLAN
5 GHz	IEEE 802.11 a WLAN
2 – 11 GHz	IEEE 802.16 WiMAX
17/19 GHz	Indoor Wireless (Radio) LANs
28 GHz	Fixed wireless access – Local point to Multipoint (LMDS)
38 GHz	Fixed wireless access, Picocellular
58 GHz	Indoor wireless LANs
57 – 64 GHz	IEEE 802.15 WPAN
10 – 66 GHz	IEEE 802.16 - WiMAX

1.4 Radio over Fibre Technology

1.4.1. What is RoF

Radio-over-Fibre (RoF) technology entails the use of optical fibre links to distribute RF signals from a central location (headend) to Remote Antenna Units (RAUs). In narrowband communication systems and WLANs, RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing, are performed at the BS or the RAP, and immediately fed into the antenna. RoF makes it possible to centralise the RF signal processing functions in one shared location (headend), and then to use optical fibre, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs, as shown in Figure 1.4. By so doing, RAUs are simplified significantly, as they only need to perform optoelectronic conversion and amplification functions. The centralisation of RF signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance. These benefits can translate into major system installation and operational savings [8], especially in wide-coverage broadband wireless communication systems, where a high density of BS/RAPs is necessary as discussed above.

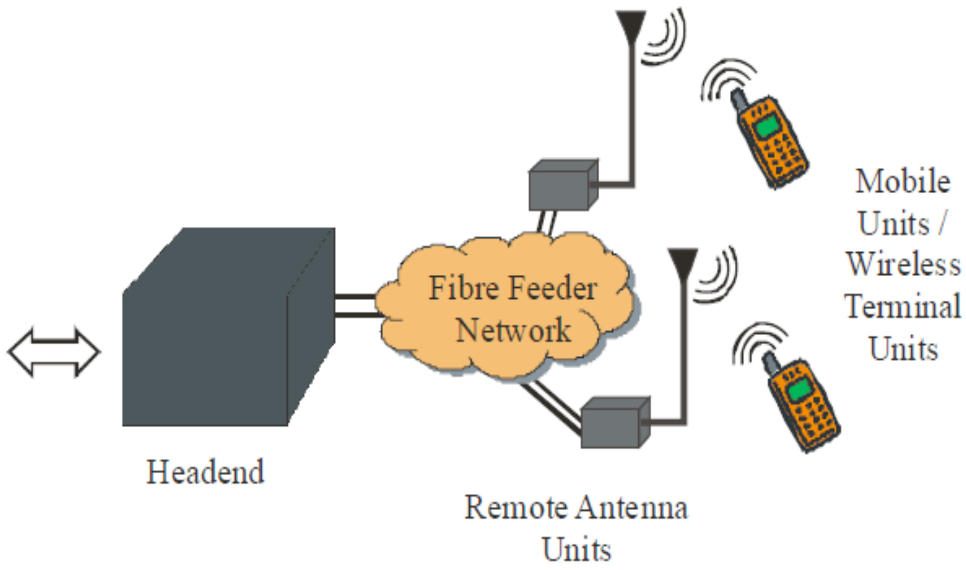

Figure 1.4: The RoF Concept.

One of the pioneer RoF system implementations is depicted in Figure 1.5. Such a system may be used to distribute GSM signals, for example. The RF signal is used to directly modulate the laser diode in the central site (headend). The resulting intensity modulated optical signal is then transported over the length of the fibre to the BS (RAU). At the RAU, the transmitted RF signal is recovered by direct detection in the PIN photodetector. The signal is then amplified and radiated by the antenna. The uplink signal from the MU is transported from the RAU to the headend in the same way. This method of transporting RF signals over the fibre is called Intensity Modulation with Direct Detection (IM-DD), and is the simplest form of the RoF link.

While Figure 1.5 shows the transmission of the RF signal at its frequency, it is not always necessary to do that. For instance, a Local Oscillator (LO) signal, if available, may be used to down-convert the uplink carrier to an IF in the RAU. Doing so would allow for the use of low-frequency components for the up-link path in the RAU – leading to system cost savings. Instead of placing a separate LO in the RAU, it may be transported from the headend to the RAU by the RoF system. Once available at the RAU, the LO may then be used to achieve down-conversion of the uplink signals. This results in a much simpler RAU. In this configuration, the downlink becomes the crucial part of the RoF since it has to transport high-frequency signals. The transportation of high-frequency signals is more challenging because it require high frequency components, and large link bandwidth. This means that high-frequency signals are more susceptible to transmitter, receiver, and transmission link signal impairments.

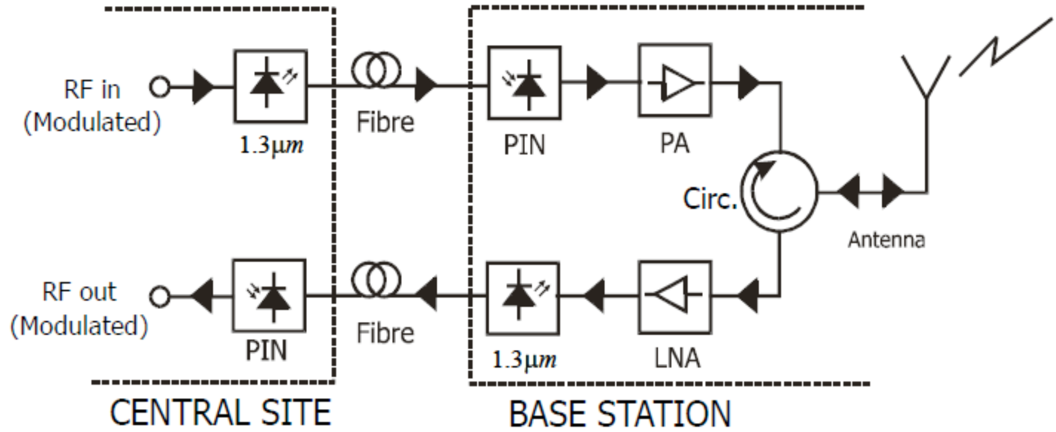

Figure 1.5: 900MHz Fibre-Radio System [9].

Apart from IM-DD, other methods, which involve signal frequency up-conversion in addition to distribution, can also be used.

1.4.2. Advantages of RoF

Some of the advantages and benefits of the RoF technology compared with electronic signal distribution are given below.

A. Low Attenuation Loss

Electrical distribution of high-frequency microwave signals either in free space or through transmission lines is problematic and costly. In free space, losses due to absorption and reflection increase with frequency [5]. In transmission lines, impedance rises with frequency as well, leading to very high losses [11]. Therefore, distributing high frequency radio signals electrically over long distances requires expensive regenerating equipment. As for mm-waves, their distribution via the use of transmission lines is not feasible even for short distances. The alternative solution to this problem is to distribute baseband signals or signals at low intermediate frequencies (IF) from the switching centre (headend) to the BS [1]. The baseband or

IF signals are up-converted to the required microwave or mm-wave frequency at each base station, amplified and then radiated. This system configuration is the same as the one used in the distribution of narrowband mobile communication systems shown in Figure 1.3. Since, high performance LOs would be required for up-conversion at each base station, this arrangement leads to complex base stations with tight performance requirements. However, since optical fibre offers very low loss, RoF technology can be used to achieve both low-loss distribution of mm-waves, and simplification of RAUs at the same time. Commercially available standard Single Mode Fibres (SMFs) made from glass (silica) have attenuation losses below 0.2 dB/km and 0.5 dB/km in the 1550 nm and the 1300 nm windows, respectively. Polymer Optical Fibres (POFs), a more recent kind of optical fibre exhibits higher attenuation ranging from 10 – 40 dB/km in the 500 – 1300 nm regions [12], [13]. These losses are much lower than those encountered in, say coaxial cable, whose losses are higher by three orders of magnitude at higher frequencies. For instance, the attenuation of a 1/2 inch coaxial cable (RG-214) is >500 dB/km for frequencies above 5 GHz [14]. Therefore, by transmitting microwaves in the optical form, transmission distances are increased several folds and the required transmission powers reduced greatly.

B. Large Bandwidth

Optical fibres offer enormous bandwidth. There are three main transmission windows, which offer low attenuation, namely the 850 nm, 1310 nm, and 1550 nm wavelengths. For a single SMF optical fibre, the combined bandwidth of the three windows is in the excess of 50 THz [15]. However, today's state-of-the-art commercial systems utilize only a fraction of this capacity (1.6 THz). But developments to exploit more optical capacity per single fibre are still continuing. The main driving factors towards unlocking more and more bandwidth out of the optical fibre include the availability of low dispersion (or dispersion shifted) fibre, the Erbium Doped Fibre Amplifier (EDFA) for the 1550 nm window, and the use of advanced multiplex techniques namely Optical Time Division Multiplexing (OTDM) in combination with Dense Wavelength Division Multiplex (DWDM) techniques. The enormous bandwidth offered by optical fibres has other benefits apart from the high capacity for transmitting microwave signals. The high optical bandwidth enables high speed signal processing that may be more difficult or impossible to do in electronic systems. In other words, some of the demanding microwave functions such as filtering, mixing, up- and down-conversion, can be implemented in the optical domain [16]. For instance, mm-wave filtering can be achieved by first converting the electrical signal to be filtered into an optical signal, then performing the filtering by using optical components such as the Mach Zehnder Interferometer (MZI) or Fibre Bragg Gratings (FBG), and then converting the filtered signal back into electrical form [17]. Furthermore, processing in the optical domain makes it possible to use cheaper low bandwidth optical components such as laser diodes and modulators, and still be able to handle high bandwidth signals [17]. The utilization of the enormous bandwidth offered by optical fibres is severely hampered by the limitation in bandwidth of electronic systems, which are the primary sources and receivers of transmission data. This problem is referred to as the "electronic bottleneck". The solution around the electronic bottleneck lies in effective multiplexing. OTDM and DWDM techniques mentioned above are used in digital optical systems. In analogue optical systems including RoF technology, Sub-Carrier Multiplexing (SCM) is used to increase optical fibre bandwidth utilization. In SCM, several microwave subcarriers, which are modulated with digital or analogue data, are combined and used to modulate the optical signal, which is then carried on a single fibre [19], [20]. This makes RoF systems cost-effective.

C. Immunity to Radio Frequency Interference

Immunity to ElectroMagnetic Interference (EMI) is a very attractive property of optical fibre communications, especially for microwave transmission. This is so because signals are transmitted in the form of light through the fibre. Because of this immunity, fibre cables are preferred even for short connections at mm-waves. Related to EMI immunity is the immunity to eavesdropping, which is an important characteristic of optical fibre communications, as it provides privacy and security.

D. Easy Installation and Maintenance

In RoF systems, complex and expensive equipment is kept at the headend, thereby making the RAUs simpler. For instance, most RoF techniques eliminate the need for a LO and related equipment at the RAU. In such cases a photodetector, an RF amplifier, and an antenna make up the RAU. Modulation and switching equipment is kept in the headend and is shared by several RAUs. This arrangement leads to smaller and lighter RAUs, effectively reducing system installation and maintenance costs. Easy installation and low maintenance costs of RAUs are very important requirements for mm-wave systems, because of the large numbers of the required RAUs. In applications where RAUs are not easily accessible, the reduction in maintenance requirements leads to major operational cost savings [8], [11]. Smaller RAUs also lead to reduce environmental impact.

E. Reduced Power Consumption

Reduced power consumption is a consequence of having simple RAUs with reduced equipment. Most of the complex equipment is kept at the centralised headend. In some applications, the RAUs are operated in passive mode. For instance, some 5 GHz Fibre-Radio systems employing pico-cells can have the RAUs operate in passive mode [21]. Reduced power consumption at the RAU is significant considering that RAUs are sometimes placed in remote locations not fed by the power grid.

F. Multi-Operator and Multi-Service Operation

RoF offers system operational flexibility. Depending on the microwave generation technique, the RoF distribution system can be made signal-format transparent. For instance the Intensity Modulation and Direct Detection (IM-DD) technique can be made to operate as a linear system and therefore as a transparent system. This can be achieved by using low dispersion fibre (SMF) in combination with pre-modulated RF subcarriers (SCM). In that case, the same RoF network can be used to distribute multi-operator and multi-service traffic, resulting in huge economic savings [8].

G. Dynamic Resource Allocation

Since the switching, modulation, and other RF functions are performed at a centralized headend, it is possible to allocate capacity dynamically. For instance in a RoF distribution system for GSM traffic, more capacity can be allocated to an area (e.g. shopping mall) during peak times and then re-allocated to other areas when offpeak (e.g. to populated residential areas in the evenings). This can be achieved by allocating an optical wavelength through Wavelength Division Multiplexing (WDM) as need arises. Allocating capacity dynamically as need for it arises obviates the requirement for allocating permanent capacity, which would be a waste of resources in cases where traffic loads vary frequently and by large margins [8]. Furthermore, having the centralised headend facilitates the consolidation of other signal processing functions such as mobility functions, and macro diversity transmission.

1.4.3. Limitations of RoF

Since RoF involves analogue modulation, and detection of light, it is fundamentally an analogue transmission system. Therefore, signal impairments such as noise and distortion, which are important in analogue communication systems, are important in RoF systems as well. These impairments tend to limit the Noise Figure (NF) and Dynamic Range (DR) of the RoF links. DR is a very important parameter for mobile (cellular) communication systems such as GSM because the power received at the BS from the MUs varies widely (e.g. 80 dB [8]). That is, the RF power received from a MU, which is close to the BS, can be much higher than the RF power received from a MU, which is several kilometres away, but within the same cell.

The noise sources in analogue optical fibre links include the laser's Relative Intensity Noise (RIN), the laser's phase noise, the photodiode's shot noise, the amplifier's thermal noise, and the fibre's dispersion. In Single Mode Fibre (SMF) based RoF, systems, chromatic dispersion may limit the fibre link lengths and may also cause phase de-correlation leading to increased RF carrier phase noise [5]. In Multi-Mode Fibre based RoF systems, modal dispersion severely limits the available link bandwidth and distance. It must be stated that although the RoF transmission system itself is analogue, the radio system being distributed need not be analogue as well, but it may be digital (e.g. WLAN, UMTS), using comprehensive multi-level signal modulation formats such as xQAM, or Orthogonal Frequency Division Multiplexing (OFDM).

1.5 Integrating Wireless and Fibre Optics

For the future provision of broadband, interactive and multimedia services over wireless media, current trends in cellular networks - both mobile and fixed are 1) to reduce cell size to accommodate more users and 2) to operate in the microwave/millimetre wave (mm-wave) frequency bands to avoid spectral congestion in lower frequency bands. It demands a large number of base stations (BSs) to cover a service area, and cost-effective BS is a key to success in the market. This requirement has led to the development of system architecture where functions such as signal routing/processing, handover and frequency allocation are carried out at a central control station (CS), rather than at the BS. Furthermore, such a centralized configuration allows sensitive equipment to be located in safer environment and enables the cost of expensive components to be shared among several BSs. An attractive alternative for linking a CS with BSs in such a radio network is via an optical fibre network, since fibre has low loss, is immune to EMI and has broad bandwidth. The transmission of radio signals over fibre, with simple optical to electrical conversion, followed by radiation at remote antennas, which are connected to a central CS, has been proposed as a method of minimizing costs. The reduction in cost can be brought about in two ways. Firstly, the remote antenna BS or radio distribution point needs to perform only simple functions, and it is small in size and low in cost. Secondly, the resources provided by the CS can be shared among many antenna BSs.

To be specific, the RoF network typically comprises a central CS, where all switching, routing, medium access control (MAC) and frequency management functions are performed, and an optical fibre network, which interconnects a large number of functionally simple and compact antenna BSs for wireless signal distribution. The BS has no processing function and its main function is to convert optical signal to wireless one and vice versa. Since RoF technology was first demonstrated for cordless or mobile telephone service in 1990 [22], a lot of research efforts have been made to investigate its limitation and develop new, high performance RoF technologies. Their target applications range from mobile cellular networks [23]-[25], wireless local area network (WLAN) at mm-wave bands [26], broadband wireless access networks [27]-[30] to road vehicle communication (RVC) networks for intelligent transportation system (ITS) [31]-[33]. Due to the simple BS structure, system cost for deploying infrastructure can be dramatically reduced compared to other wireline alternatives. In addition to the advantage of potential low cost, RoF technology has the further a benefit of transferring the RF signal to and from a CS that can allow flexible network resource management and rapid response to variations in traffic demand due to its centralized network architecture. In summary, some of its important characteristics are described below [8]:

1. The system control functions, such as frequency allocation, modulation and demodulation scheme, are located within the CS, simplifying the design of the BS. The primary functions of the BSs are optical/RF conversion, RF amplification, and RF/optical conversion.

2. This centralized network architecture allows a dynamic radio resource configuration and capacity allocation. Moreover, centralized upgrading is also possible.

3. Due to simple BS structure, its reliability is higher and system maintenance becomes simple.

4. In principle, optical fibre in RoF is transparent to radio interface format (modulation, radio frequency, bit rate and so on) and protocol. Thus, multiple services on a single fibre can be supported at the same time.

5. Large distances between the CS and the BS are possible.

On the other hand, to meet the explosive demands of high-capacity and broadband wireless access, millimetre-wave (mm-wave) radio links (26ñ100 GHz) are being considered to overcome bandwidth congestion in microwave bands such as 2.4 or 5 GHz for application in broadband micro/picocellular systems, fixed wireless access, WLANs, and ITSs [34]-[37]. The larger RF propagation losses at these bands reduce the cell size covered by a single BS and allow an increased frequency reuse factor to improve the spectrum utilization efficiency. Recently, considerable attention has been paid in order to merge RoF technologies with mm-wave band signal distribution [38]-[44]. The system has a great potential to support cost-effective and high capacity wireless access. The distribution of radio signals to and from BSs can be either mm-wave modulated optical signals (RF-over-fibre), or lower frequency subcarriers (IF-over-fibre). Signal distribution as RF-over-fibre has the advantage of a simplified BS design but is susceptible to fibre chromatic dispersion that severely limits the transmission distance [45]. In contrast, the effect of fibre chromatic dispersion on the distribution of intermediate-frequency (IF) signals is much less pronounced, although antenna BSs implemented for RoF system incorporating IF-over-fibre transport require additional electronic hardware such as a mm-wave frequency local oscillator (LO) for frequency up and down conversion. These research activities fuelled by rapid developments in both photonic and mm-wave technologies suggest simple BSs based on RoF technologies will be available in the near future. However, while great efforts have been made in the physical layer, little attention has been paid to upper layer architecture. Specifically, centralized architecture of RoF networks implies the possibility that resource management issues in conventional wireless networks could be efficiently addressed. As a result, it is required to reconsider conventional resource management schemes in the context of RoF networks.

1.6 The Research Aim and Contributions

The aim of this work is to enhance the multi radios over fibre architecture in the following aspects:

A. Application Controlled Handover

This work provides a solution to enhance the radio interface selection for the mobile user. The radio interface selection criterion is based on the application type such as HTTP, FTP and video conferencing and communications. The proposed enhanced handover mechanism is cross layer design according to the current request and session of the device application. Applying the proposed approach leads to better radio interface selection and more network efficiency as shown in the achieved results in Chapter three.

B. Cross Layer Information Exchange

The second major goal of this research is to introduce the cross layer concept to the wired wireless converged standard. According to this concept, the Application, Transport, MAC and PHY layers exchange application type information to initiate radio interface suitable for application requested by user. This concept enhances the standard network convergence and integration. If the user has lower battery, the handover mechanism will initiate for suitable interface for lower power consumption.

C. Mesh Formation and Scalability

Mesh formation for multi radio over optical network integration has been introduced in Chapter four. Wireless gives you mobility, optical fibre is more secure, and have terahertz of bandwidth. WiFi and WiMAX have been used for mesh connectivity to router traffic through mesh routers with a functionality of radio access units.

D. Power Management

Power management in wireless radios has been studied in this work. A simple model is based on controlling the transmitter power to reach the minimum required power at the receiver. The data sender and the data receiver devices exchange control messages before and during data transmission. These control messages are used to maintain the transmission power in the sender device to the minimum. This approach is simple and efficient comparing to other power management approaches. This approach minimises the interference and reduces the general power consumption in the network.

E. Application Priority Assignment for BWSN

Furthermore, application priority based on the important of medical data has been proposed in order to enhance the wireless sensor network model. This simulation model is used to emulate the real-life wireless sensors, where the medical data is related upon the application type. In the proposed model, the device applications are switched between different applications and virtual data queues are prioritised. An intelligent application priority assignment mechanism has been described, developed and proved by simulation that end-to-end delay is reduced and the network throughput is increased comparing to the normal standard of BWSN as presented in Chapter five.

F. Mobility Strategies for IAPAM enabled BWSN

An IEEE 802.15.4 based IAPAM enabled BWSN is composed at variable speeds (5m/s, 10 m/s and 20 m/s) which depicts a mobile patient at hospital or home. In proposed scenarios, the mobile node uses different mobility patterns and their impact on the performance over the mobile BWSN.

1.7 Applications and the Future Networks

RoF technology is generally unsuitable for system applications, where high Spurious Free Dynamic Range (SFDR = maximum output signal power for which the power of the third-order inter-modulation product is equal to the noise floor) is required, because of the limited DR. This is especially true of wide coverage mobile systems such as GSM, where SFDR of > 70 dB (outdoor) are required. However, most indoor applications do not require high SFDR. For instance, the required (uplink) SFDR for GSM reduces from >70 dB to about 50 dB for indoor applications. Therefore, RoF distribution systems can readily be used for in-building (indoor) distribution of wireless signals of both mobile and data communication (e.g. WLAN) systems. In this case the RoF system becomes a Distributed Antenna System (DAS). For high frequency applications such as WPAN, the cell size will be small due to high losses through the walls, bringing the advantages of RoF discussed above. The in-building fibre infrastructure may then be used for both wired and wireless applications. Using MMF or indeed POF instead of SMF fibres to feed the RAUs may further reduce system installation and maintenance costs, especially for in-door applications. In-building data communications LANs are often based on MMF.

RoF systems are also attractive for other present and future applications where high SFDR is not required. For instance, UMTS MUs are required to control their transmitter power so that equal power levels are received at the BS. Thus, UMTS does not need the high SFDR required in GSM, so that RoF distribution systems may be used for both indoor and outdoor UMTS signal distribution [8]. Another application area is in Fixed Wireless Access (FWA) systems, such as WiMAX, where RoF technology may be used to optically transport signals over long distances bringing the significantly simplified RAUs closer to the end user, from where wireless links help to achieve broadband first/last mile access, in a cost effective way.

High data rate and quality of service QoS are crucial for video, audio and Internet interaction. Furthermore, future applications such as health care and personal security applications should be considered in the WPAN HR protocol with special requirements for power consumption and data security. New approach for more efficient Service Discovery (SD) algorithm is required in order to enhance the expanding WPAN networks. Several approaches of service discovery could be applied to the WPAN and cross-layered with the MAC HR protocol.

Internet dynamic access and smart house applications could be adapted by the WPAN protocol. Internet gateway interaction with WPAN could be developed in the aspect of access point to access point handover, where the personal device could maintain external connectivity when it is relocated.

Cross Layer interaction could be applied in order to exchange parameters, which belong to various layers in the wireless device (from PHY to APP layers). Lower layers such as PHY/MAC and D-LINK could exchange some parameters with higher layers such as the TRANS and APP layers. These parameters provide more information about the user and the device/network status.

1.8 Objectives and Research Methodology

This research is based on the following steps:

1. Review of the wireless and fibre optics standard and the related publications about their convergence and integration protocols.

2. Intensive study and assessment of the potential weakness in the optical wireless hybrid standard and suggest a network architecture solution to enhance FMC.

3. Modelling and analysis of the application controlled protocol performance in order to prove the improved network design.

4. Introducing power management scheme and mesh formation in wireless domain to enhance application controlled proposed converged next generation network.

5. Simulate the proposed approach and compare it with the standard optical wireless integrated network.

6. Application priority assignment for BWSN to enhance the transmission mechanism of patient’s critical data.

7. Verify the models and analyze the mobility patterns for biomedical wireless sensor networks.

1.8.1. Simulation Environment

In this thesis, OPNET [46] and JSIM [47] are used to implement and study optical wireless integrated environment and wireless sensor network design. Prior to start implementing the model, a training period is required in order to build some skills in simulation tools. Some simple models are implemented in OPNET and improved to accomplish the final design. Furthermore, simulators documentations help files and the supplied tutorial have been applied to enhance the simulation experience.

1.8.2. Model Design

Building a custom model using OPNET node simulates the application controlled handover model. Behaviour of all devices in the network is implemented in this design. The node model is mapped to a process model, which is designed using C/C++ languages and some built-in OPNET library functions. JSIM is used for simulations for BWSN. Based on same theory of application controlled handover, application priority assignment is developed in JSIM to enhance the proficiency of standard BWSN.

1.8.3. Comparison of Simulation Results

The proposed designs are compared with the original standards in order to show the enhancement achieved in the proposed approaches. The new designs are based on introducing the user applications and improvement of BWSN. The simulation results are presented in Chapter Three, Chapter Four, Chapter Five and Chapter Six respectively.

1.9 The Thesis Structure

This section presents the organization of this thesis, where Chapter One presents the introduction of the work with some background about the wireless communication systems and radio over fibre technologies. For none-expert readers, this chapter is important to understand the rest of this thesis.

Chapter Two presents the relevant literature review, where previous work and several papers in the related field have been presented.

Chapter Three is dealing with the proposal of application controlled handover scheme, enhancement of the integrated network protocol by proposing a new capability of switching criteria of radio interfaces. In this chapter, the integrated hybrid network based on multiple radio interfaces and RoF technology are described. Then, the smart handover scheme presented, developed and simulated. Finally, the comparative results are discussed in details.

In Chapter Four, the power management scheme is presented. The power controlled scheme is implemented on top of application controlled handover to enhance the network performance in terms of power and data transmission. A WiFi and WiMAX mesh access units (Mesh Routers) are also deployed. The proposed approach uses much lower power and higher throughput. The mesh based power and application controlled handover concept in the optical wireless integrated network is described in detail in this chapter and simulation scenario using OPNET™ modelor is implemented and results have shown the network improvements.

In Chapter Five, description of the BWSN simulation model and JSIM simulation environment are presented. In this chapter, intelligent application priority assignment mechanism is described with the control and switching module. Virtual queues and new set of parameters proposed in superframe of standard BWSN. Priority queue collects the critical data and triggers the urgent transmission for patient's timely monitoring. The scheme is proposed, discussed, developed and simulated and compared in this chapter.

In Chapter six, description of the mobility models for IAPAM enabled BWSN has been presented. In this chapter, a successful study of variable mobility has been introduced over IAPAM enabled BWSN. The random, controlled and directed mobility schemes are discussed, deployed and simulated and discussed in this chapter.

Chapter Seven presents the research conclusions and the future work. Furthermore, summary of the challenges and solutions, which are presented in this thesis are included in Chapter Seven.

At the end of the thesis, a list of the published and submitted papers is presented.

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Chapter 2

Background and Literature Review

This chapter presents some basic background of Radio over Fibre technology, a brief description of wireless technologies, handover issues and in depth literature review for proposed handover technologies addressed in Chapters 3, 4 and 5. This chapter constitutes of three major parts. The first part briefly covers basic optical fibre transmission link and RoF technologies. The second part presents all related wireless and mobile technologies; WLAN, WiMAX, WPAN (UWB, ZigBee) and UMTS, while the third part unfolds the related work done in the relevant research area of handover management schemes.

Therefore, this chapter will present the background and literature review in the following fields:

- Radio over Fibre Technology
- Wireless Mobile Technologies
- Handover in Wireless Mobile Networks

2.1 Radio over Fibre Technologies

Wireless networks based on RoF technologies have been proposed as a promising cost-effective solution to meet ever-increasing user bandwidth and wireless demands. Since it was first demonstrated for cordless or mobile telephone service in 1990 [1], a lot of research has been carried out to investigate its limitation and develop new and high performance RoF technologies. In this network a central station (CS) is connected to numerous functionally simple BSs via an optic fibre. The main function of BS is to convert optical signal to wireless one and vice versa. Almost all processing including modulation, demodulation, coding, routing is performed at the

CS. That means, RoF networks use highly linear optic fibre links to distribute RF signals between the CS and BSs.

Figure 2.1 presents a general RoF architecture. At a minimum, RoF link consists of all the hardware required to impose an RF signal on an optical carrier, the fibre optic link, and the hardware required to recover the RF signal from the carrier. The optical carrier's wavelength is usually selected to coincide with either the 1.3 µm at which standard single-mode fibre has minimum dispersion, or the 1.55 µm at which its attenuation is minimum.

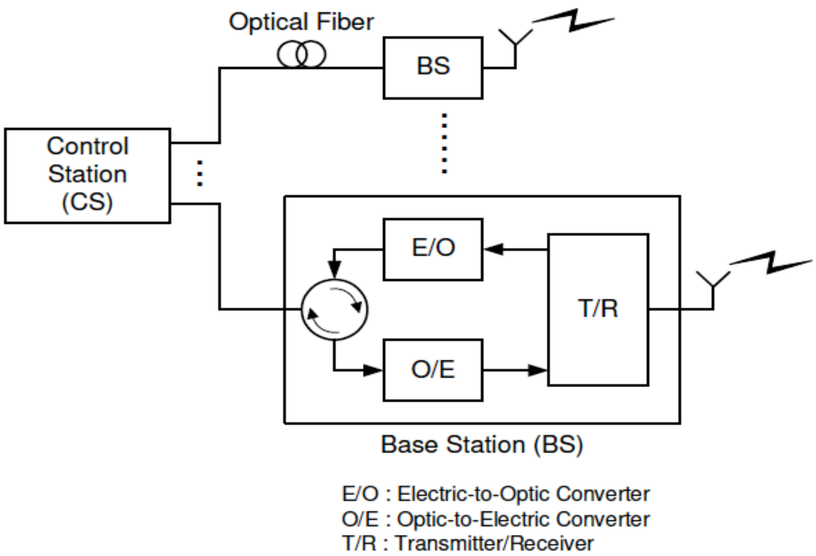

Figure 2.1: Radio over Fibre System [1].

2.1.1. Optical Transmission Link

In the first part of this section, a general optical transmission link, shown in Figure 2.2, is briefly described for which it is assume that a digital pulse signal is transmitted over optical fibre unless otherwise specified. The optical link consists of an optical fibre, transmitter, receiver and two amplifiers.

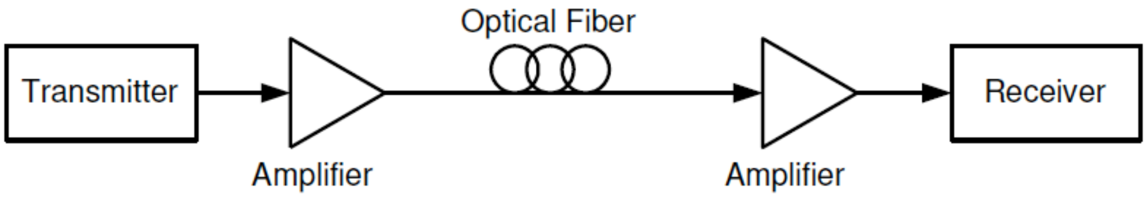

Figure 2.2: Optical Transmission Link [1].

2.2 Wireless Mobile Technologies

Ever since the emergence of wireless networks as a ubiquitous solution that increases connectivity in inaccessible areas, security has been a major concern. This section presents different wireless networks by providing a better insight of their functionalities and limitations. Furthermore a detailed analysis on the IEEE 802.x wireless networks, with special focus on the WiFi and WiMAX is provided. As much as the convergence of these two wireless networks is the main focus of this research, other wireless networks such as UWB, Blutooth and ZigBee and private owned mobile cellular networks are discussed as alternative technologies. The mobile cellular technology is analyzed in terms of their suitability when mixed with either WiFi or WiMAX in providing data, voice and video services to wireless networking clients. The analysis of the converged WiFi and WiMAX highlights the protocols and mechanism functionalities and limitations.

2.2.1. The IEEE 802.x wireless networks

The IEEE has established a variety of wireless standards and protocols, which are defined within the 802 families. The 802.x family has a series of specifications for different local area network (LAN) technologies [2]. In this section below brief overview of IEEE 802.x wireless standards are presented.

A. IEEE 802.11 standards (WiFi)

The IEEE 802.11wireless standard, also known as Wireless Fidelity was designed to provide flexibility and portability compared to the traditional wired networks. These wireless standards specify the wireless interface between wireless clients and the access point. The 802.11 standard is part of the IEEE 802 Networks family. This standard defines how the wireless network handles the lower layers of the OSI (Physical and Medium Access Control layers) [2] as they are different from their wired networks counterpart. The PHY layer specifies all the details for transmission and reception will the MAC layer set rules to determine how to access the medium and transmission. The major aim for defining the 802.11 standard was to resolve compatibility issues from wireless equipment manufacturers. The diagram shows the detailed overview of the IEEE 802 network family

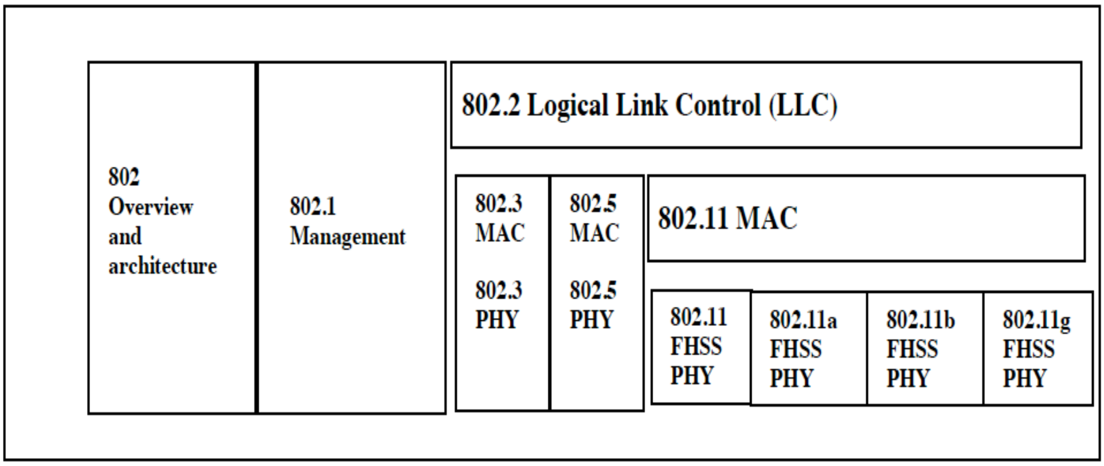

Figure 2.3: IEEE 802 in the OSI Layers [2].

Wireless devices are just like wired LAN devices in applications but differ in their ability to operate and utilize wireless medium. Though the 802.11 based wireless networks emerged from Ethernet networks their access methods are different. The wired networks use Carrier Sense Multiple Access with Collision Detection (CSMA/CD) that proved not to work well in wireless networks since they send and receive data at the same time.

Therefore 802.11 networks use Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), which improves the performance as it prevents wireless clients to send data simultaneously to avoid packet collision. The 802.11 make use of the distributed co-ordination function (DCF) to achieve collision avoidance

The 802.11 standard was first ratified in 1997 as an extension to the Local Area Network with a data rate of between 1-2 Mbps. The early version wireless LAN standard was not welcomed successfully for a long time because of its very low data rates and conflicting modulation techniques compared to the Ethernet. Therefore was quickly superseded by the 802.11b in 1999. There are other ratifications that followed afterwards. Table 2.1 below presents the other 802.11 wireless standard family specifications in accordance with IEEE and WiFi Alliance.

Table 2.1: 802.11 Wireless Network Standards [3]

Standard	**802.11**	**802.11a**	**802.11b**	**802.11g**	**802.11n**
Year	1997	July 1999	June 1999	June 2003	Mar 2008
Data Rate	1-2Mbps	54 Mbps	11Mbps	54 Mbps	400 Mbps
Modulation	FHSS / DSSS	OFDM	DSSS	DSSS / OFDM	DSSS / OFDM
Radio Frequency	2.4 GHz	5GHz	2.4GHz	2.4 GHz	2.4 GHz or 5GHz
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

The failure to define the 802.11a frequency band components led to late availability of hardware though it was ratified in the same period as the 802.11b network standard [4]. The 802.11a has co-existence issues with other 802.11 network standards as it operates in 5 GHz. This became a major disadvantage in network with other 802.11 network standards already deployed. As much as the 802.11b network improved the initial wireless LAN in terms of data rate and reliability, the number of clients sharing an access point negatively affects its throughput performance for each client on the 802.11b network. Despite 802.11b standard being widely deployed it is on the verge of being replaced by 802.11g [4]. The 802.11g has backward device compatibility with 802.11b. It uses the Orthogonal Frequency Division Multiplexing (OFDM), which thereby creates a problem for 802.11b devices that cannot sense the 802.11g devices. The throughput for 802.11g network was decreased to 11Mbps in case of co-existing with the 802.11b.

The 802.11g network is prone to much RF interference from microwaves, cordless phones and other 2.4 GHz devices as compared to 802.11b.

Currently, the IEEE 802.11 Task Group [TGn] is developing a 802.11n wireless network standard which promises to provide a high data rate compared to previous ratifications. According to the IEEE Working Group Project Times, its final ratification is projected to be March 2008 [5]. The 802.11n is expected to use Multiple Input Multiple Output (MIMO) a new technology that uses multiple transmitters and receiver antennas to allow increased data throughput. It will also be expected to operate in both the 2.4 and 5 GHz, thereby being able to support all the 802.11 devices

There are two ways WiFi can be implemented: ad hoc and infrastructure mode. In the ad hoc mode, the nodes or devices communicate directly with each other without the use of the access point (AP) whereas in infrastructure mode, the devices communicate with each other via an Access Point forming a Basic Service Set (BSS). Ad hoc is also being referred to as “peer to peer “ or Independent Basic Service Set (IBSS). This ad hoc mode is useful in cases where there are no proper networks. The infrastructure mode is mostly deployed in companies and institutions.

2.2.2. IEEE 802.15

The 802.15 is a communication specification approved by the IEEE Standard Association (IEEESA) for wireless personal area networks (WPAN) in early 2001. The 802.15 standard was designed based on the Bluetooth v1.1 Foundation Specifications. The IEEE licensed Bluetooth technology from Bluetooth Special Industry Group (SIG) to adapt and copy a portion of the Bluetooth specifications based on material from IEEE Standard 802.15.1-2002 [6]. It is a wireless communication technology and a standard primarily addressing short distance networking requisite for low-power consumption devices. It communicates the wireless data and voice among electronic devices based on the low-cost transceiver microchips. Bluetooth operates in the unlicensed 2.4 GHz providing data rates up to 7kbps. Bluetooth devices cause RF interference problems with the 802.11 standard devices. Most modern Bluetooth standard have a data rate between 2 -3Mbps, such as the 2.0 + Enhanced Data Rate (EDR) [7].

WPAN could be used for sensor network, which is based on a group of sensors used to several data reading such as medical measurements of heart rate (telemetrical environments) [8]. There are some experiments to integrate communication medium into user's clothes, as an "intelligent clothes" [9]. Another example of WPAN useful application is the "in-vehicle" applications, where WPAN is used to connect the user processing devices such as PDAs to the car electronics [10].

The modern software applications of the fast file download and audio/video applications require high data rate protocol. Therefore, the high data rate WPAN MAC protocol has been proposed in 2003 (IEEE 802.15.3). This standard is a personal wireless protocol that can provide data rate of: 11, 22, 33, 44 and 55 Mbps [11].

The High Rate (HR) WPAN standard (IEEE 802.15.3) is the next step of the WPAN group (IEEE 802.15). The first version of WPAN is the IEEE 802.15.1 (Bluetooth) is widely applied in the mobile sets, the laptops and the PDAs. It suffered from several problems related to the security issues and coexistence with WLAN. However, security of Bluetooth has been enhanced and coexistence has been developed but the data rate is still lower than 1Mbps.

Table 2.2 shows a brief comparison between WPAN, WLAN and the Bluetooth. The HR WPAN standard is proposed to satisfy the QoS and network requirements of data transmission in low range (about 10 meters) and low power consumption.

Table 2.2: IEEE 802.15.3 vs. WLAN and Bluetooth [12]

	802.15.3	**802.11b,g**	**802.11a**	**Bluetooth1.1**
Frequency Band	2.4 GHz	2.4 GHz	5 GHz	2.4 GHz
Data Rate	Up to 55 Mbps	Up to 22 Mbps	Up to 54 Mbps	1 Mbps
Current Drain	< 80 mA	< 350 mA	> 350 mA	< 30 mA
Nr. of Video Channels	4	2	5	None

Range	10 m	100 m	100 m	10/100 m

A. IEEE 802.15.3

IEEE 802.15.3 standard is designed to enable wireless connectivity of high-speed, low power, low-cost and multimedia-capable portable consumer electronic devices [11]-[15]. It provides data rates from 11 to 55 Mbps at distances of greater than 70 m while maintaining the required quality of service (QoS) for the data streams. On top of that, this standard is designed to provide simple ad hoc connectivity that allows the devices to automatically form networks and exchange information without the direct intervention of the user.

The standard defines the PHY and MAC specifications for HR wireless connectivity with fixed and portable devices within or entering a personal operating space. The goal of the standard is to achieve a level of interoperability or coexistence with other 802.15™ standards. WPAN channel allocation analytical model shows that channel allocation conflicts occurs in all cases, and is especially severe between IEEE 802.15.3 and IEEE 802.15.4 networks [16]. A personal operating space is a space around a person or object that typically extends up to 10 m in all directions and envelops the person whether stationary or in motion.

B. IEEE 802.15.4

In the designing and implementation of wireless sensor network the power efficiency has a great influence due to its power limitation. The wireless sensor network applications are required low data rate but it is important the long life of network. In this context the IEEE 802.15.4 is very suitable protocol for wireless sensor networks. The IEEE 802.15.4 is low data rate, low power consumption, flexible, reliable, scalable and extremely low cost communication network which allows the wireless connectivity in application with limited power and relaxed throughput requirements.

The main objectives of a LR-WPAN are ease of installation, reliable data transfer, short-range operation, appropriate level of security and a reasonable battery life. Due to suitability the physical (PHY) and data link layer (MAC) of IEEE 802.15.4 protocol are used by ZigBee specification. Many features of IEEE 802.15.4 are suitable for wireless sensor networks [16]. Assigning a GTS (Guaranteed Time Slot) to some nodes is also a useful feature for transmitting a critical data in time sensitive network.

The communication in WSNs depends on which communication protocol is used. It is considered the latest ZigBee technology. ZigBee is wireless technology that supports the short-range communication systems applications. In this technology it is relaxed throughput and latency requirement in wireless personnel area network. It is the most popular worldwide standard for wireless radio networks in the monitoring and control fields. The main feature of ZigBee wireless technology is low capacity and supported by all cheap fixed mobile devices. The main field of application of this field technology is the implementation of WSNs [17].

ZigBee network supports star, tree and mesh topologies. The physical layout of star network is just like a star. In the star topology the network is controlled by one single device known as coordinator. The coordinator is a central node that is linked to all other devices. The star networks are usually single hop networks. In the tree networks the coordinator is the root node. The routers are used to form the branches and end devices are used as leaves nodes. The structure of mesh network is just like tree but there also some end nodes that are directly connected with each other. Messages can travel across tree using multiple paths. The root of mesh network is coordinator node. In mesh and tree topologies the coordinator is responsible for starting the network and for choosing the certain key parameters but the network may be extended through the routers. In the tree network routers move the data and control messages through the network using a hierarchical routing strategy. Tree networks may be employ beacon-enabled communication as described in the IEEE 802.15.4-2003 specification. Mesh network allow full peer-to-peer communication. ZigBee router in mesh network shall not emit the regular IEEE802.15.4-2003 beacons. This specification describes only the intra PAN networks that is networks in which communication begin and terminate with in same network.

2.2.3. Ultra Wideband (UWB)

Ultra wideband (UWB) communication is a fast emerging technology that offers new opportunities and is expected to have a major impact on the wireless world vision of 4G systems [18]. Principal characteristics of UWB signals are their wide bandwidth (3.1 to 10.6 GHz, and more recently 57-64 GHz) and low intensity, with levels comparable to that of parasitic emissions observed in typical indoor environments (FCC part 15: -41.3 dBm/MHz) [19]. UWB radios can have low complexity and power consumption implying that this technology is suitable for the mass market deployment of wireless personal area networks (WPAN). Furthermore, UWB combines high data rates (480Mbps) with localization and tracking features, and hence introduces many other interesting applications such as safety and homeland security. For these reasons, UWB is considered a complementary communication solution within future 4G systems. However, the current high data rate UWB systems (existing and future evolving multi-gigabit UWB version IEEE802.15.3c at 60 GHz) are inherently limited to short-ranges of less than 10 m [20].

A significant range extension of UWB communications, through a marriage of radio and optic channels has been achieved in this thesis. Satisfying conditions such as integrated laser photodetector system (E/O to O/E conversion and vice versa), wavelength conversion; up and downstream channel performance, thereby simplifying customer premises equipment (CPE). As the Wimedia UWB is OFDM based technique, its impact on any systems' optical components is prominent and needs to be addressed for a RoF system. In this thesis the external modulator is characterised for a range of RF power levels. The wideband (528 MHz per band) imposes further penalties in terms of second order distortion as it falls within the transmission band.

2.2.4. IEEE 802.16

WiMAX is the industry name for the set of IEEE 802.16 standards. It is a point-to-multipoint (PMP) wireless technology that operates in the radio spectrum of 10-66 in the Line of Sight (LOS) and 2-11 GHz in the Non-LOS (WiMAX forum). WiMAX is an emerging broadband wireless access technology that delivers a carrierclass, high speed at a much lower-cost than the cellular services while providing more long distances coverage than WiFi. WiMAX was designed to be a cost-effective technology with a theoretical data rate of 70Mbps over a wide area up to 50km in the NLOS, at the same time handling high quality voice, data and video services [21].

WiMAX requires LOS for higher frequencies and has compatibility advantage with other wireless technologies such as asynchronous transfer mode (ATM) and Internet Protocol (IP). WiMAX is classified as a wireless metropolitan area network (WMAN). The 802.16 standard was developed after the security failures that weighted down the progress of IEEE 802.11 wireless networks.

The IEEE 802.16 Working Group in their design for a robust mechanism incorporated Data over Cable Service Interface Specification (DOCSIS) a solution to the last mile cable problem. Since security was a major priority in the design of IEEE 802.16 Working Group are busy designing several mechanisms to protect theft of service and unauthorized information modification and disclosure [22].

2.3 Wireless Networking Characteristic Comparison

There are different wireless technologies that are available today on the market. The Table 2.3 below provides an overview of these technologies' specifications.

All the technologies mentioned in the diagram are wireless technologies with similarities and differences. Since the table above provides an overview of these wireless technologies, there is need a to engage in a comparative discussion about their suitability in achieving wireless convergence in providing services to mobile users and wireless Internet connectivity.

Table 2.3: Wireless Technologies Comparison [23]

Wireless Protocol	Data Rates	Radio Spectrum	Airwaves	Range
Bluetooth	1 Mbps	2.45 GHz	Unlicensed	10m
UWB	480 Mbps	3.1-10.7 GHz	Unlicensed	10m
Zigbee	20-250 Kbps	2.4 GHz	Unlicensed	50m
WiFi-a **WiFi-b** **WiFi-g** **WiFi-n**	54 Mbps 11 Mbps 54 Mbps 100 Mbps	5GHz 2.4 GHz 2.4 GHz 2.4 GHz- 5GHz	Unlicensed	30m 100m 100m 30m
EDGE	384 kbps	0.9,1.8,1.9 GHz	Licensed	Several Miles depending on signal free of interference
3G	2 Mbps	1.9-2.1 GHz	Licensed	Typically 1-5 miles depending on free signal interference
WiMAX	70 Mbps	2-11GHz, 10-66GHz	Licensed and unlicensed	50 km

2.3.1. WiFi vs. Bluetooth

Bluetooth and WiFi use the same 2.4 GHz unlicensed radio spectrum. These are important communication technologies that provide different functionalities to different indoor wireless applications [23]. Bluetooth is a short-range (~10metres) wireless technology suitable for transferring data file from one device to another in a close proximity. Bluetooth exist in various devices such as phones, printers, personal digital assistance, modems and computers.

Due to low bandwidth of Bluetooth, it is not effective to set up a network for remote applications. Therefore, WiFi technology's is a better networking consideration for accessing files compared to Bluetooth. The 16 bit PIN used for Bluetooth authentication and data encryption is not robust compared to the 80211i security enhanced protocol used in WiFi [23], [24].

2.3.2. WiFi vs. 3G/UMTS

Looking at these two wireless technologies, both facilitate mobility. They enable mobile devices to be moved around a particular coverage and remain connected without worry reinstalling cable infrastructure [25]. WiFi mobility is referred to as local mobility since it is an Ethernet Network extension with a higher data rate (bandwidth) for a particular entity whereas the 3G offer narrower bandwidth while covering a large area. In the bid to counter the low data rates offered by 3G, the telecommunication industry introduced the HSDPA. The HSDPA significantly offers much better speeds up to 10mbps with lower packet delay. Mobile technologies are still constrained by limited coverage as signals fade and service diminishes as one moves away from the city (urban area centres). The cellular connectivity for these mobile technologies to mobile users moves from HSDPA, through 3G, to GPRS and finally to EDGE if the cellular network connectivity allows [26] as it moves outwards from the central business district (CBD). The other important similarity of these two wireless networks is that they are both access technologies. T3G can be referred to as an access technology and also as an end-to-end service. The major difference between mobile technologies (3G, GPRS, EDGE, and HSDPA) and WiFi technology is in the use of the airwaves frequency bands and the equipment for infrastructure. The mobile technologies operate on a licensed radio spectrum while the WiFi uses the open unlicensed 2.4 ISM spectrum.

The use of the unlicensed spectrum has major benefits such as cost of service, quality of service, congestion management and industry structure. Since the mobile technologies can be used as an end-to-end service, therefore the integration of WiFi in the mobile technologies might reduce some of the cost involved in mobile networks [25]. Though the WiFi technology is still facing security challenges, VPN is becoming more secure though it adversely affects network performance. The UMTS provides security to its network users by a smart card device referred to as subscriber identity module (SIM). Therefore, the SIM will contain all the identification information, which is used to identify users accessing the services and resources on the network.

2.3.3. WiMAX vs. 3G/UMTS

Though the mobile technologies provide ability for users to use it as an access technology, its data rates speeds are not able to compete with WiMAX. Theoretically, the mobile technologies have data speeds from 115 kbps for GPRS, 384 Kbps up to 2Mbps for UMTS and 14.4 Mbps for HSPDA while WiMAX offers high data speeds of up to 70Mbps for coverage of 50 km. The HSPDA can provide a much faster theoretical maximum data rate of 14.4 Mbps within a kilometer making it only suitable for short distance access technology [26]. Similar to other mobile technologies WiMAX has the same capabilities to transmit data and voice. The choice of using mobile technologies in transmitting voice is more expensive compared to the VoIP/WiMAX as to WCDMA/HSDPA.

The HSDPA uses a users' Subscriber Identification Module (SIM) card for authentication, while WiMAX supports the strong modern cryptographic algorithms, which is more robust to protect secret data transmissions [27]. The overall cost for the WiMAX equipment is much lower as compared to the UMTS. The main advantage of using the UMTS cellular system is that, its infrastructure for 3G, HSPDA, GPRS and EDGE is available where there is cellular network coverage while the WiMAX requires a new infrastructure setup for it to operate. Since UTMS are more easily available it is more preferred for mobile communication than WIMAX.

2.3.4. WiFi vs. WiMAX

These two wireless technologies have common components in their operations with a major difference in the communication range. There is a need for many WiFi access point in order to cover the same distance covered by one WiMAX base station. Hence it is costly to deploy WiFi for longer distances. WiFi is an access technology suitable for indoor use due to its short ranges as an extension to LAN technology while WiMAX was designed for long distance, backhauling and optimized for MAN. As much as the WiFi has an advantage of providing end user access capabilities, it can only support a limited number of users (not more than 12 per base station) whereas the WiMAX base station can support an average of about five hundred users. WiMAX base station has a scheduling algorithm (First-In First-Out), which allocates a variable channel for each subscriber station to minimize the congestion, and degrading throughput other than the random queue assignment based on MAC address in WiFi whereas.

WiMAX uses a licensed and unlicensed spectrum where as the WiFi uses unlicensed spectrum with a limited channel bandwidth of 20 MHz. Due to the fact that WiMAX can support high bandwidth, low cost of ownership and provides backhaul capabilities, it can therefore can be considered as the future broadband access technology to bridge the 'digital divide'. WiMAX is more reliable and have better QoS as it was designed with security as a major priority since the frailness of WiFi [28]. Despite the similarity in equipment cost, WiMAX technology requires a costly infrastructure while the WiFi can be easily install using low cost access points. In conclusion, WiFi has been adopted as an extension for Ethernet some years ago making it a mature technology compared to WiMAX which is currently license assignments and infrastructure deployment.

2.3.5. Wireless Convergence Infra

In sections detailed discussion, possible ways have been discovered through which convergence can be achieved. However, there were factors, which were highlighted, in each proposed wireless convergence according to its functional suitability, strengths and weaknesses. Bluetooth, UWB, WiFi and mobile technologies can be categorized as access technologies, whereas the WiMAX can be classified as service provider technology.

The capabilities for the WiMAX to connect Internet wirelessly at higher data rates over a long distance made them suitable technology for backhauling. WiFi among the access technologies mentioned, offers much higher data rates and cheaper as (since no expense on service) compared to 3G. Though 3G has a greater range than WiFi, it operates on the licensed radio spectrum, which makes it expensive due to monthly charges. As much as the mobile technologies can provide backhauling, it is usually limited in coverage as one move away from the main base tower. However, the convergence of WiFi and WiMAX is suitable for rural Internet connectivity.

2.4 Handover in Wireless Mobile Networks

In conventional cellular networks and wireless networks handover can be defined as the mechanism by which an ongoing connection between a mobile host (MH) and a corresponding terminal or host is transferred from one point of access to the fixed network to another [31]. When an MH moves away from a BS, the signal level degrades and it needs to switch communications to another BS. It is very important in any cellular-based wireless networks because ongoing connection should be maintained during handover. In cellular voice telephony and mobile data networks, such points of attachment are referred to as BSs and in wireless networks; they are called access points (APs). In either case, such a point of attachment serves a coverage area called a cell. Handover, in the case of cellular telephony, involves the transfer of a voice call from one BS to another.

In the case of wireless networks, it involves transferring the connection from one AP to another. In hybrid networks, it will involve the transfer of a connection from one BS to another, from an AP to another, between a BS and an AP, or vice versa.

For a voice user, handover results in an audible click interrupting the conversation for each handover; and because of handover, data users may lose packets and unnecessary congestion control measures may come into play. Degradation of the signal level, however, is a random process, and simple decision mechanisms such as those based on signal strength measurements result in the ping-pong effect. The ping-pong effect refers to several handovers that occur back and forth between two BSs. This exerts severe burden on both the user's quality perception and the network load.

In this part of this chapter, a discussion of general handover-related issues, and handover procedures of representative conventional wireless networks [29]-[31] is presented.

2.4.1. Introduction to Handover

Handover is a process of transferring an active mobile user session from one Base Station (BS) or Access Point (AP) to another in order to keep the user's connection uninterrupted. In the traditional circuit-switched wireless networks such as GSM, handover is employed mainly for maintaining a mobile user's telephony voice.

The handover in such a circumstance is motivated by the fact that the coverage area of a single BS transceiver cannot cover the whole service area. The coverage area of one or more BS transceivers at a single physical site is referred to as a cell.

In Frequency Division Multiple Access (FDMA) based systems, a cluster is a group of cells in which frequencies are not reused. Clusters can be repeated with careful planning to minimise interference among cells using the same frequency so as to enlarge radio coverage as shown in Figure 2.4. Such a flat compound architecture can be supplemented by more intelligent radio resource management techniques such as the macrocell/microcell overlay [32], which consists of large-size macrocells and small-size microcells for balancing network capacity and network control load associated with handover.

When a mobile user connection to an AP or BS degrades below an acceptable threshold, it has to switch the session to a neighbouring cell. If the neighbouring cell employs the same type of access technology, handover across these cells is often seen being done horizontally. Horizontal handover refers to handover between base stations using the same type of network interface. This is common in homogeneous circuit-switched cellular systems such as GSM and Code Division Multiple Access (CDMA) networks.

Apart from being implemented in circuit-switched cellular systems, horizontal handover can be utilised for maintaining the continuity of wireless data services. Such applications are seen in packet-switched cellular systems such as General Packet Radio Service (GPRS) and Universal Mobile Telecommunications System (UMTS) networks.

The growing demands for high speed wireless data services drive the development of new access technologies. Wireless Local Area Networks (WLAN) such as IEEE 802.11 are able to provide high speed access but with small radio coverage. For example, IEEE standard 802.11g [33] supports a data rate up to 54Mbps but an outdoor coverage of 140 meters. In contrast, the Third Generation (3G) cellular systems, e.g. UMTS, can offer much wider coverage through more complex network architecture.

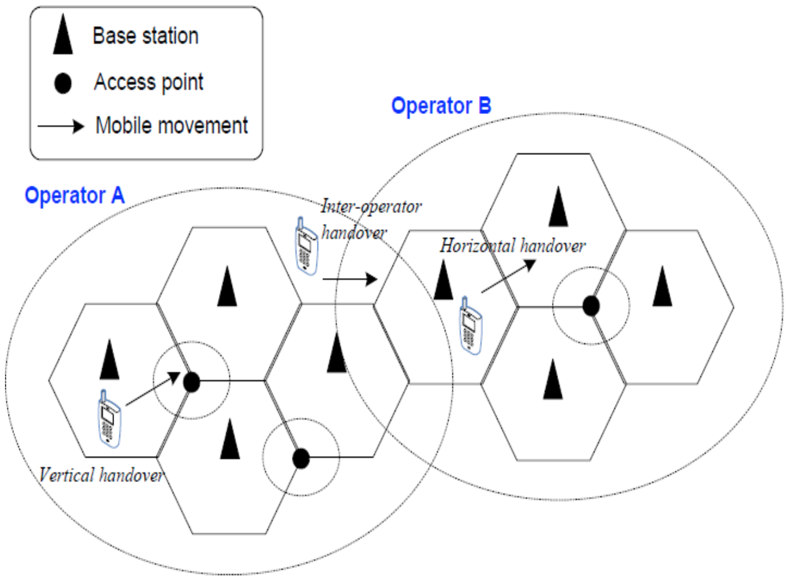

Figure 2.4: Handover Scenarios [32].

However, the data rates they can offer are not unfavourable for many real-time applications, which need high bandwidth. Thus, an integration strategy of the two technologies (e.g. 3G UMTS and WLAN) has been proposed and widely accepted in the literature [34]-[37] as an economical and feasible solution for providing ubiquitous access [38]. This integration is expected to result in a heavy demand for handover between heterogeneous wireless networks, which is recognised as an important feature of the NG wireless networks. Handover between two networks based on different access technologies is known as vertical handover. Vertical handover is further divided into two categories: upward (move-out) vertical handover and downward (move-in) vertical handover. An upward vertical handover occurs from a BS/AP with smaller radio coverage to a BS/AP with wider coverage. A downward vertical handover occurs in the reverse direction to an upward vertical handover. Apart from handover for radio link quality reasons, vertical handover can be initiated for optimising service quality for wireless data services. In this context, vertical handover has to deal with the heterogeneities existing in the interconnected wireless networks.

The objective of supporting various forms of handover on a mobile user is to provide ubiquitous access across heterogeneous wireless networks and a number of network operators without manual user intervention [39]. This is supplemented by the demands for comprehensive and personalised services, stable system performance and service quality [40]. Seamless handover in the NG wireless networks needs additional capabilities in network architectures, protocols and control mechanisms, all of which combine to facilitate the smooth interworking of heterogeneous wireless systems. Accordingly, the interworking raises a number of research issues, which can generally classified into two categories: Mobility Engineering and Handover Methodology.

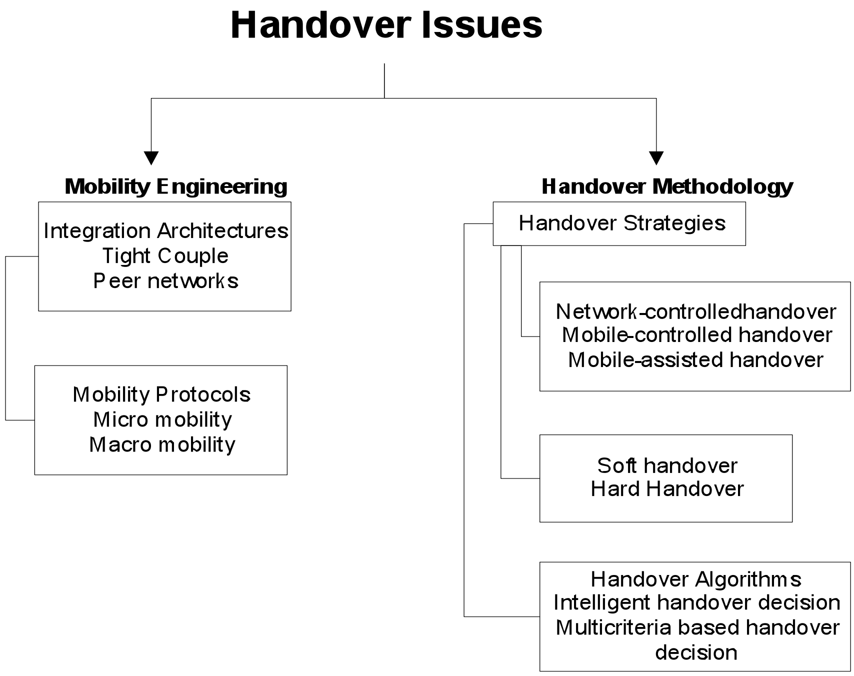

Figure 2.5: Handover Issues in the Multiple Wireless Networks.

Figure 2.5 summarises the major issues in each category. Mobility engineering provides basic building blocks, which underpin handover functionality. Mobility engineering provides a common platform for all the mobile users, and comes with network infrastructure. Integration architectures and mobility protocols lie in this category. Handover methodology, on the other hand, specifies the way, in which handover should be performed. Unlike network protocols being "hardcoded" for all the mobile users, handover methodology can be made different for each individual mobile user for optimised service quality. Handover methodology is comprised of handover strategies and handover algorithms.

2.4.2. Handover Methodology

A. Handover Strategies

With a well-engineered interworking architecture, handover across heterogeneous wireless networks can be made possible. Considering current widespread deployment of cellular networks, it is reasonable to assume that a MH is within the coverage range of at least one base station at all times. The dimensions of a base station's coverage depend upon various factors such as network type, transmission power and so forth. Therefore, a key issue for both network and mobile user is to reach a decision as to which network would be selected, and how handover should be handled when a link transfer is necessary. In an interconnected heterogeneous wireless infrastructure, the coverage of different wireless networks may be overlapped in some service areas as illustrated in Figure 2.4.

B. Handover Algorithms

Once a handover control scheme is determined for a specific integrated network, relevant handover procedure can be executed. Handover procedure in a heterogeneous environment is more complex than that in a homogeneous wireless network, which is single technology based. As a rule of thumb, the switching of underlying access technologies should be kept transparent to higher layer applications of a mobile user during a handover.

During a handover across heterogeneous wireless networks, once the target network is determined, the following procedure is defined by the interworking mechanisms including mobility protocols, authentication methods, integration architecture and so forth. Handover algorithms are employed to determine the target network for handover, and make the corresponding decision. This is driven by the introduction of "Always Best Connected" (ABC) concept in mobile service provisioning [41].

Basically, a handover algorithm deals with two essential tasks in a handover: network selection and handover triggering. Network selection determines where a mobile user would be switched to when a handover is necessary. Practically, it is usually complemented by a separated handover triggering process, which decides WHEN the switching action to the selected network should be triggered. These two processes are seen as two consecutive steps in a handover as shown in Figure 2.6.

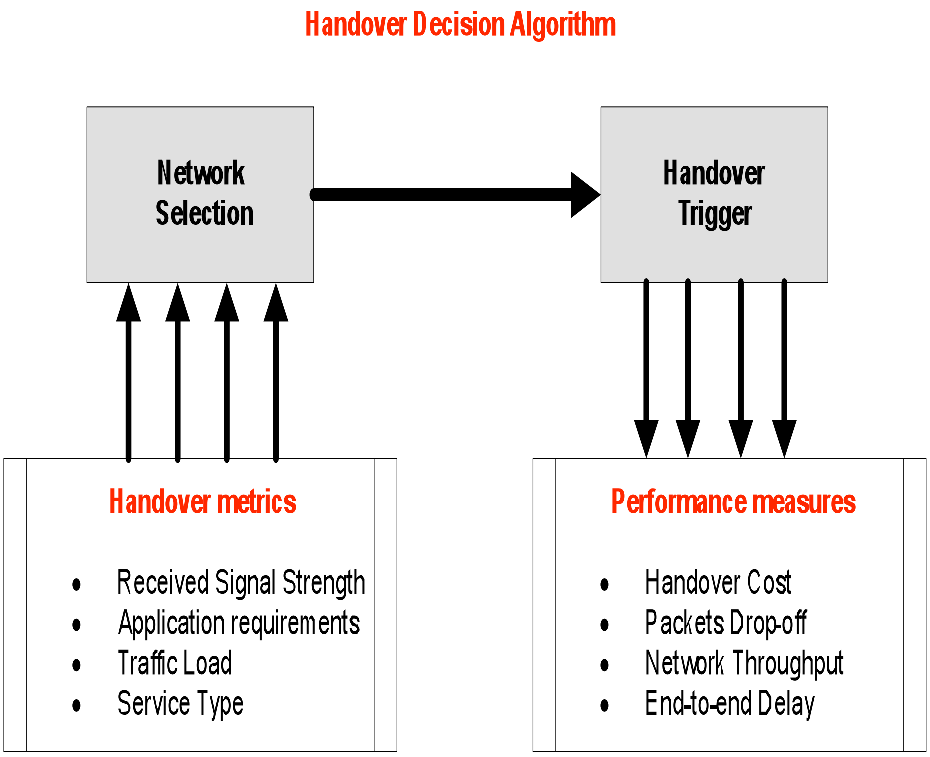

Figure 2.6: Controlled Handover Algorithm.

2.4.3. Handover Issues

In this subsection general issues related to handover that should be taken into account in any kinds of wireless networks as long as they involve handover. In this dissertation handover issues are classified into three parts:

(1) Architectural issues

(2) Handover decision algorithms

(3) Handover related resource management.

Architectural issues are those related to the methodology, control, and software/hardware elements involved in rerouting the connection. Issues related to the handover decision algorithms are the types of algorithms; metrics used by the algorithms, and performance evaluation methodologies. Handover-related resource management deals with the maintenance of quality of service (QoS) during handover.

A. Architectural Issues

The issues are concerned with handover procedures that involve a set of protocols to notify all the related entities of a particular connection that a handover has been executed and that the connection has to be redefined as shown in Figure 2.7 [29].

In data networks, the MH is usually registered with a particular point of attachment. In voice networks, an idle MH would have selected a particular BS that is serving the cell in which it is located. This is for the purpose of routing incoming data packets or voice calls appropriately. When the MH moves and executes a handover from one point of attachment to another, the old serving point of attachment has to be informed about the change. This is usually called dissociation. The MH will also have to re-associate itself with the new point of access to the fixed network.

Other network entities involved in routing data packets to the MH or switching voice calls have to be aware of the handover in order to seamlessly continue the ongoing connection or call. Depending on whether a new connection is created before breaking the old one or not, handovers are classified into hard and seamless handovers. Figure 2.8 illustrates hard handover between the MH and the BSs. A hard handover is essentially a break before make connection. The link to the prior BS is terminated before or as the user is transferred to the new cell's BS; the MH is linked to no more than one BS at any given time. In CDMA, the existence of two simultaneous connections during handover results in soft handover. The decision mechanism or handover control may be located in a network entity or in the MH itself. These cases are called network controlled handover (NCHO) and mobile-controlled handover (MCHO), respectively. In global system for mobile communications (GSM), information sent by the MH can be employed by the network entity in making the handover decision. This is called mobile-assisted handover (MAHO). In any case, the entity that decides on the handover uses some metrics, algorithms, and performance measures in making the decision.

B. Handover Decision Algorithms

Several algorithms are being employed or investigated to make the correct decision to handover. Traditional algorithms employ thresholds to compare the values of metrics from different points of attachment and then decide on when to make the handover. A variety of metrics have been employed in mobile voice and data networks to decide on a handover.

Primarily, the received signal strength (RSS) measurements from the serving point of attachment and neighboring points of attachment are used in most of these networks. Alternatively or in conjunction, the path loss, carrier-to-interference ratio (CIR), signal to interference ratio (SIR), bit error rate (BER), block error rate (BLER), symbol error rate (SER), power budgets, and cell ranking have been employed as metrics in certain mobile voice and data networks. In order to avoid the ping-pong effect, additional parameters are employed by the algorithms such as hysteresis margin, dwell timers, and averaging windows. Additional parameters (when available) may be employed to make more intelligent decisions.

Some of these parameters also include the distance between the MH and the point of attachment, the velocity of the MH, and traffic characteristics in the serving cell. The performance of handover algorithms is determined by their effect on certain performance measures. Most of the performance measures that have been considered, such as call blocking probability, handover-blocking probability, delay between handover request and executions, and call dropping probability, are related to voice connections. Handover rate (number of handovers per unit of time) is related to the ping-pong effect, and algorithms are usually designed to minimize the number of unnecessary handovers. Traditional handover decision algorithms are all based on received power (P).

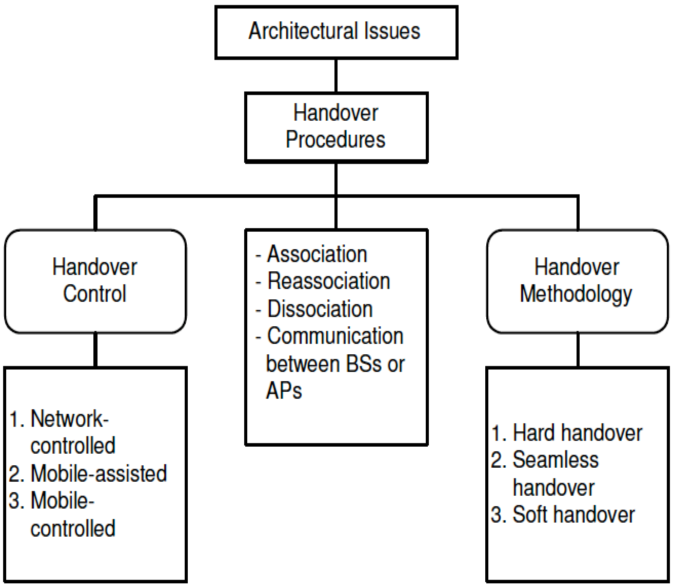

Figure 2.7: Architectural Issues [31].

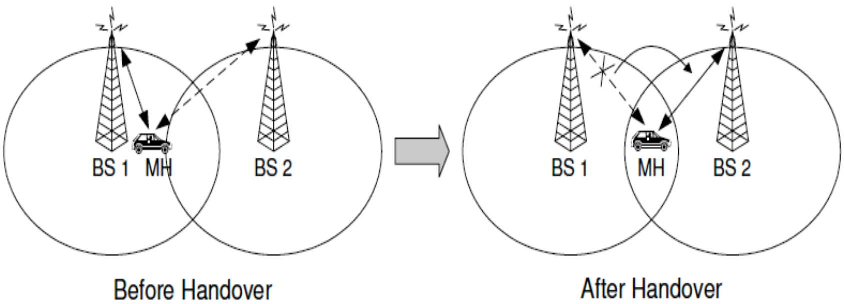

Figure 2.8: Hard Handover.

C. Handover-related Resource Management

QoS guarantees during and after handover will become more significant and challenging in the near future since the current trends in cellular networks are:

1. To reduce cell size to accommodate more MHs that will cause more frequent handovers.

2. To support not only voice traffic but also data and multimedia traffic such as video.

One of the issues is how to control (or reduce) handover drops due to lack of available bandwidth in the new cell, since MHs should be able to continue their ongoing sessions. Here, two connection-level QoS parameters are relevant: the probability (PCB) of blocking new connection requests and the probability (PHD) of dropping handovers. In ideal case, it would like to avoid handover drops so that ongoing connections may be preserved as in a QoS-guaranteed wired network. However, this is impossible in practice due to unpredictable fluctuations in handover traffic load.

Each cell can reserve fractional bandwidths of its capacity, and this reserved bandwidth can be used solely for handovers, not for new connection requests. The problem is then how much of bandwidth in each cell should be reserved for handovers.

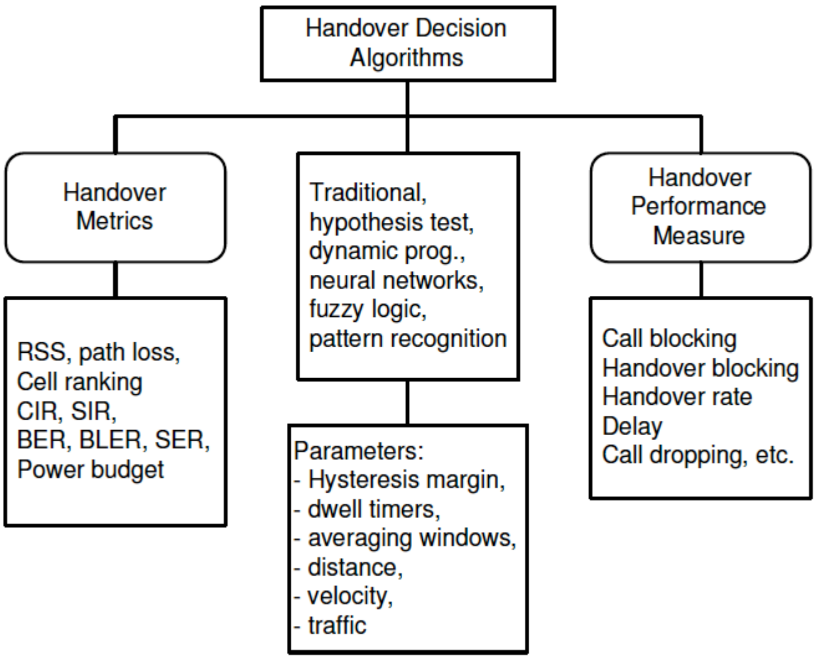

Figure 2.9: Decision Algorithms in Handover [31].

This concept of reserving bandwidth for handover was introduced in the mid-1980s [31]. In this scheme, a portion of bandwidth is permanently reserved in advance for handovers. Since then intensive research efforts have been carried out for developing better schemes. Most existing bandwidth reservation schemes for handover assume that the handover connection arrivals are Poisson, and each connection requires an identical amount of bandwidth with an exponentially distributed channel holding time in each cell [43]-[45]. But, it is known that the channel holding time of handed-over connections is not really exponentially distributed [45].

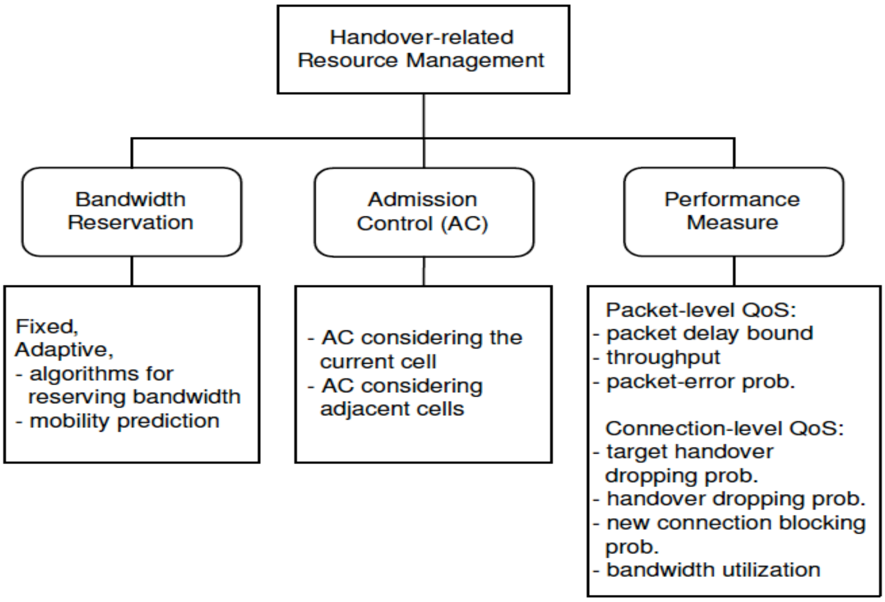

Figure 2.10: Handover Resource Management [31].

Recently, some schemes attempting to limit PHD to a perspective target value for multimedia mobile cellular networks have been proposed [47]-[49]. A probabilistic prediction of user mobility has been proposed in [48] based on the idea that mobility prediction is synonymous with data compression. From the observation that a connection originated from a cell follows a specific sequence of cells, rather than a random sequence of cells, the scheme utilizes character compression technique to predict future mobility of MHs. In [48], a handover probability at some future time has been derived using the aggregate history of handovers observed in each cell. These algorithms depend on the mobility history of users for statistical prediction to guarantee that PHD is maintained below a prespecified target probability. Thus, they need a large amount of history data for proper operation. A much simpler scheme has been proposed in [50]. In this scheme each BS counts the number of handover successes and failures to adaptively change the reserved bandwidth for handover, and it does not depend on a large amount of handover history data.

This chapter described Radio over Fibre technology, wireless and mobile network technologies and handover-related management and issues in conventional mobile wireless networks with a special emphasis on hybrid wireless technologies. In this thesis, an application-controlled handover scheme investigated in mobile wireless inter-technology and intra technology [51].

2.5 Conclusions

This chapter has reviewed a number of papers and books related to several issues of the RoF technology such as the structure, components, signalling and transmission. This chapter also reviews wireless and mobile network group standards and their history has been presented briefly. The application controlled handover development presented in this work is a novel approach.

This thesis presents the concept of applying an intelligent application controlled handover over heterogeneous wireless access technologies. Some examples of handover protocols have been overviewed in this work. Converging protocols have some features that are applied in such as supporting fixed mobile network architecture. Furthermore, self-organised and scalability are some of the crucial features in hybrid networks that are applied in the proposed development.

This chapter is crucial for the multiple wireless network handover non-expert readers in order to understand the enhancement presented by this work to the next generation networks.

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Chapter 3

Application Controlled Handover Proposed Architecture

3.1 Introduction

The Wired Wireless Integration Network (WWIN) can be categorised as Fixed Mobile Convergence (FMC). FMC means the convergence of the existing Wired Network and Wireless Network. Therefore a mobile device needs the function of connection and control to the FMC infrastructure. An application controlled handover is developed in this chapter, which keeps channel continuity in the wired wireless synergy network environment that consists of 3G (UMTS) + WLAN + WPAN (UWB) and optical fibre network. This chapter presents a novel handover mechanism that transmits and receives data by using the proposed application selection criteria. It maintains the channel and the seamless transmission from mobile device to the remote optical fibre network, to provide real time service continuity for multimedia traffic.

The integration of all modes of electrical communication is under great progress and the fact remains that there is an undeniable and healthy competition between wire and wireless networks [1]. With the rapid development of communication and network technologies, traditional voice networks and data networks have been gradually merged together into multimedia networks which supply various services ranging from email, web browsing to telephony, visual conference and video on demand. The horizon of the integrated multimedia network is extended further to incorporate wired, wireless and cellular networks.

The progress of beyond 3rd generation or 4th generation (B3G/4G) networks will depend largely on the close coordination between mobility, resource and quality of service (QoS) management schemes [1]. The B3G/4G networks are expected to serve stationary as well as mobile subscribers under dynamic network conditions and provide any type of service – anytime - anywhere and anyhow. Here a discussion of a hierarchical, layered and modular B3G/4G network architecture with wired-wireless integrated network coordination and distributed network functionalities has been presented.

An Application Controlled mechanism for control/signalling for multi-radio is adopted to facilitate enhanced wireless system performance. Reconfigurable architecture for multi-application, multi-homed and multi-service supported mobile device has been presented to enable seamless mobility across different access technologies including wired and wireless infrastructures.

In an integrated 3G+WLAN+WPAN, as illustrated in Figure 3.1, more data and multimedia applications are carried end-to-end over the current Internet protocol infrastructure. Fundamentally, Wired Wireless Integrated Networks (WWIN) will reshape the telecommunications industry. Technological changes in the telecommunication industry have not only led to the creation of new trends in the deployment of next generation networks, but also to the convergence of telecommunication technology sector. In particular, the so-called WWIN has become a reality due to the market demand and industrial competition.

FMC enables users to work with existing wired and wireless networks. UMTS has nationwide coverage and access to UMTS network is achieved by using cellular networks. WLAN and UWB are free of charge communication air-interfaces. WLAN, UWB and UMTS can serve the Internet core network on the Transmission Control Protocol/Internet Protocol (TCP/IP). TCP/IP enables a user to adopt client server communication by accessing an individual network.

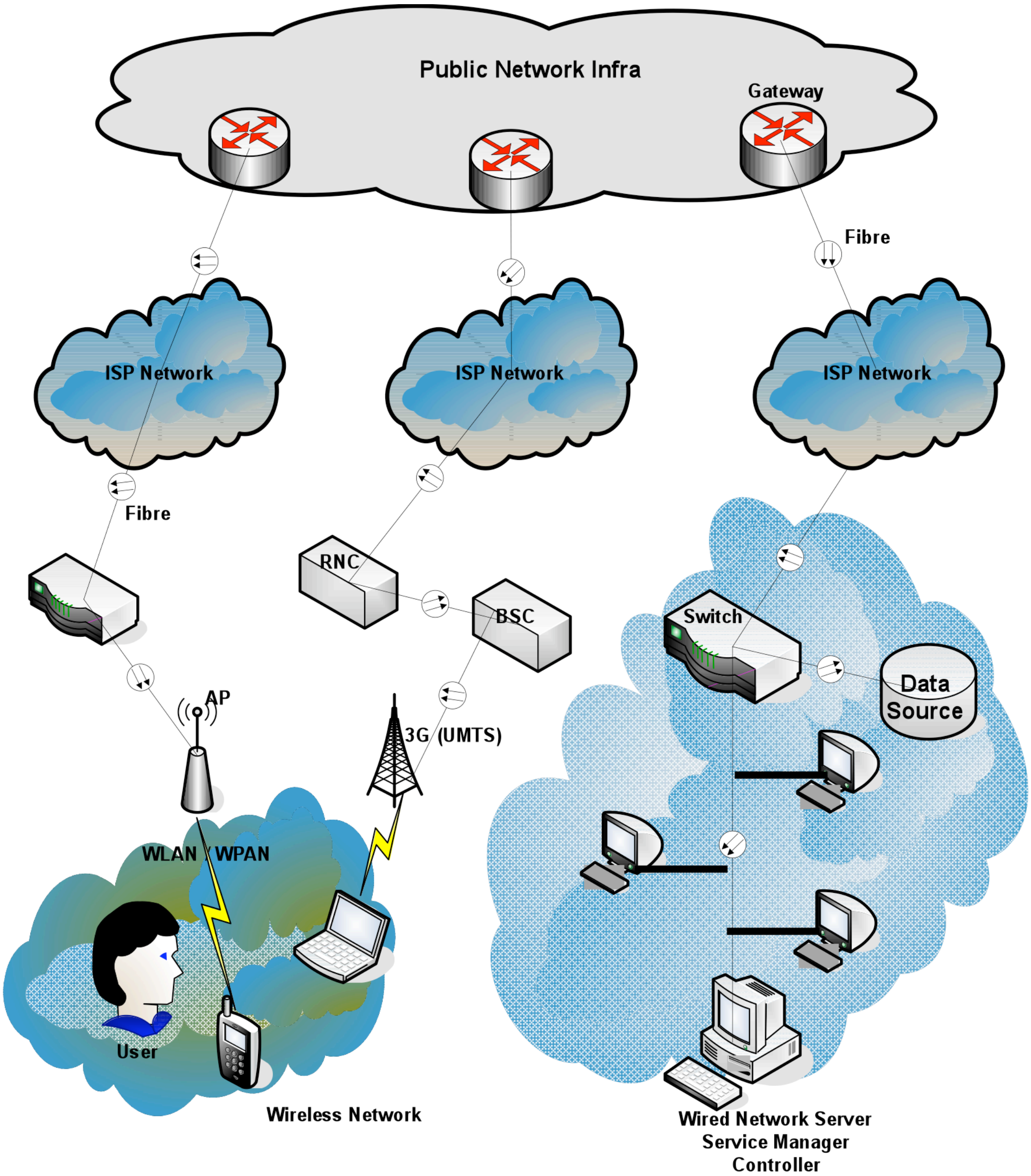

Figure 3.1: An Integrated Wired Wireless Network Environment.

This chapter is organised as follows. Section 3.2 highlights the research contribution and related work done in this area. Section 3.3 presents the current WWIN capabilities and the research challenges. Section 3.4 presents the proposed WWIN architecture and organisation of communication environment for FMC. In Section 3.5, the design of ACH has been discussed in detail. Section 3.6 demonstrates simulation network model, scenarios and layout for proposed technique. Section 3.7

shows the results leading to the conclusions of this chapter that are presented in section 3.8.

3.2 Global Contribution and Related Work

The architecture classification for WWIN is defined as: Intracellular, Inter-cellular and Extra-cellular. In Intracellular architectures, each Access Point or Base Station (AP/BS) communicates with any mobile node (MN) in its coverage area in a multi-radio mode.

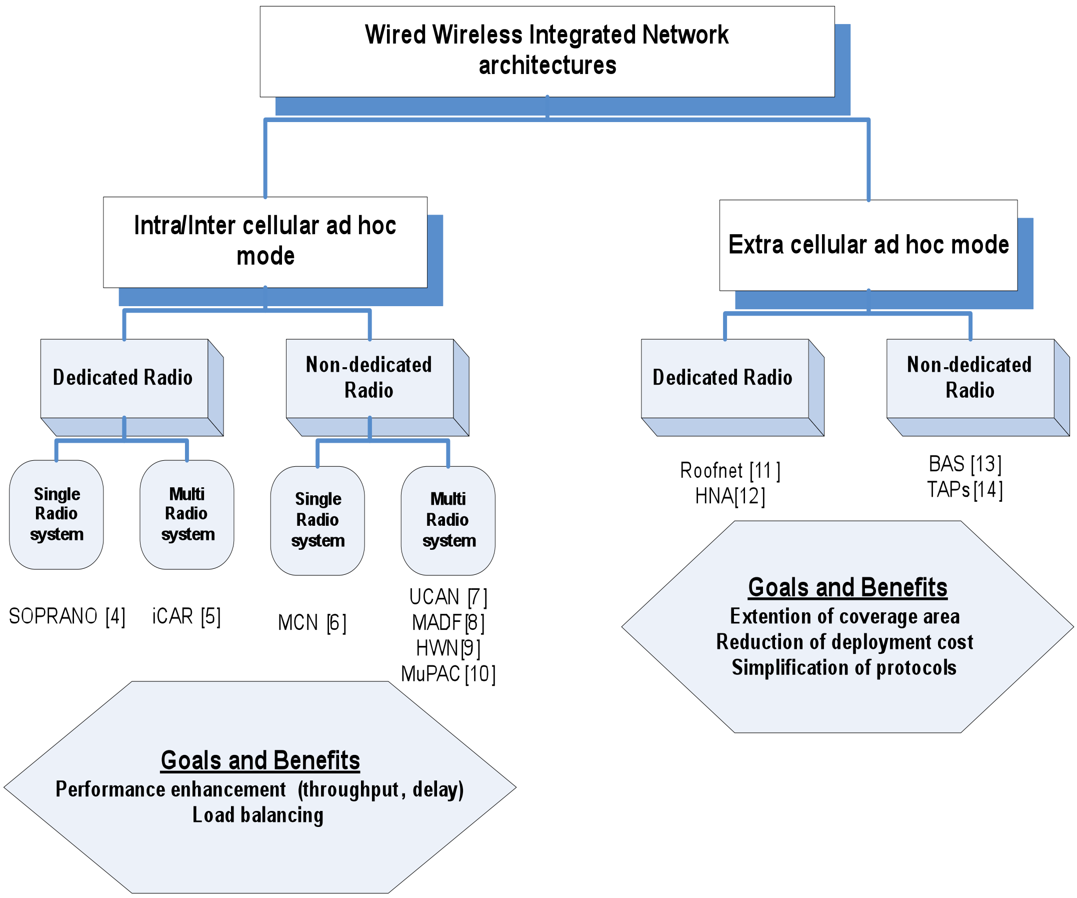

Figure 3.2: Hierarchical Classification of Wired Wireless Network Architectures.

On the other hand, in Inter-cellular architectures, each AP/BS communicates with any MN in the coverage area of other APs/BSs in a multi-radio mode. Finally, Extra-cellular architectures enable an AP/BS to communicate with MNs that are not in the coverage area of any AP/BS. Any of these classifications may employ dedicated radio stations. Furthermore, Intra/Inter cellular ad hoc mode architectures can be classified as multi-radio systems in which MNs act either in single-radio mode or multi-radio mode. Figure 3.2 illustrates this classification with respect to the well-known references such as [2]-[12] in this research era.

3.3 Current WWIN Capabilities

In the future Internet where wired and wireless networks are integrated, traffic volume of wireless user should expand greatly and QoS of wireless user will be one of the most important technical issues. In wireless network environment TCP, one of most important protocol of TCP/IP, suffers from significant throughput degradation due to the lossy characteristics of a wireless link. Therefore, in order to design the next generation networks, it is necessary to know how much improvement can wired/wireless integrated network brings.

Throughput of TCP connection is well known to be dependent upon both packet loss and application response delay. Several papers have been published in wireless TCP, for example, [13] evaluates throughput performance of a single wireless TCP connection experimentally and [14] analyses the throughput performance mathematically using fluid flow model. These papers only dealt with wireless TCP and did not take care of interaction of wireless and wired TCP in FMC environment.

3.3.1. Wired Wireless Convergence Era

Wireless broadband is the next phase of the wireless evolution. While 3G has already taken off, the R&D effort in the wireless area is concentrating on higher bit rates, high bandwidth availability, less power consumption, high security and etc. The pace of introduction of new radios and architectures continue to increase; therefore, the traditional era based on long standardization processes is not possible anymore. The broadband battlefield may change the classical operator model due to new entrants using alternative technologies in other frequency ranges for different usage scenarios under different regulatory conditions. Additionally, new proprietary systems are being proposed for broadband, one of which is convergence of wireless and optical fibre.

Optical fibre media will do better transmitting high frequency radio signals over a longer distance because optical fibre cables are immune to EMI, provide excessive bandwidth in the region of THz, and are more secure. More importantly, its ability to handle very large numbers of radio frequency (RF) and digital data signals at different frequencies simultaneously over one optical cable with less attenuation which makes it a better choice over conventional copper based wiring achieving higher data rates and better Quality of Service (QoS) in terms of bandwidth hungry and real time application. In the network side, the generic solution to seamless connectivity lies in the IP protocol that runs over a range of heterogeneous transport physical mediums Fixed and wireless access technologies are further being integrated at the service layer by devising new control plane solutions such as Unlicensed Mobile Access (UMA) and IP Multimedia System (IMS). In addition, the industry is moving rapidly towards integrating all types of electronics, including entertainment systems, and this has generated a lot of interest in convergence of wireless and fixed approach.

3.3.2. The Research Challenge

Original work in this chapter is the development and realisation of handover technique for multiple access technologies, which can provide data transmission and service continuity in the FMC environment The algorithm uses a cross layer solution to operate on transport layer between wired and wireless network infrastructure. The PDA, Mobile phone and a Laptop were used in the wired and wireless network simulation environment. The devices have installed handover algorithm and moves freely in the WWIN environment.

The handover provides service continuity and data transmission by selecting appropriate wireless technology depending on the required data rate for specific application. The traffic was recorded at the remote server that was located in wired network and traffic was transported from devices that were located in wireless network.

3.4 Proposed Modification in WWIN Architecture

The existing integrated high-speed wired and wireless networks are shown in Figure 3.3, it also reveals general constitution of FMC. Both Wired and Wireless networks have separate service platform, as shown in Figure 3.3. FMC is managed by using Integration Service Server (ISS) [15]. FMC network supports data service in the existing voice/data based wireless infra, and the existing high bandwidth wired network infrastructure.

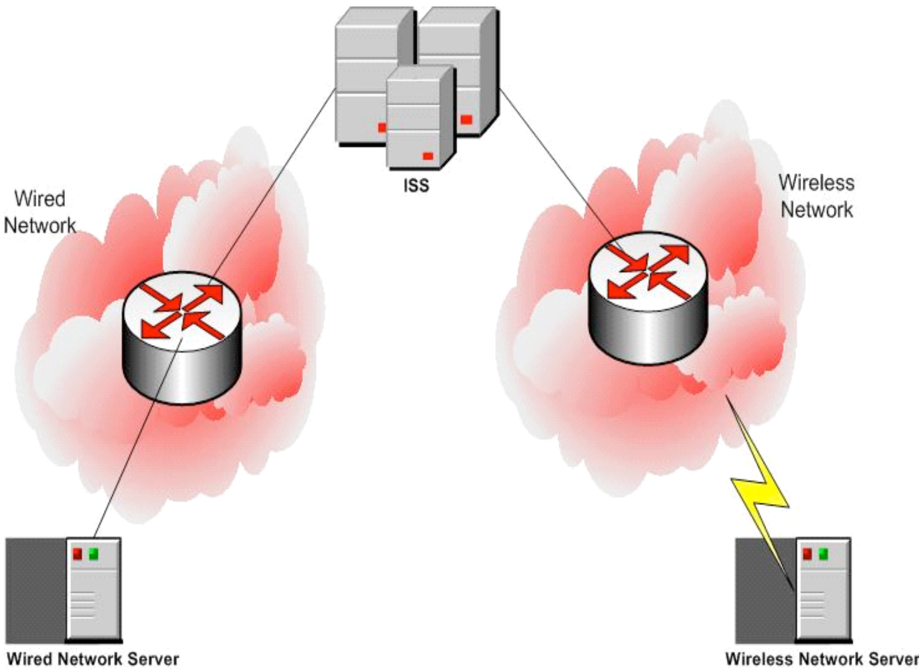

Figure 3.3: Proposed FMC Architecture for Wired Wireless Integrated Network.

3.4.1. Constitution of Communication Environment for FMC

The proposed FMC environment is based on multi-radio such as UMTS, WLAN, UWB and optical fibre network. Proposed constitution of communication environment for FMC is shown in Figure 3.1. This research work realizes FMC environment by using TCP/IP and transport layer between wired wireless networks not by using ISS. It can be seen from Figure 3.1, there is no physical ISS for proposed FMC. Application controlled handover uses transport layer and TCP/IP for each network constituting FMC. So accordingly there is no physical ISS. In the architecture, mobile devices select radio access technology according to the user requested application. Light FTP data can be accessed using UMTS cellular network, heavy

FTP and Database applications (remote account management and payroll systems for a multinational corporate) may use WLAN and for video conferencing UWB is prominent candidate supporting up to 200 Mbps [16].

Figure 3.1 shows a user carrying mobile devices in the wireless network domain having access to UMTS, WLAN and UWB air interfaces. Mobile device network protocol stack can communicate cross layer PHY to APP Layer to detect the transmission of data, handovers to the suitable air-interface and sends it to the remote server. Once server gets the request, it records real time data transmitted from user's device.

3.4.2. Application Controlled Handover Classification

The definition of Application Controlled Handover is explained as follow. When the mobile device moves in wireless network domain having access to UMTS, WLAN and UWB, a certain process is required in order to switch and maintain network connection channel. In the proposed handover technique, if average required data rate for a specific application is greater than the threshold of achievable data rate, a handover to the acquired radio access initiates. The handover is classified at the point of various communication resources as shown in Table 3.1.

Table 3.1: Classification of Handover

At the point of domain controlling network
• **Inter domain handover:** The action of handover in different domain networks. It is called roaming. • **Intra domain handover:** The action of handover in same domain networks.
At the point of an object controlling handover
• **Controlled Handover:** The device checks the signal strength and required data rate and controlling manager decides to trigger handover.
At the point of an access platform
• **Vertical Handover:** The action of handover in different platform environment. • **Horizontal Handover:** The action of handover in same platform environment
At the point of handover service
• **Connectionless:** During handover, the home server keep the position information and route of

device

- **Switching Platform:** Handover depends on the required bandwidth to perform a particular task; i.e. for heavy real time application such as video conferencing; a handover from WLAN to UWB due to high bit rate requirements.

In this chapter, the proposed FMC architecture uses vertical handover for application controlled mechanism.

3.5 Information Element of the Proposed ACH

An ACH has been proposed which keeps the continuous channel service for wired and wireless networks. The mobile devices not only sense the signal strength but also determine the application type and initialise the handover process. A soft handover has been considered in the simulation network due to the session handling for connections to more than two radios e.g. connections to UMTS, WLAN and UWB can be maintained by one device at the same time. It is a trade off between the one channel occupancy (hard handover) and the QoS in terms of soft handover's make-before-break (session continuity).

This section elaborates the application controlled based network protocol stack, the design of network components and finally the soft handoff process model for ACH.

3.5.1. Application Controlled Network Protocol Stack

Figure 3.4 depicts the protocol stack for the proposed handover technique. Seamless bridging is supported natively by this protocol, which enables both information and process data to be easily exchanged in heterogeneous environment.

Device handover manager adopts the lower layers of the protocol stack (PHY). Despite the relatively low speed of UMTS (up to 384 Kbps), it is able to guarantee deterministic behaviour. As long as the load on the network is well below the theoretical available bandwidth, handover technique guarantees that any low or high data is delivered to the server within the suitable application response time.

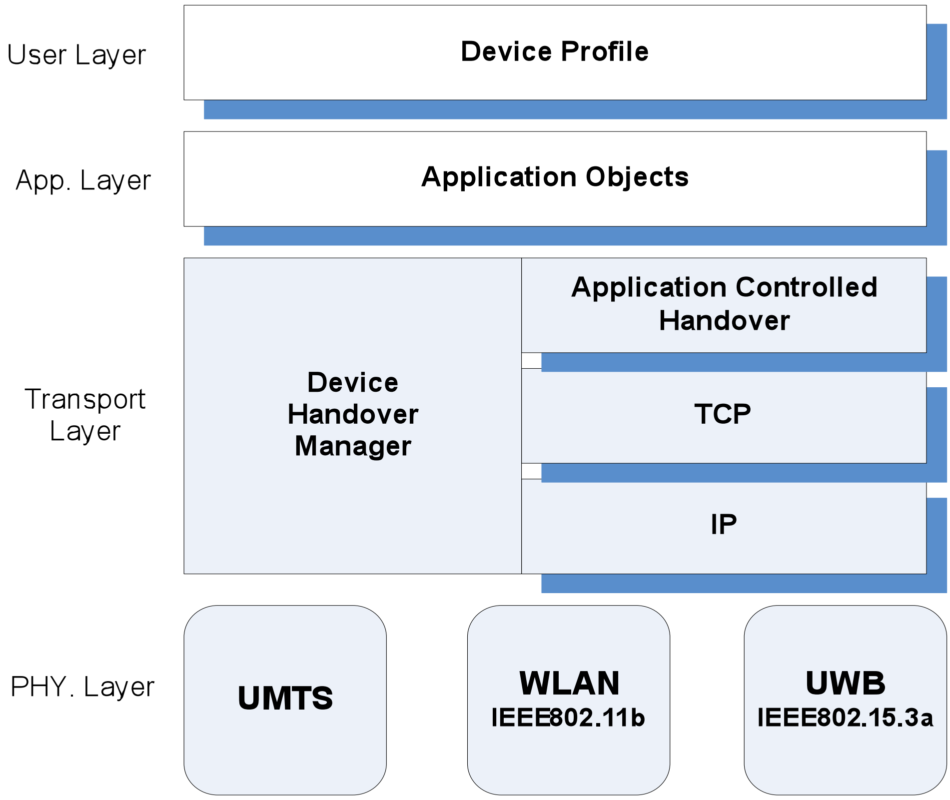

Figure 3.4: Application Controlled Network Protocol Stack.

3.5.2. Selection of Random Application by Probability Function

Real-life devices run several applications (such as word processing and Internet browsing) simultaneously ("user profile" as defined in OPNET™) [17]. The user profile (Students, Engineers, Researchers, etc.) is identified depending upon the user specialisation, professional background and interests. The user profile is a set of applications, which lead to a particular level of power consumption. However, prediction of next application "consumption weight" (heavy or light) and duration is not an easily solved problem. Therefore, this work has applied the probability theory (Probability Distribution Function PDF) in order to simulate the running applications on the devices [18]. Battery analytical models have been presented in [19]-[23].

Although the literature has proposed interesting battery lifetime models, these models are not easily implemented because they focus on physical study of power source and the wireless device [19]-[23]. The work proposed in this chapter presented a new approach based on PDF, which leads to simplicity in implementation. Applications in the wireless devices (such as computer games and word processing) are manually turned ON and OFF by the user. Therefore the probability function could be used to provide an accurate estimation for the expected application type (i.e. heavy or light power consuming).

Accordingly, power consumption and battery lifetime could be calculated and provided to the simulation model of the device for further analysis and decision such as route selection or switching the device ON/OFF. The proposed algorithms for battery power model and charger (shown in Figure 3.5 and Figure 3.6) are quite simple.

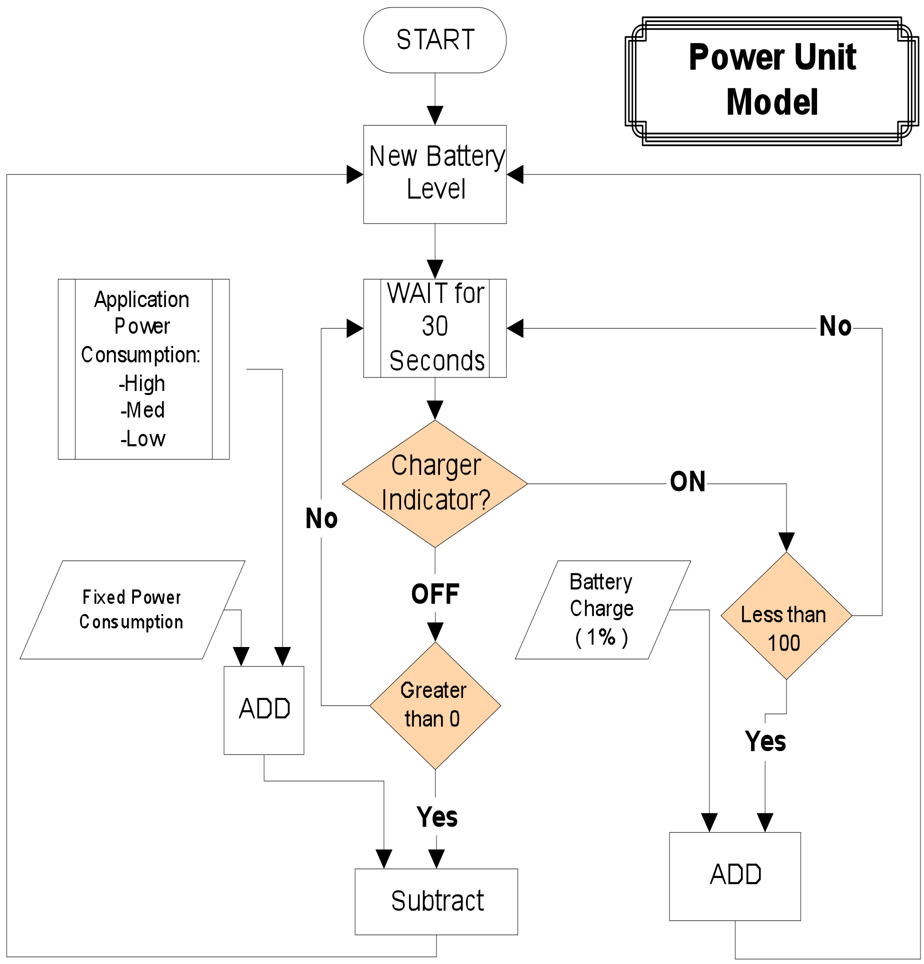

Figure 3.5: Battery Power Management Flowchart.

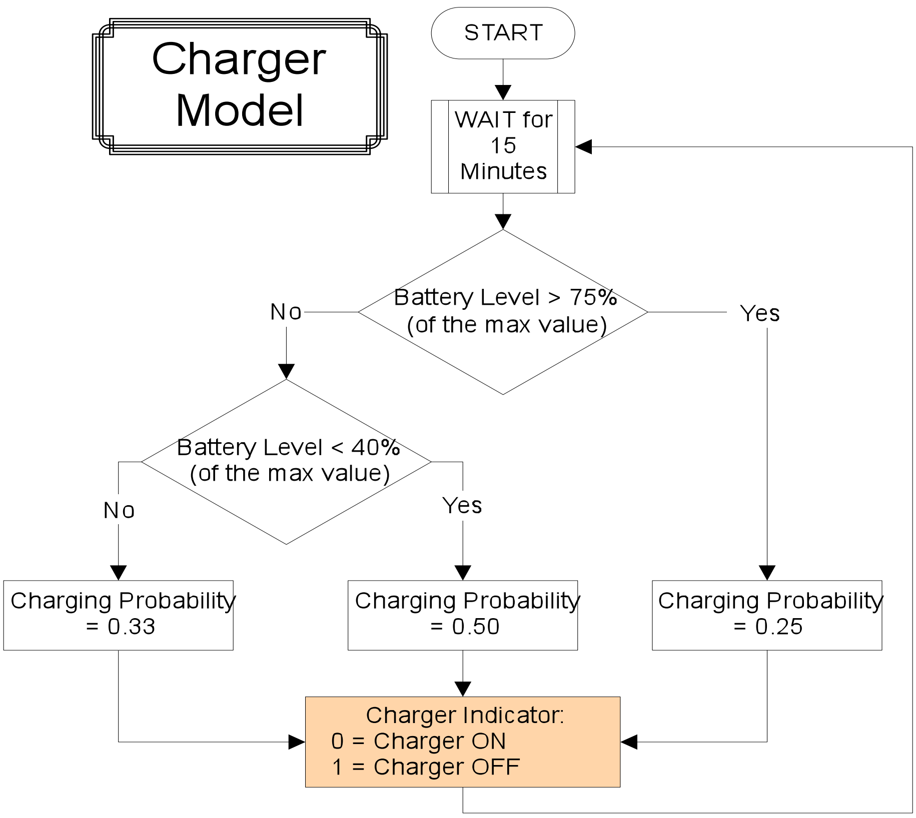

Figure 3.6: Charger Model Flowchart.

These models are implemented by C/C++ using network simulation tool such as OPNET and NS2. The PDF Equation (3.1) is applied to identify the probability of power consumption due to the instinctual application [24].

$$P(X \leq x) = \int_{x_{\min}}^{x} P(x)dx \tag{3.1}$$

In Equation (3.1), $P(x)$ *is the probability* when X is less or equal to a certain value *x*. The simulation model proposed in this work could be applied for simulated wireless devices in any air-interface such as WLAN, WPAN, UMTS and WiMAX.

3.5.3. Battery Lifetime Model of the Wireless Device

The goal of the simulation model is to demonstrate the battery lifetime for several wireless devices and charger process algorithm. The battery level capacity (the device lifetime) is one of important criterion, which could be used for node selection in route discovery in ad hoc networks or PNC selection in WPAN. The device battery power capacity is modelled using the rules shown in Equation 3.2, where P_{charge} is the probability of charging a battery and Bat_{power} is the Remaining Battery Power in Percentage. All of the values used in Equation 3.2 are assumed in the proposed model.

$$P_{charge} = \begin{pmatrix} 25\% & if & Bat_{power} \geq 75\% \\ 33\% & if & 40\% < Bat_{power} < 75\% \\ 50\% & if & Bat_{power} \leq 40\% \end{pmatrix} \tag{3.2}$$

Equation 3.2 is proposed based on the assumption of a logical user behaviour of charger usage. In this aspect, the probability of using a charger in the battery-operated device is a function of the battery remaining power. In a typical regular-user behaviour, the probability of charging a battery is dependent on the remaining battery power of the device. The device is most probably charged when the remaining power is low. On the other hand, if a device has a larger remaining battery power (defined by Bat_{power}), the probability of charging the device battery (P_{charge}) is lower. If the battery remaining power is lower, the probability of charging the battery is increased. It is assumed that if the battery remaining power is higher or equal to 75% of the maximum value, the probability of charging the battery is 25% as shown in Equation 3.2. If the battery remaining power is equal or less than 40%, the probability of charging the battery is 50%. Typically, the lower the battery level is, the higher the probability of charging.

Power Unit management algorithm is shown in Figure 3.5, where the battery value is updated every 30 seconds. The charger model is shown in Figure 3.6. If the charger indicator is not present (the charger is not connected), the battery power level of the device will decrease due to power consumption in the device. Power consumption could be estimated according to the application in the device. Assuming that the power consumption is divided into four levels (Idle, Low, Medium and High), the algorithm presented in Figure 3.5 is responsible for random switching between these levels.

The device applications have been divided into four categories as outlined in Table 3.2. The lowest power consumption rate is shown when the device is idle. At this state, only the device essential parts such as the display and the memory are activated. The processor load is at minimum required level in order to maintain the operation system running. The values in the fourth column (in Table 3.2) are calculated according to the assumption made in this work. Based on this assumption, if the device is idle, maximum battery life is reached (250 minutes).

However, if a low-power consumption application is used (power consumption rate is 0.6 of maximum value per minute), the device would run for 167 minutes. The selection process for the battery consumption rate uses a uniform distribution to switch between the four values. The selected power consumption value will be subtracted from the current battery-power level. However, if the charger indicator is ON, the device battery will recharge at a rate of 2%/min.

Table 3.2: Power Consumption Rates in Battery-operated Devices

#	Applications	Consumption Rate (Max. Value per min)	Max Battery Lifetime (min)
1	Idle (No Application Running)	0.4	250
2	Low Power Consumption App. + Idle	0.6	167
3	Med. Power Consumption App. + Idle	0.8	125
4	High Power Consumption App. + Idle	1.0	99

This value will be added onto the current battery level up to value 100 (full-battery) as shown in Figure 3.5. If the probability density function presents that the charger is connected, the power unit model will go to the Charger Indicator state 'Yes' while 'No' indicates that a charger is not available. The presence of a charger is calculated every 15 minutes. Hence, the Power Unit management model will maintain the current Charger Model indicator state for 15 minutes during its repeated 30 seconds iteration.

3.5.4. Battery Lifetime Simulation Results

As shown in Figure 3.7, simulation results in OPNETTM have been obtained using five wireless devices (DEV1, DEV2, DEV3, DEV4 and DEV5). The simulation time is five hours. The simulation results show that the random behaviour of charging and battery power consumption due to the four categories of the applications as shown in Table 3.2

In the simulation results (Figure 3.7), the positive slop (rising curve) is the time when the charger is connected. In this simulation, devices are assumed identical. Therefore the charging curves are at the same rising slop. On the other hand, the "negative" slop of the remaining battery power reflects the power consumption (battery discharging) at that time.

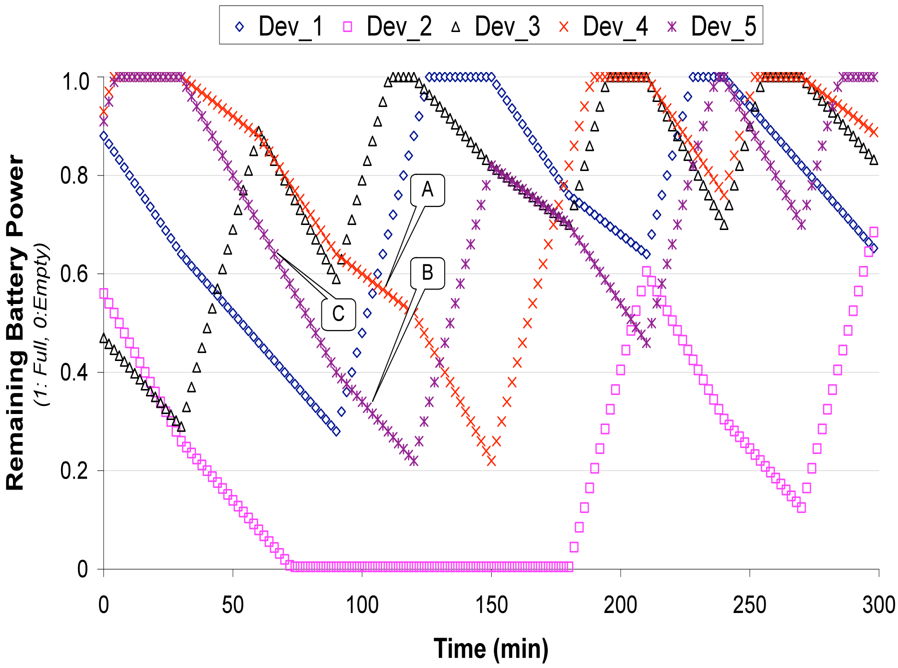

Figure 3.7: Battery Power in Mobile Devices.

For example, in the period between 32 minutes and 120 minutes, Dev_4 and Dev_5 illustrate three rates of power consumption pointed as "A", "B" and "C". Period "A" is for lower power consumption when the device is at the idle mode where the power consumption source is the device physical parts such as RAM and monitor.

The power consumption of period "A" is referred to as number one in Table 3.2. Power consumption at "B" represents light applications such as word processing tasks. This power consumption is categorised as number two in Table 3.2. Finally, number three in the power consumption levels in Table 3.2 is shown in the period “C” (Figure 3.7).

As illustrated in Figure 3.7, the power consumption rate is randomly changed between the four levels, which are presented in Table 3.2. These applications simulate the real-life user profile, where the devices switch between multiple tasks according to the user requirements.

At the same time, the charger usage in the simulation results follows Equation 3.2. Several applications are shown in Figure 3.7 distributed on random basis. This simple simulation model could be applied in any network simulation tool in order to utilise the device lifetime in the route selection or devices comparison.

3.5.5. Application Controlled Handover Network Components

The design of components for mobile device is illustrated in Figure 3.8. It consists of the (I) data component that can exchange data with external device, (II) the signal acquisition component that can receive radio signal strength of wireless network, (III) socket control component that controls the communication resources inside the device and the application control handovers to the wireless network platform according to the demand of quality data transmission requirements.

Application controlled handover used a virtual socket to connect UMTS, WLAN and UWB network access infra. It is designed as if there is only one virtual socket device [25].

However UMTS, WLAN and UWB can access the data by using data buffer in the virtual socket and control of access is designed and serviced by application controlled handover technique. The application handover manger needs to decide the connectivity between the mobile devices and AP/BS [26]. In addition, wireless radio selection criteria were mainly emphasised.

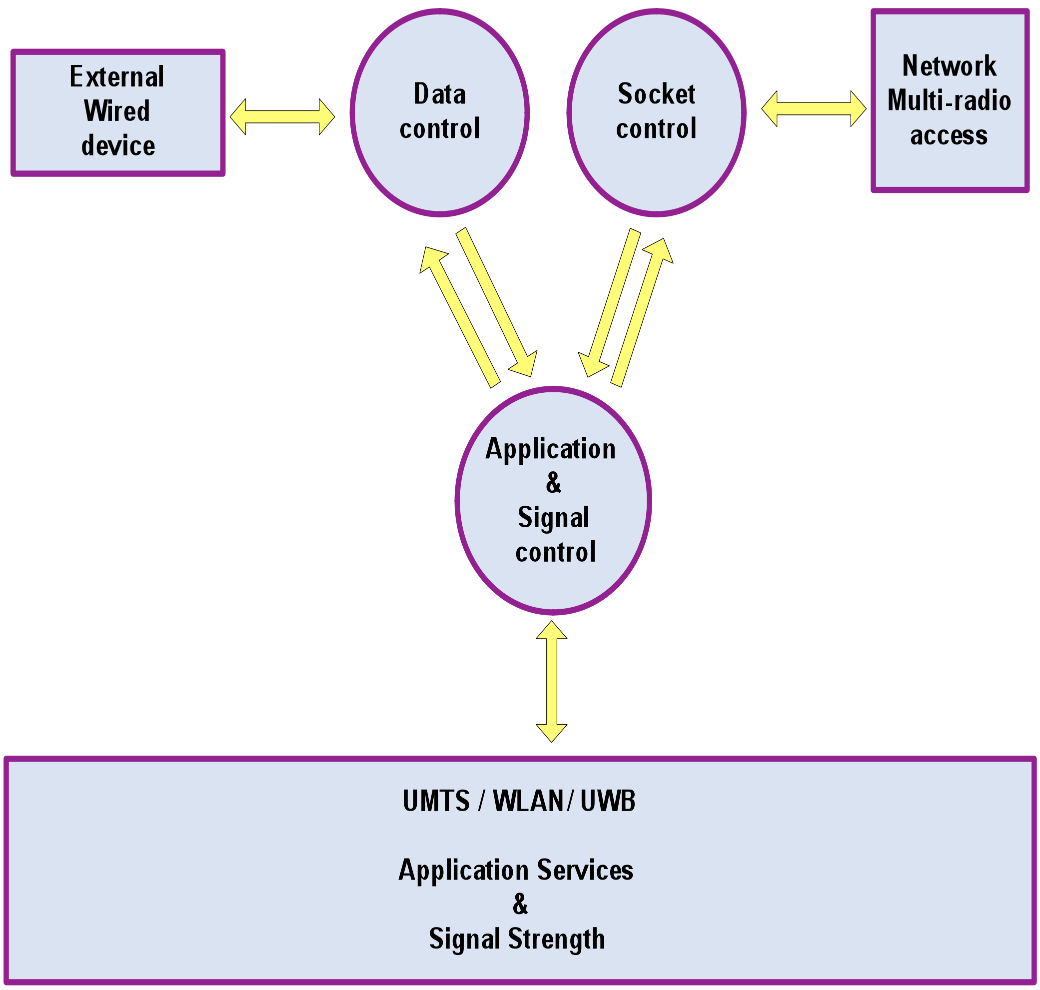

Figure 3.8: The Network Components of ACH.

It is shown in the Figure3.9, signal control component can control all the three signals together between data control and socket control component.

The Signal acquisition component provides the signal strength of AP/BS. Application controller is connected to application manager for handover process. Figure 3.9 shows the implementation of how the components of Figure 3.8 are connected with the TCP. Data control component is connected with external device and it collects data from external device (server) periodically.

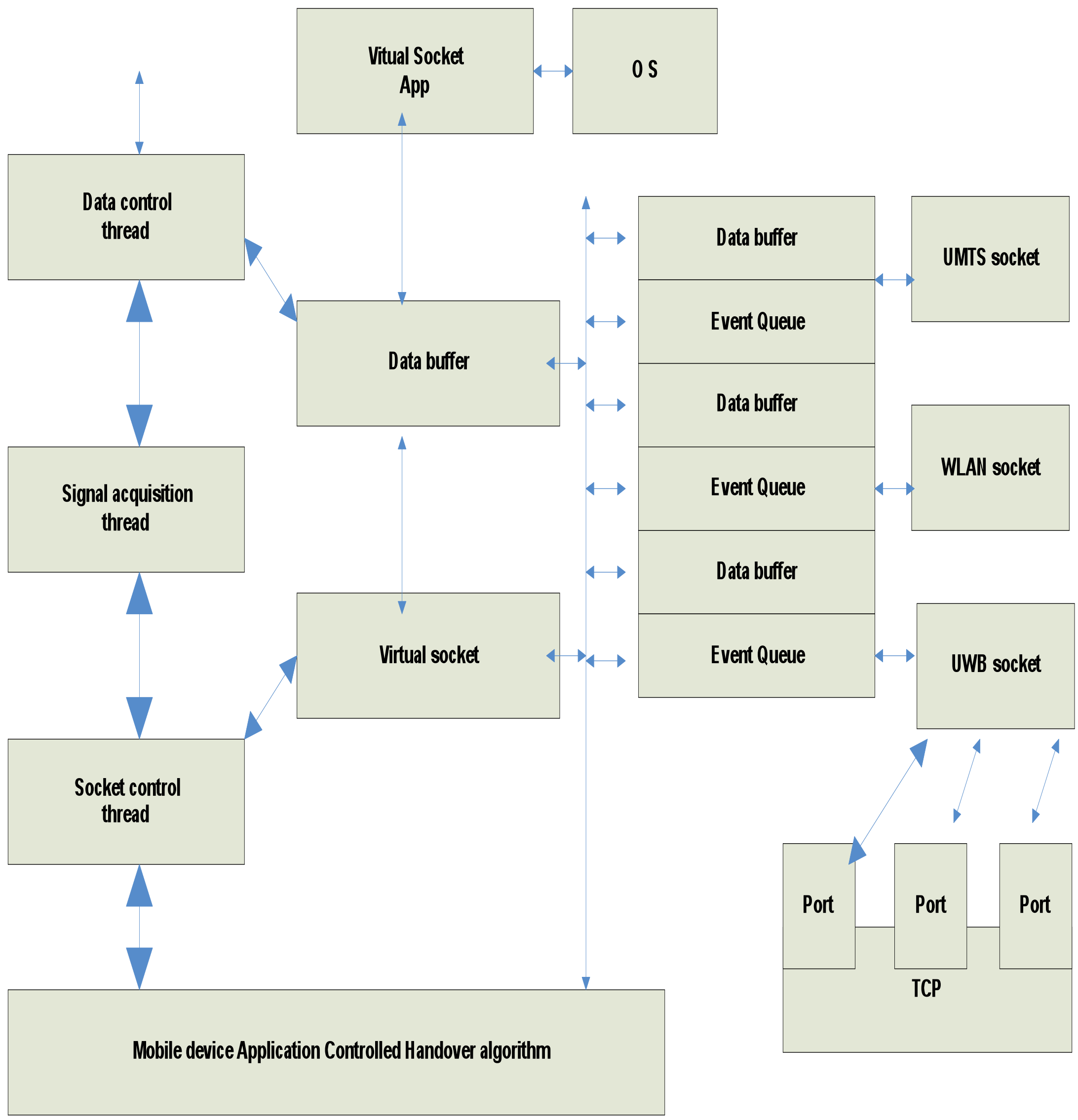

Figure 3.9: Data and Socket Control Components of ACH.

3.5.6. Application Controlled Handover Process Model

Soft handover sets up a new channel on condition that it maintains the existing channel where as hard handover sets up a new channel after breaking the existing channel. The socket control component controls a virtual UMTS, WLAN and UWB socket in Application Controlled Handover.

A socket control component controls three sockets; UMTS, WLAN and UWB respectively. The buffer is connected to hidden UMTS, WLAN and UWB sockets. A soft handover process design is shown in Figure 3.10.

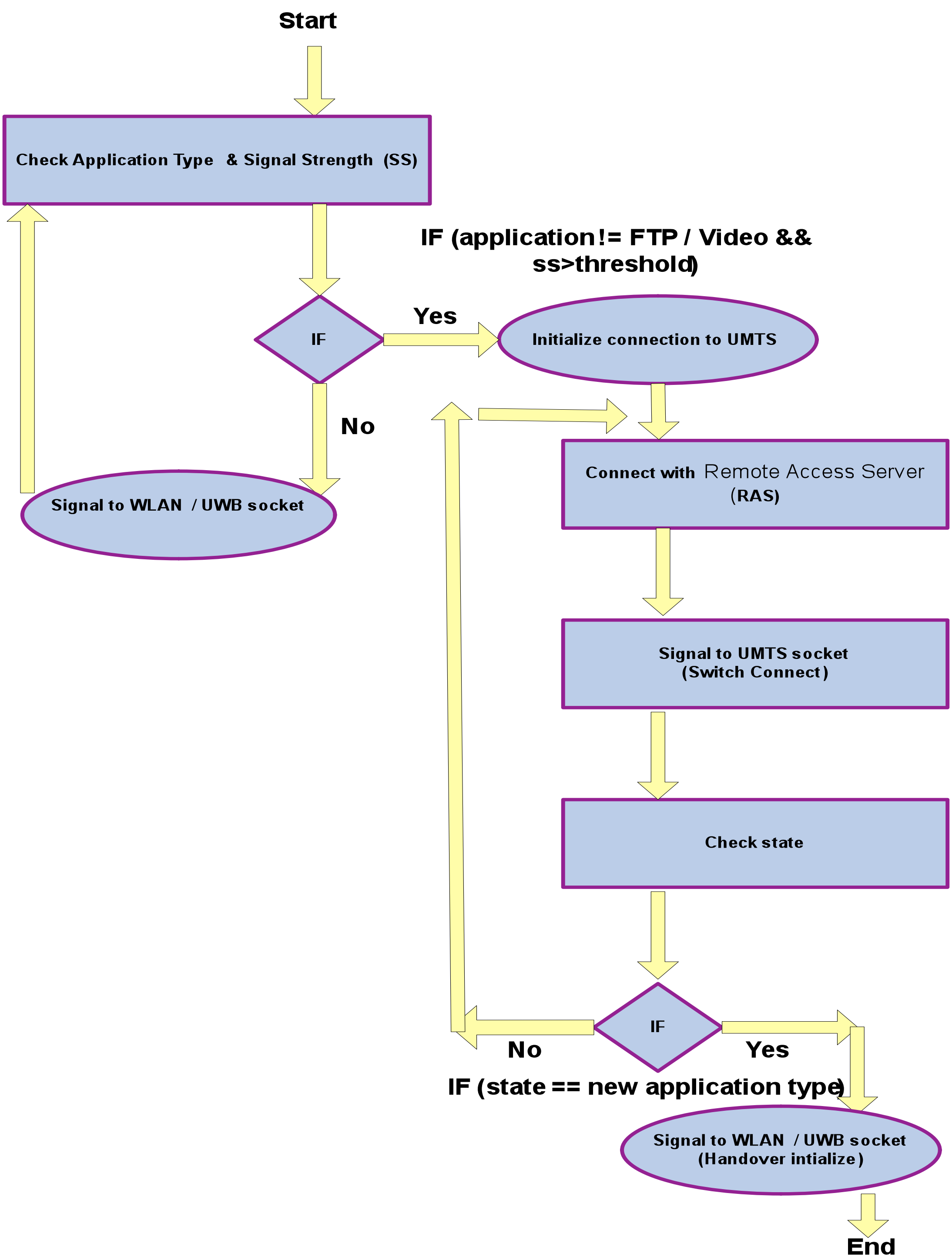

Figure 3.10: ACH Process Model Flow.

3.6 Proposed Network Model Layout

Network model implementation has been divided into two major scenarios

(I) Multiple radios over fibre network without ACH (base network model)

(II) ACH based multiple radios over fibre network.

Both scenarios are simulated parallel and compared on the basis of same parameters; the details are in the following sub sections.

The client subnet in Figure 3.11 represents the wireless client with multi radio mobile devices capable of WLAN, UWB and UMTS connectivity in OPNET™ [17]. The AP supports both PHY layers of WLAN and UWB. UWB model used here is 10-12 meters in range with a data rate up to 200 Mbps. Network was simulated to analyse the scope of the simulation and to achieve reasonable simulation time.

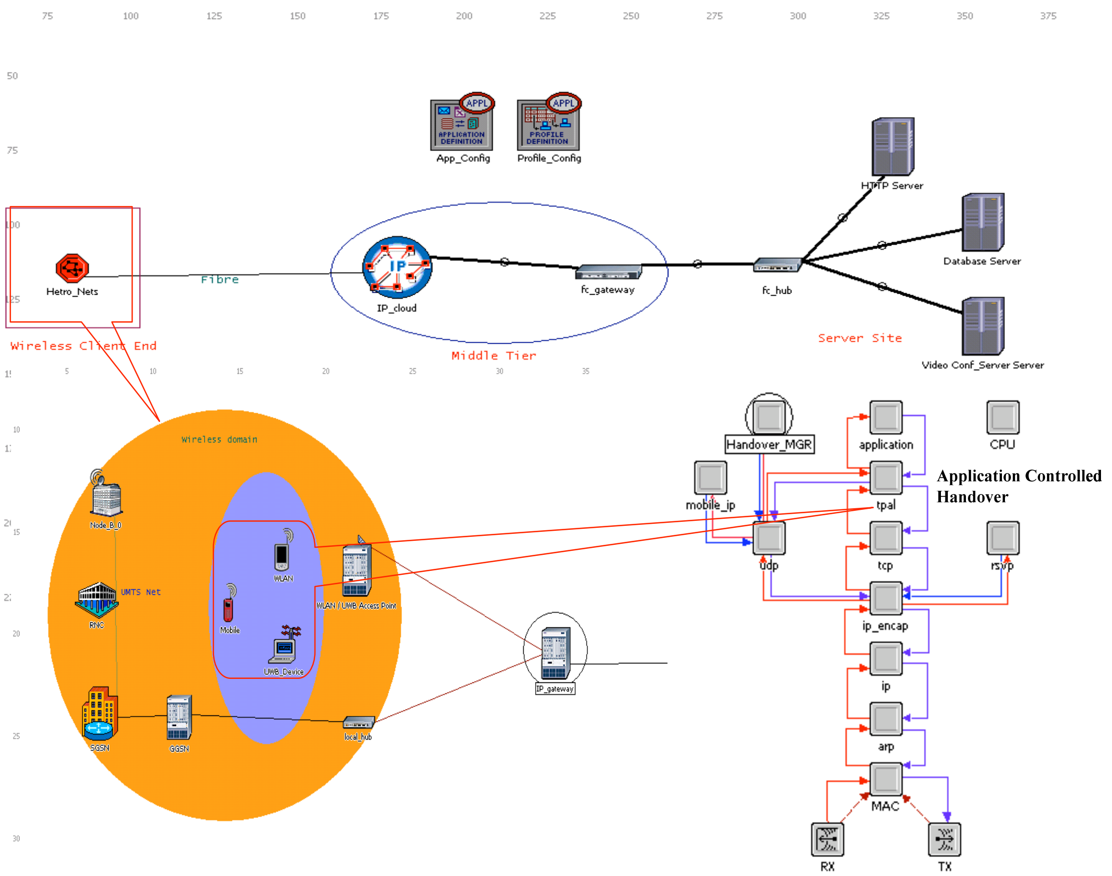

Figure 3.11: Network Simulation Model Layout.

3.6.1. Multiple Radios over Fibre Network

In this scenario, the behaviour of three wireless technologies UMTS, WLAN and UWB were examined within the framework of a deployed FMC to simulate the WWIN without an efficient handover technique. Firstly, the mobile device communicates to remote server using simple http application with UMTS infrastructure. The data traffic changed from HTTP to FTP (Databases) and then to Video conferencing respectively. The WLAN and UWB were accessed via AP, which was connected to wired backbone server through a central hub using optical fibre (2 Gbps) simulating a real life office environment [27], [28]. An IP gateway (i.e. an enterprise router) connected the wireless network to an IP cloud used here to represent the backbone Internet connectivity. The remote server supports three kinds of traffic FMC such as HTTP, FTP/Heavy FTP (Databases) and real time video calling/conferencing.

3.6.2. Multiple Radios over Fibre Network with ACH

In this second entire network simulation settings and configurations were kept same as for the first scenario. The only addition is mobile devices have been equipped and updated with ACH functionality.

3.6.3. Network Parameters

ACH made the data exchange very bandwidth efficient and enhance system performance as discussed and presented in this section. The simulation network parameters and traffic type for both scenarios are described in Table 3.3 and Table 3.4 respectively.

Table 3.3: Network Simulation Parameters

Multimode Fibre Channel bit rate	2Gbps
Number of Nodes	3
Simulation Area	500x500 Meters
Simulation Time	60 Min

Table 3.4: Network Data Traffic Profiles

UWB / WLAN / UMTS devices	APPLICATIONS H= Heavy L=Light		
	HTTP	**FTP**	**Real Time-Video Conf.**
No Handover	L	H	H
App Controlled Handover	L	H	H

3.7 Performance Evaluation and Discussions

In this chapter, an imperative performance evaluation has been carried out for multiple radios over fibre network with a special focus on the performance of the UMTS, WLAN and UWB when subjected to rich multimedia applications. Real time traffic was introduced in the network in the form of video conferencing. Video conferencing encompasses data, voice and images and adequately represents the ultimate heavy multimedia traffic.

No extensive network management techniques were configured but the application controlled handover technique has been used to identify the effect of multiple wireless radio interfaces on the performance of the optical fibre network.

The performance measurements those are relevant to network traffic, such as wireless and cellular link utilisation in terms of throughput was obtained and discussed. More specifically, the response times of applications (HTTP, Database and Video Conferencing) at the mobile devices were also compared to ascertain the user alleged QoS.

Additionally some critical network parameters such as media access delay, end-to-end packet drop, bit error rate and network power consumption has also been evaluated for both scenarios. A simulation time of one hour was set for both scenarios to achieve feasible results.

3.7.1. Network Throughput

Comparing the multiple radios over fibre network in both scenarios showed that a high network throughput has been achieved for the Application Controlled scenario. Figure 3.12 presents a comparison of average network throughput for same type data traffic run for both scenarios.

One scenario used ACH mechanism and results in 83% improvement on the throughput of the network. Application controlled optical network has reached up to an average of 12000 bps as compared to 2000 bps by the network without handover technique.

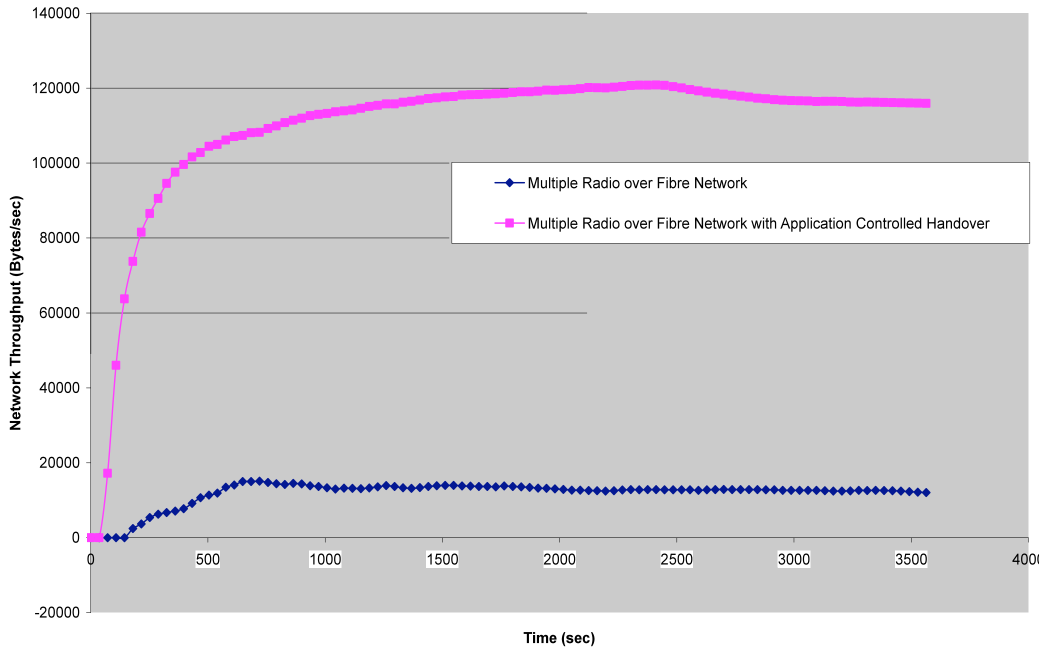

Figure 3.12 Network Average Throughput.

3.7.2. HTTP Client Server Response Time

There was enormous improvement in the HTTP response time of the optical network with ACH when subjected to http traffic as shown in Figure 3.13.

The result shows that optical network with handover can handle higher load than the base model (without handover) due to the selection of appropriate wireless air interface. It can be seen clearly from Figure 3.13 that both network models performed similar when the network data traffic was kept simple in the start of simulation time. Whereas, after introducing heavy http browsing, the response time reached to the 27.5 seconds for optical network without handover technique. Whereas optical network with handover performed excellent comparatively and reached an average response time of 4.5 seconds which is 23 seconds less than the base model.

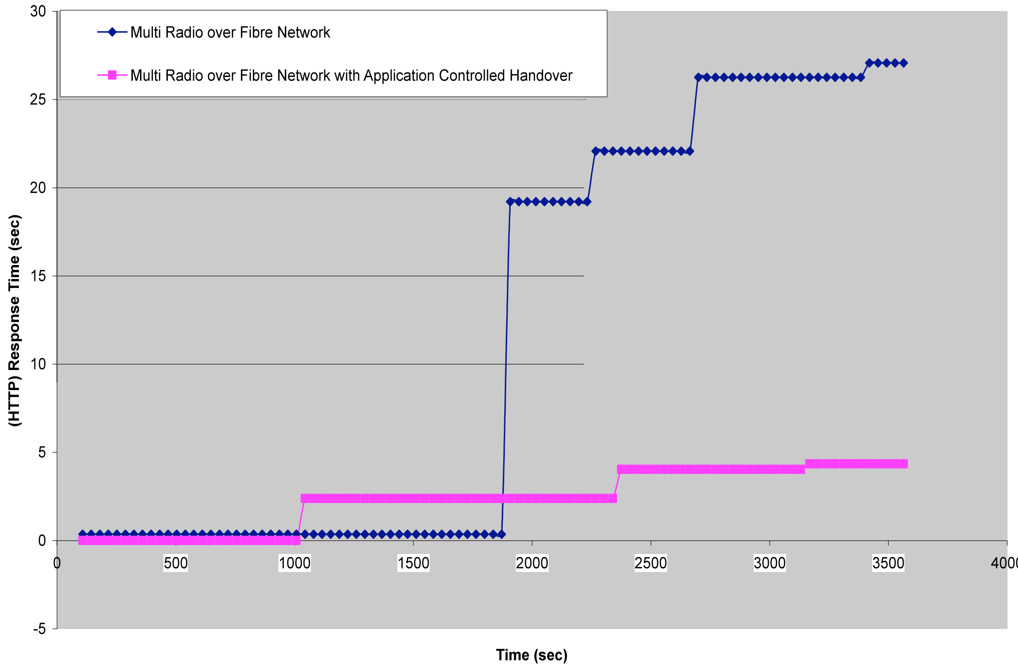

Figure 3.13: HTTP Average Response Time.

3.7.3. Database Client Server Response Time

A similar improved performance was seen in database response time (FTP) during the simulation. Database needs higher authentication and security information comparing to simple HTTP application. Therefore it enhanced the load on the communication technology.

After 3000 seconds of simulation time, the database response time reached up to 1000 seconds for base model while using UMTS for database access as shown in Figure 3.14. However, application controlled handover improved network response time by switching to WLAN. Database response time for controlled handover reached to 10 seconds, which is 100 times less than the base network.

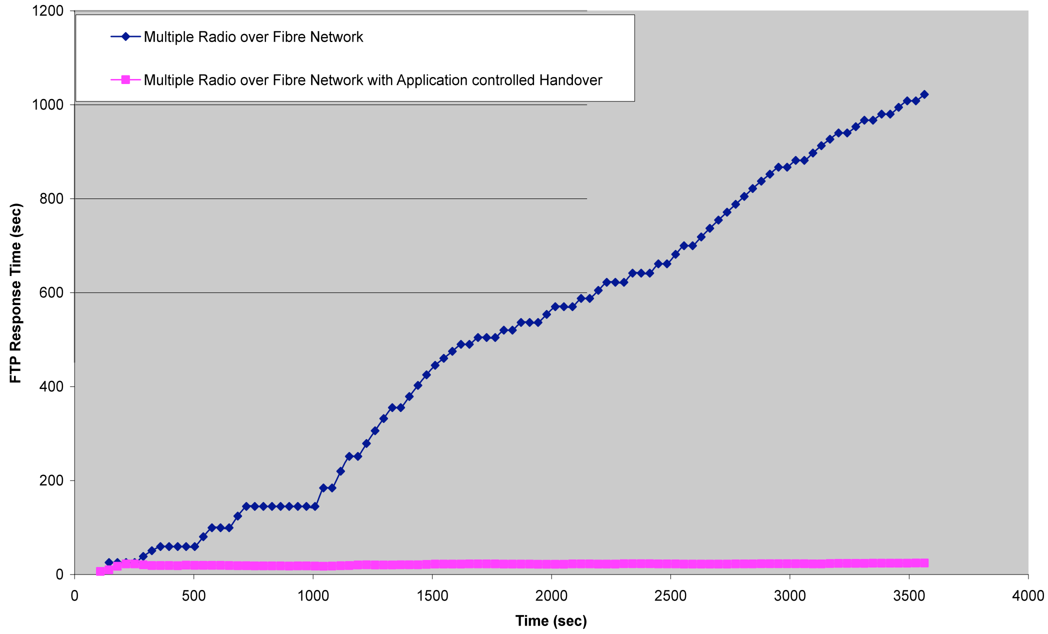

Figure 3.14: FTP Average Response Time.

3.7.4. Video Conferencing Response Time

Optical fibre network without handover used UMTS service for real time video conferencing, but heavy multimedia video data transmission overloaded the radio link. The Handover technique in optical network enhanced the response time from the video server. An average improvement of 3 packet/sec for video transmission delay can be seen in Figure 3.15.

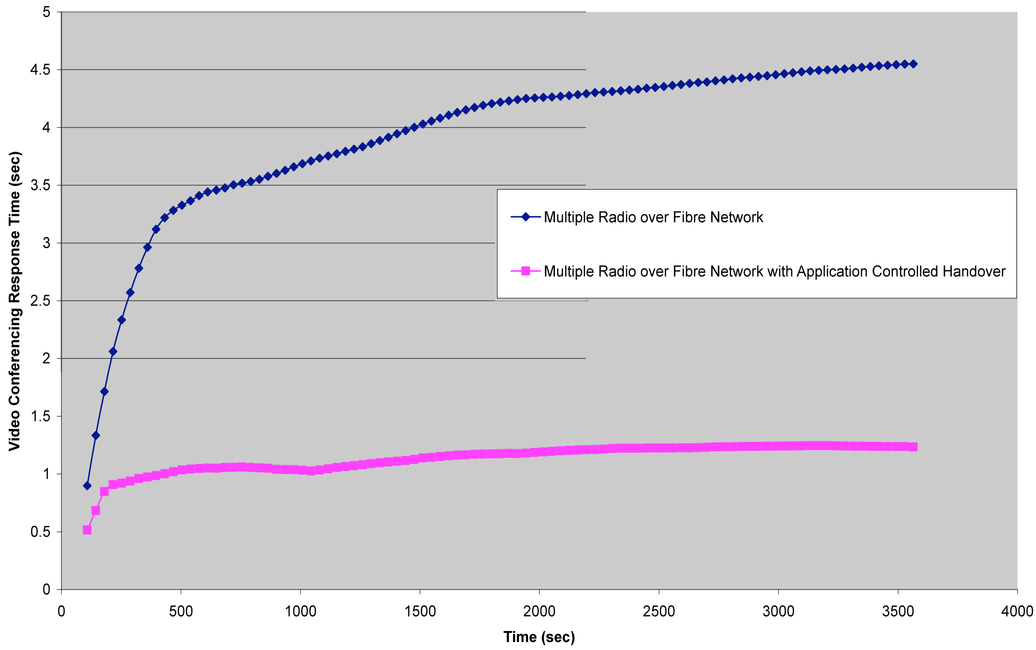

Figure 3.15: Video Conferencing Average Response Time.

3.7.5. Network Multiple Media Access Delay

In Figures (3.12-3.15), it was seen that ACH improved the network efficiency and enhanced the performance enormously. ACH works on cross APP–TRA-PHY layers; the algorithm's working architecture is based on the selection of particular wireless technology for specific application type. Handover mechanism increased the medium access delay of the network because of handover between different wireless access technologies, whereas with base network it resulted in 0.00005 seconds less delay as shown in Figure 3.16.

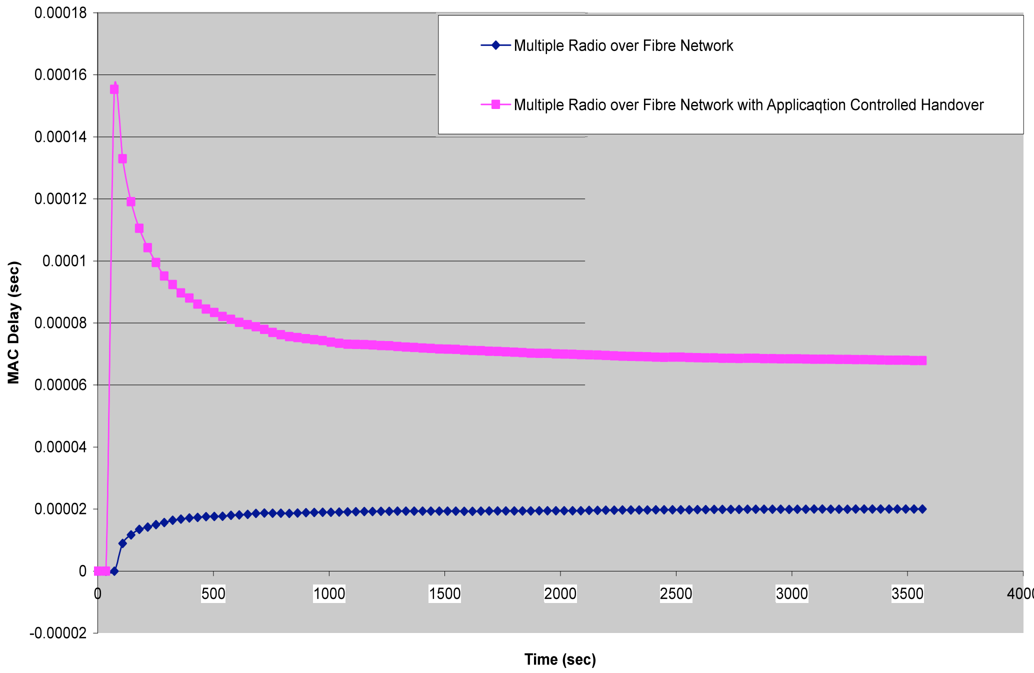

Figure 3.16: Network Average Media Access Delay.

The medium access delay is function of handover algorithm and traffic characteristics. That is why, where this algorithm enhanced the network efficiency, it led to increase in medium access delay too. Once the network was established a linear behaviour was observed from both network scenarios.

3.7.6. Network Packet Drop

Figure 3.17 shows the peak-to-peak network average packet drop comparison for both network scenarios. Base network shows very non-linear behaviour because of high variation in transmission. It has dropped up to 18 packets/second and gradually improved to an average of 10 packets/second. On the other hand, application controlled handover performed well by reducing the packet drop up to 83% comparatively.

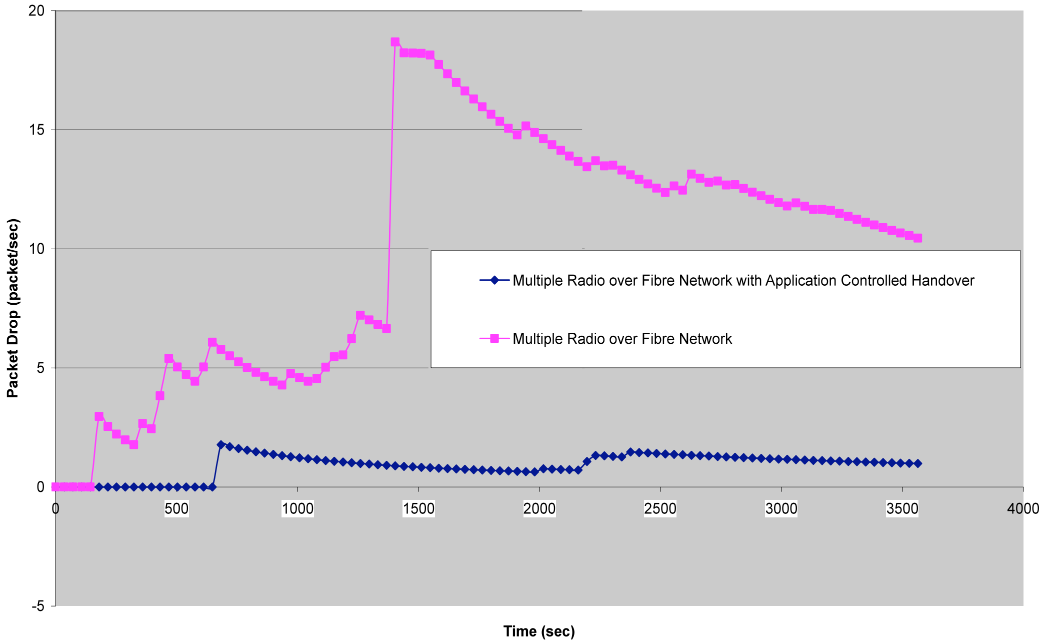

Figure 3.17: Network Average Packet Drop.

3.7.7. Network BER and Power Consumption

Base network model showed very non-linear behaviour for both BER and power transmitted. The glitches in the graphs are because of the variation in data traffic and high bit rate demand. It can be seen that ACH have reduced the BER and power consumption to 74% and 85% as shown in Figure 3.18 and Figure 3.19 respectively. The proposed scheme has reduced an average of 0.005 BER/packet and 8 nano-joules power in comparison to base network model without ACH.

Minimum power consumption and high data rate in any wireless network is of great importance for a given QoS. The wireless devices mostly have limited battery power and the selection of appropriate air interface in ACH has proved the significant advantage of the proposed technique. Reduced packet drop and BER by application controlled handover technique not only enhance the bandwidth efficiency but also reduce the number of re-transmission of packets which is directly proportional to the power and complex error recovery techniques.

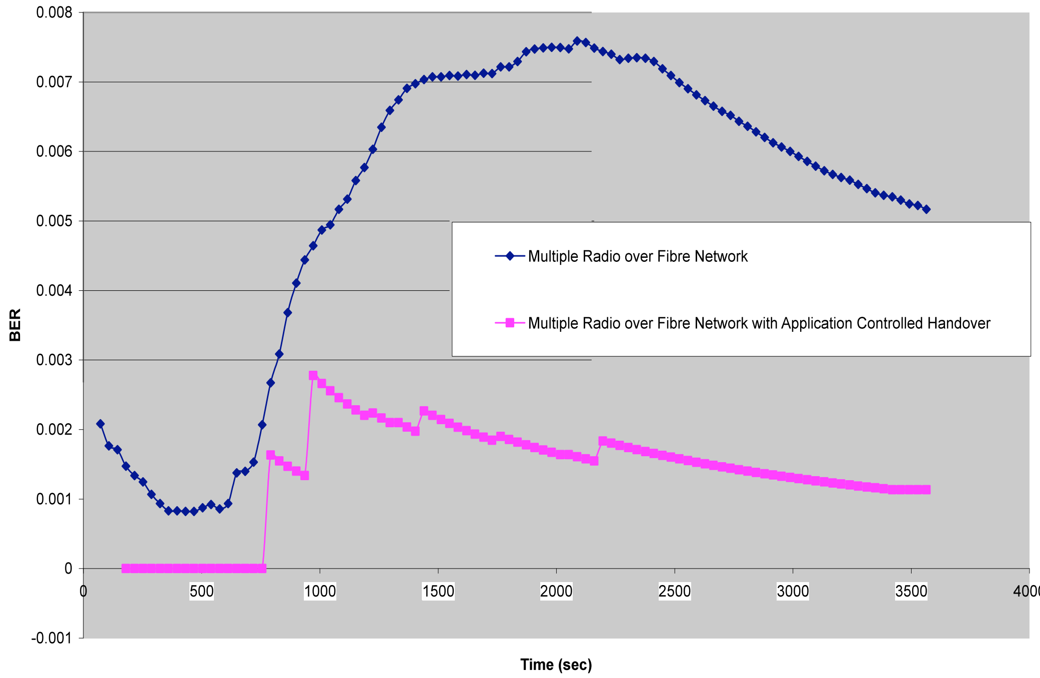

Figure 3.18: Network Average BER.

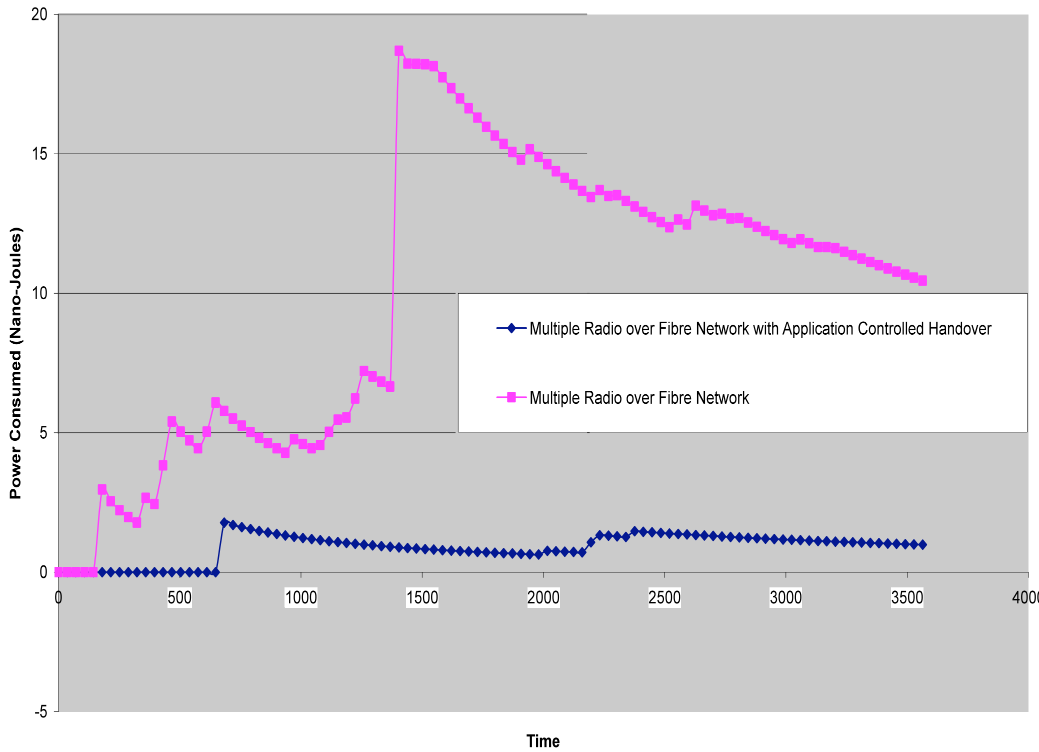

Figure 3.19: Network Average Power Consumption.

3.8 Conclusions

In this chapter it has shown how the development of novel Application Controlled Handover (ACH) technique for FMC has been achieved. The modification works in complementary with the standard WWIN architecture. Since most of the modern wireless devices are mobile and battery-operated, it is important to detect the device expected running time. This parameter could be used to enhance the network functionality continuation by avoiding devices with short lifetime. Furthermore, battery charger algorithm has been presented and simulated in order to approach the real-life power model for the wireless battery-operated devices in this work.

In this chapter, transport layer enhancement (ACH) for the selection of multiple radios according to application type, has been successfully proposed, designed and implemented in terms of end to end network simulation. This chapter concludes that an optical network with an Application Controlled technique would act as a better convergence platform for future broadband network communication systems. Handover algorithm not only enhanced the network overall performance but also the reduction of packet drop up to 83%, BER to 74%, response time to 100% and power consumption to 85%, which is an enormous achievement for any wired wireless converged platform. On the other hand, there is decay in medium access delay using proposed ACH.

The mesh and power controlled framework will be built on the ACH based architecture, which is proposed by this work. A meshed and power controlled ACH enhancement is proposed, discussed and compared in the next chapter.

3.9 References

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Chapter 4

Power Controlled Mesh Multi Radios over Optical Fibre using ACH

The wireless-optical meshed network architecture has been proposed, as a flexible solution to meet the ever-demanding needs of next generation hybrid networks. In this chapter a meshed multiple radios approach that consists of 3G (UMTS), WLAN, UWB, 802.15.4 and WiMAX over fibre has been implemented in comparison to Application Controlled Handover (ACH) based network and simple multi radio end-to-end wireless transmission. The proposed architecture implements energy enhanced traditional distance based multihop mesh technique and maintains the multi radio channels to provide real time quality of service continuity for multimedia traffic.

4.1 Introduction

Radio over Fibre (RoF) is a rather ideal technology for the integration of wireless and wired networks. The main reason being is that it combines the best attributes of two common communication methodologies. A wireless network connection frees the end-user from the constraints of a physical link to a network, which is a drawback of conventional fibre optic networks. Meanwhile optical networks have an almost limitless amount of bandwidth with which to satiate even the most bandwidth hungry customers where bandwidth for wireless networks can be a significant bottleneck. Thus RoF networks offer customers the best of worlds by allowing them to maintain their mobility while also providing them with the bandwidth necessary for both current and future communication/entertainment applications (i.e. HDTV, Video on Demand, 3DTV, video teleconferencing, etc.). Such network topologies could be useful in places such as large buildings, subways and tunnels where large amounts of people are mobile thereby making physical connections impossible and standalone wireless systems being aced with the difficulty of bandwidth limitations and handover issues.

While the concept of RoF networks has been around for several decades now, there is still a substantial amount of work that needs to be undertaken in order to improve their characteristics and capabilities. Several research priorities have been identified that should be addressed in order to improve not only the capabilities of RoF networks but also their cost effectiveness and robustness [1]. The requirement to communicate a very high data rate such as rich multimedia with low power and low cost are the reason behind the integration between wireless and wired domains using RoF as this integration is the only way to allow high data rate with low power and low cost. The integration has the potential to make the networks more transparent, dynamic, faster and greener. Reconfigurable enhanced mesh architecture for multi-application, multi-homed and multi-service supported mobile device is presented to enable seamless mobility across different access technologies including wired and wireless infrastructures.

In an integrated 3G+WLAN+WPAN+WiMAX architecture as illustrated in Figure 4.1, more data and multimedia applications are carried end-to-end over the current Internet protocol infrastructure. Fundamentally Wired Wireless Integrated Networks (WWIN) will reshape the telecommunications industry. Technological changes in the telecommunication industry have not only led to the creation of new trends in the deployment of next generation networks, but also the convergence with information technology sector. In particular, the so-called WWIN has become a reality due to market demand and industrial competition. Fixed Mobile Convergence (FMC) enables users to work with existing wired and wireless networks. 3G has been under global deployment and it accesses the network by using the cellular and WiMAX networks. WLAN and UWB are free of charge high data rate communication air-interfaces. WLAN, UWB, WiMAX and UMTS can serve the Internet core network via the Transmission Control Protocol/Internet Protocol (TCP/IP). TCP/IP enables users to adopt client server communication by accessing the individual network.

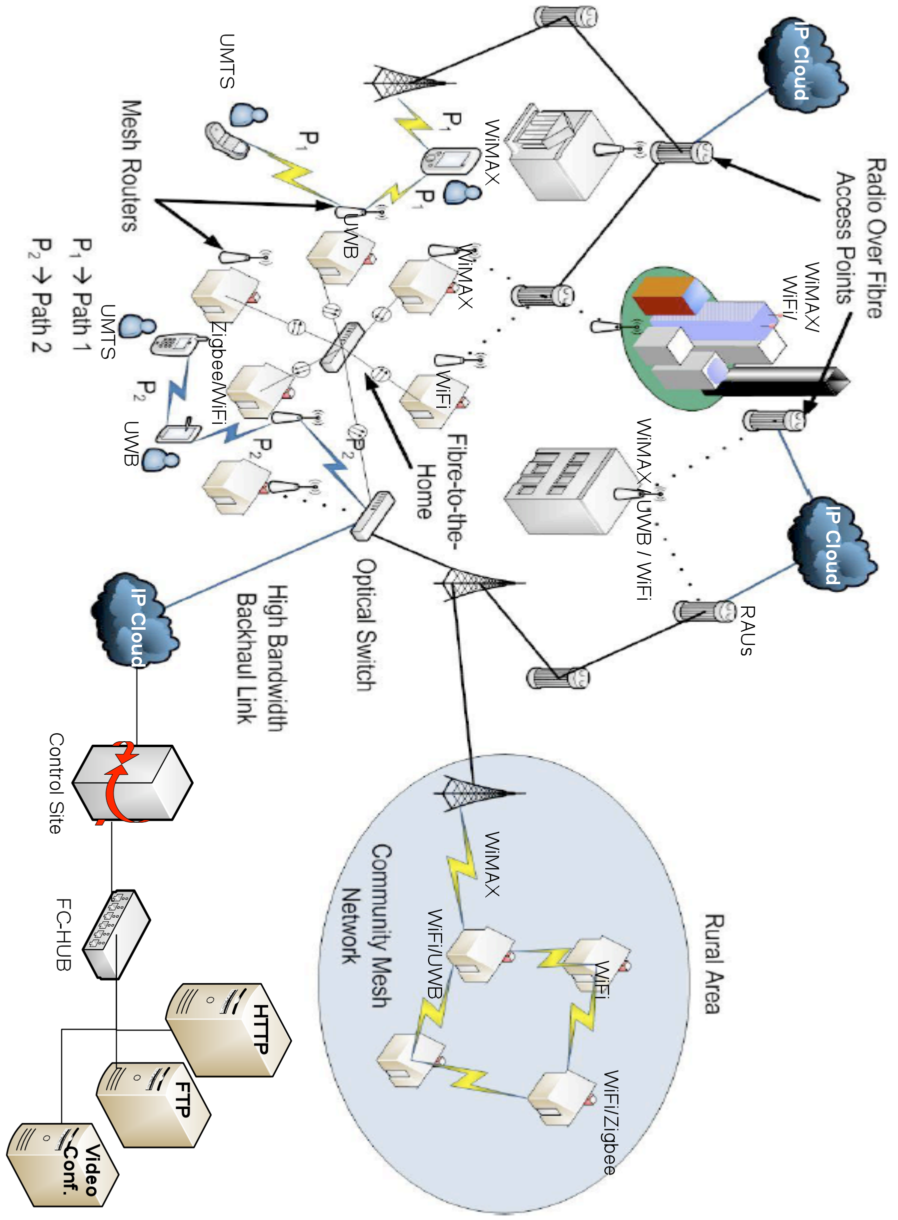

Figure 4.1: Proposed Power Controlled Mesh Multi Radio Network.

A. Research Challenge

The work in this chapter is the enhancement and realisation of the proposed architecture for next generation multi radio wired and wireless converged networks and enhanced power efficient scheme for multi radio mesh networks, which provide data transmission and service continuity in the WWIN environment. The proposed mesh architecture uses a cross layer design to operate on the transport layer between the wired and wireless network infrastructures. The multi radio mesh devices have installed power efficient scheme and move freely in the wireless domain. The handover provides service continuity and data transmission by selecting the wireless technology depending on the required power. The traffic was recorded at the remote server that was located in the wired network and it was transported from devices that were located in the wireless network as presented in Figure 4.1.

This chapter is organised in 7 sections. Section 4.2 outlines the related work in the era and hierarchy of the classification. Section 4.3 presents the brief architecture of proposed multi radio mesh over fibre architecture and organisation of methodology. In Section 4.4, the development and design of core network has been discussed in details. Section 4.5 demonstrates the network scenarios, implication of scenarios and layout for the proposed architecture. Section 4.6 elaborates the results and discussions leading to precise conclusions in Section 4.7.

4.2 Global Contribution and Related Work

In future Internet where wired and wireless networks are integrated, the traffic volume of wireless users should expand greatly and the QoS for wireless users will be one of the most important technical issues. In the wireless network environment, TCP is one of most important protocol, suffers from significant throughput degradation due to the lossy characteristics of a wireless link. Therefore, in order to design the next generation networks, it is necessary to know how much improvement a WWIN brings. The throughput of a TCP connection is dependent upon both packet loss and application response delay. Several papers have been published in the domain of wireless TCP, for example, reference [2] evaluates throughput performance of a single wireless TCP connection experimentally, and reference [3] analyses the throughput performance mathematically using a fluid flow model. These papers only dealt with wireless TCP and did not take care of the interaction of wireless and wired TCP in the FMC environment.

The architecture classification for WWIN is based on: Intracellular, Inter-cellular and Extra-cellular architectures as shown in Figure 4.2. In Intracellular architectures, each Access Point or Base Station (AP/BS) communicates with any mobile node (MN) in its coverage area in a multi-radio mode. On the other hand, in Inter-cellular architectures, each AP/BS communicates with any MN in the coverage area of other APs/BSs in a multi-radio mode. Finally, Extra-cellular architectures enable an AP/BS to communicate with MNs that are not in the coverage area of any

AP/BS. Any of these classifications may employ dedicated radio stations. Furthermore, Intra/Inter cellular ad hoc mode architectures can be classified as multi-radio systems in which MNs act either in single-radio mode or multi-radio mode. Figure 4.2 illustrates this classification with respect to the well-known references such as [4]-[18] in this research era.

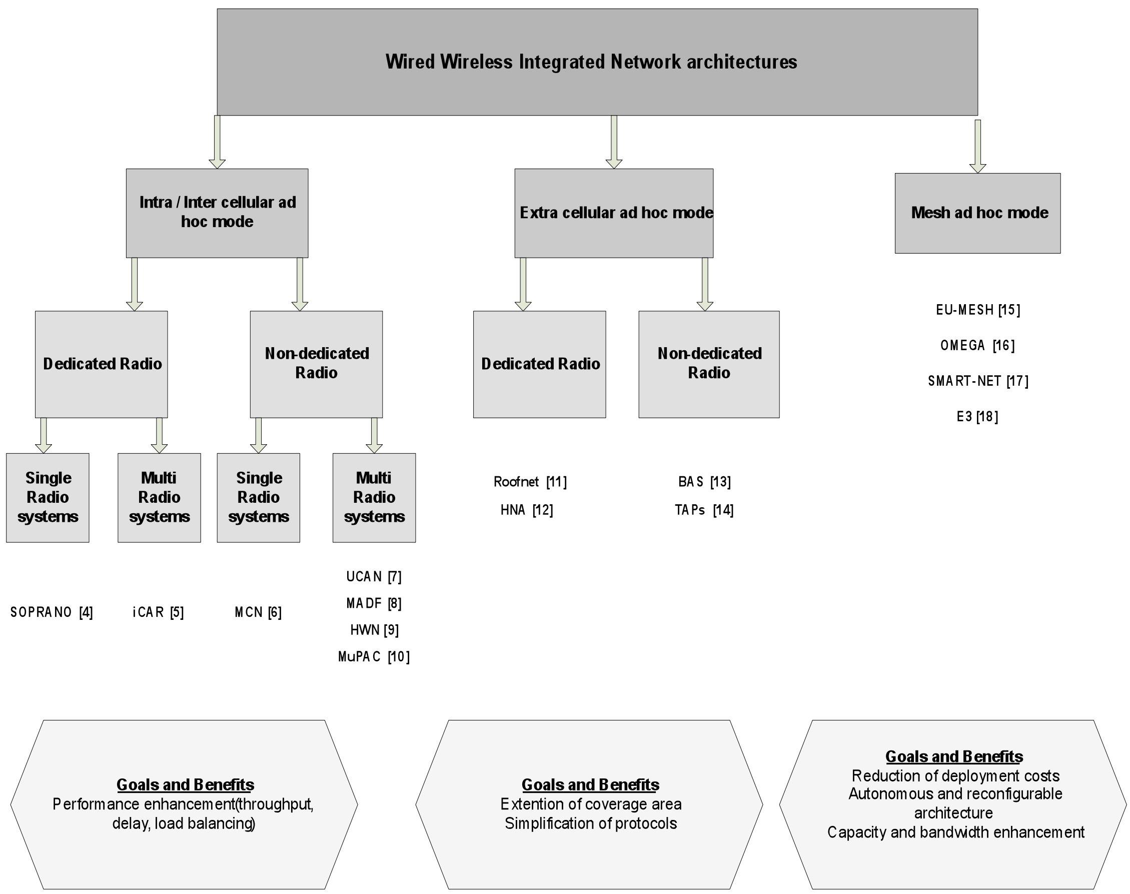

Figure 4.2: Classification of Wired Wireless Converged Network Architectures.

4.3 Proposed Network Framework

The existing integrated high-speed wired and wireless mesh networks are shown in Figure 4.1 that reveals the general constitution of proposed architecture. Both wired and wireless networks have separate service platforms. FMC network supports data service in the existing voice/data based wireless infra, and the existing high bandwidth wired network infrastructure.

The proposed FMC simulation architecture is based on energy efficient multi-radio mesh such as UMTS, WiMAX, WLAN, UWB, ZigBee and optical fibre networks. In this chapter a novel FMC environment is proposed by using converged TCP/IP and a transport layer between wired and wireless networks. The proposed architecture uses the transport layer and TCP/IP for each network constituting FMC. In this mesh architecture for energy efficiency, mobile devices select next hop according to the distance instead of random nodes. The hybrid interface selection depends on the access of HTTP data using the UMTS cellular networks. For FTP and real time database applications, such as remote account management and payroll systems for a multinational corporate, WLAN and WiMAX is a widely used solution. For real time video calling and video conferencing UWB is prominent candidate supporting 200 Mbps [2]. [3]. WiMAX has a shared bandwidth up to 72Mbps [3].

Figure 4.1 shows various mobile networks in the wireless network domain having access to UMTS, WLAN, WiMAX, ZigBee and UWB air interfaces. The network protocol stack can communicate in a cross layer fashion from PHY to APP Layer to detect the transmission of data, handover to the suitable air-interface, distance measurements and send it to the remote server. Once the server gets the request, it records real time data transmitted from user’s device.

4.4 Development of Core Network Components

This section presents an energy efficient multi radio over fibre components for wired and wireless integrated networks. The heterogeneous mobile devices not only sense the signal strength but also determine the closest relay node if the Radio Access Unit (RAU) is at distance. A soft handover has been considered in the simulation network due to the session handling of connections of more than two radios e.g. connections to UMTS, WLAN, WiMAX and UWB can be maintained by one device at the same time. It is a trade off between the one channel occupancy (hard handover) and the QoS in terms of soft handover’s make-before-break (session continuity). This section elaborates the wireless and optical components for proposed network protocol stack, the design of network components (wired and wireless) and finally the mathematical process model for an energy efficient mesh.

The proposed components perform the following functionality:

1. Cross Layer Network Protocol Stack
2. Multi Radio Network Connection Schematic
3. Multi Radios over Fibre Uplink/Downlink Design
4. Meshed Network Architecture
5. Distance Controlled Power Efficient Mesh

A. Cross Layer Network Protocol Stack

Figure 4.3 depicts the protocol stack for the proposed architecture. Seamless bridging is supported natively by this protocol, which enables both information and process data to be easily exchanged in heterogeneous environment. The multi radio transportation manager adopts the lower layers of the protocol stack (PHY). Despite the relatively low speed of UMTS (384 kbps), it is able to guarantee deterministic behaviour. As long as the load on the network is well below the theoretical available bandwidth, the proposed architecture guarantees that any low or high data is transmitted to the server within the suitable application response time.

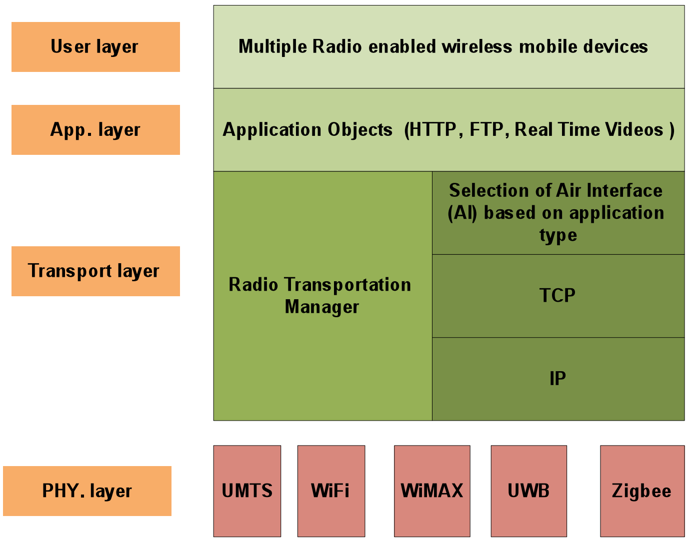

Figure 4.3: Proposed Multi Radio Network Protocol Stack.

B. Multi Radio Network Connection Schematic

The design of components for mobile devices is illustrated in Figure 4.4.

(I) The Data Control component that can exchange data with external device,

(II) The Application and Air Interface signal acquisition component that can receive the radio signal strength of the wireless network,

(III) The Socket Control component that controls the communication resources inside the device with the wireless network platforms according to the demand of quality data transmission requirements.

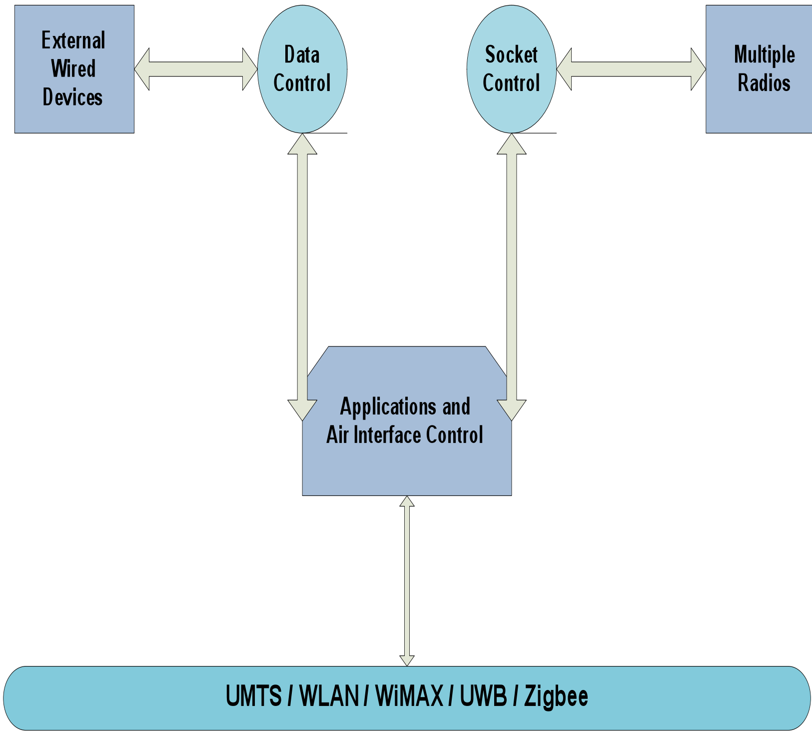

Figure 4.4: Multi Radio Network Connection Control.

The proposed wireless mesh mode used virtual sockets for all multiple air interfaces such as UMTS, WLAN, WiMAX, ZigBee and UWB [19]. [20]. In this chapter a design of five virtual sockets for the five radios have been proposed and developed. In the Figure 4.4, the signal control component can control all the five radio interfaces between data control and the socket control component. The application and air interface acquisition component provides the signal strength of AP/BS. The network controller is connected to the multi radio transportation manager.

C. Multi Radios over Fibre Uplink/Downlink Design

The general optical network components are depicted in Figure 4.5. The uplink where packets are transmitted from and downlink signals are separated using a RF circulator as shown in Figure 4.5b and Figure 4.5c. A single mode fibre (SMF) is used with different wavelength for uplink and downlink. To eliminate the effect of the wireless channel on the system performance an RF cable connects the RAU. The uplink and downlink RF signals are separated using a circulator. The proposed design of uplink and downlink are shown. The electrical signal is converted to an optical signal using a variable bandwidth distributed feedback (DFB) laser. An optical combiner is used which allows a single length of SMF to be used for both directions. To ensure that the optical power levels in the system were constant, a bidirectional optical attenuator was employed for each fibre length. At the receiver end, an RF amplifier is used to increase the radio signal power level, which has a maximum value of 100mW in Europe [20]. It should be noted that all amplification occurs at the RAU.

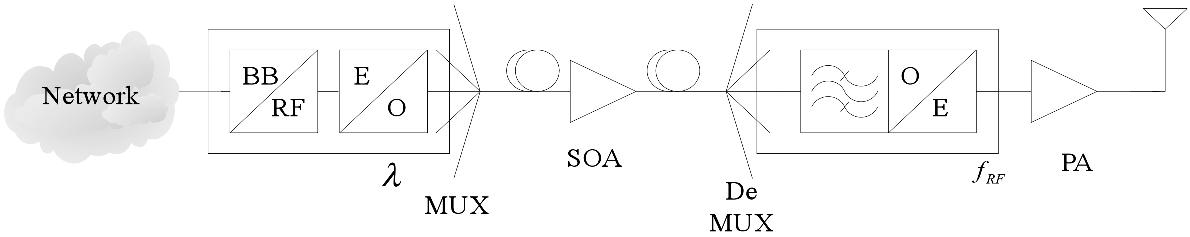

Figure 4.5 a: Multi Radios Design.

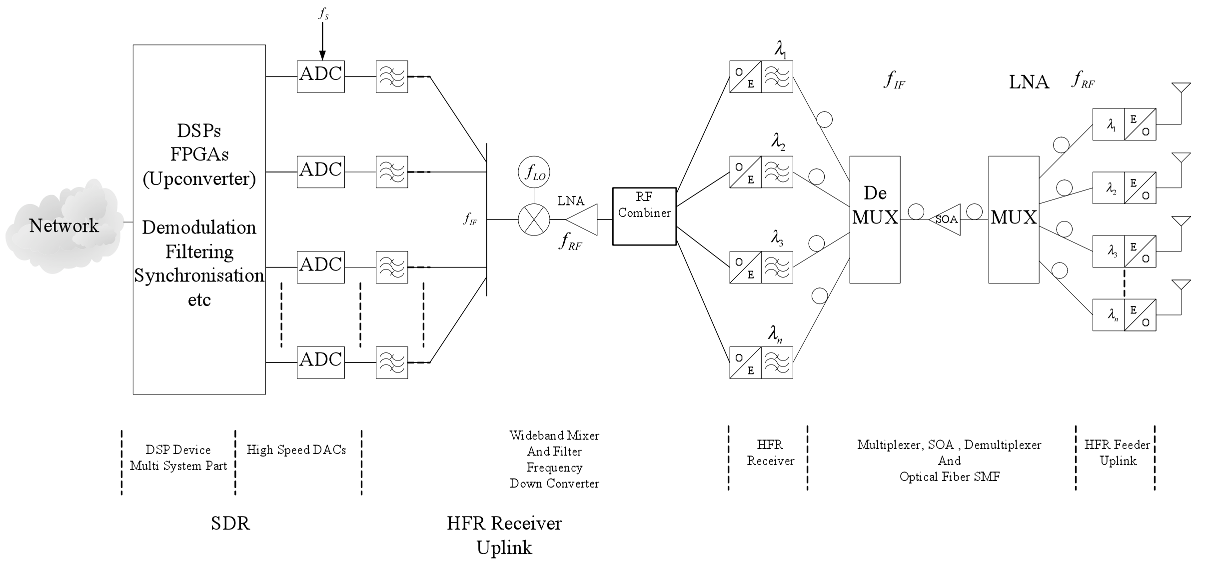

Figure 4.5 b: Multi Radios Downlink.

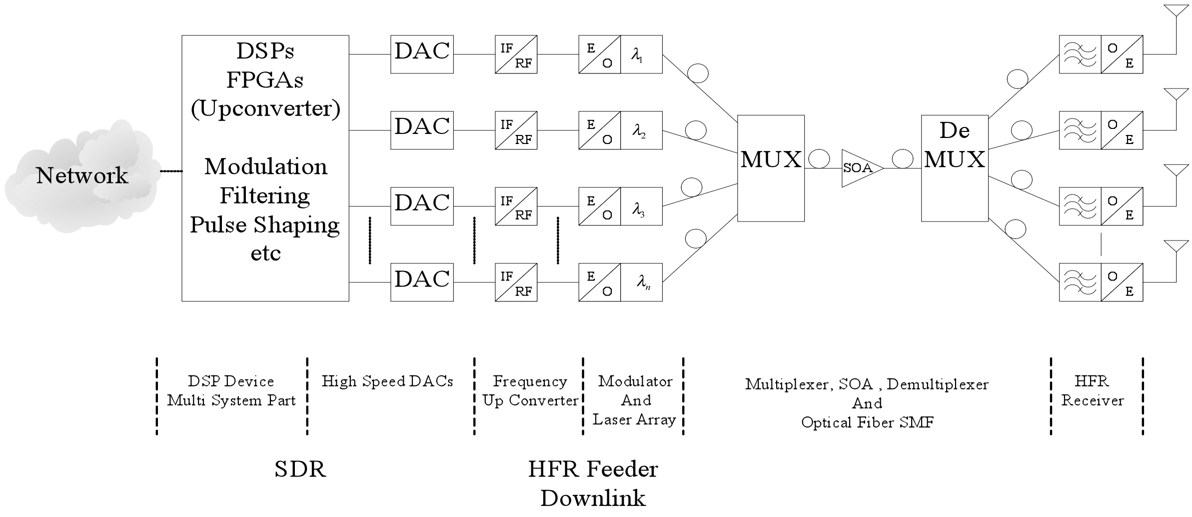

Figure 4.5 c: Multi Radios Uplink.

D. Meshed Network Architecture

In a meshed network, there are mesh devices (MDEVs) and mesh network coordinators (MNCs) in addition to the legacy 802.15.3 devices and Communication between MDEVs that belong to different independent networks is possible in a mesh configuration. The MNCs can communicate with each other and they can also manage their own networks that can contain the MDEVs . Thus both inter-network and intra-network communication can take place in meshed structure as shown in Figure 4.6.

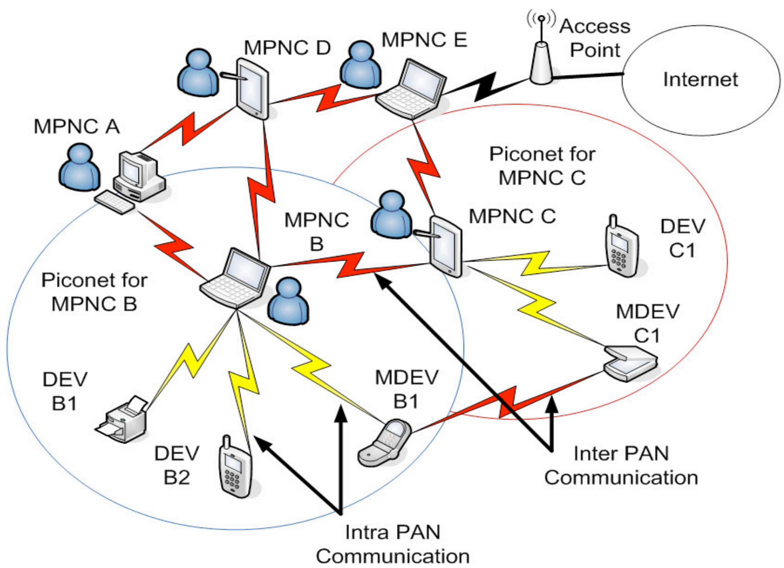

Figure 4.6: Mesh Network Architecture.

Unlike the intra-network communication that takes place in the legacy single hop network in which a single network coordinator coordinates the channel time in the superframe, several MNCs share the channel time in the superframe among them. For this reason, the superframe is divided into Medium Access Slots (MASs) that are of equal length. The length of the superframe is kept the same throughout the mesh network and all the MNCs synchronize their beacons to a common reference MNC.

At the front end, proposed architecture consists of a multi-hop wireless mesh network while at the back end an optical access network provides connection to the Internet. At the back end the dominant technology is the passive optical network (PON) having optical line terminals (OLTs), located at the central office (CO), and optical network units (ONUs) to provide connection to wireless gateway routers. Different PON segments are supported, with each segment radiating from a single OLT at the CO to multiple ONUs near end-users. The PON interior elements are basically passive combiners, couplers and splitters. Since no active elements exists between the OLTs and the ONUs the PONs are considered robust networks. In traditional time-division-multiplexed (TDM) PONs an upstream and a downstream wavelength channel is used for bidirectional communication as shown in Figure 4.5. The network architecture is illustrated in Figure 4.1. To provide connection between PONs a reconfigurable optical backhaul, allowing easy bandwidth reallocation, can be used.

Although having low installation and maintenance cost, due to the passive infrastructure, in the traditional PON, all end users share the CO. That is, a packet sent to a specific user, connected to a particular ONU, is broadcast to all ONUs. As users demand for more bandwidth, wavelength division-multiplexing (WDM) PONs may become a better alternative. A WDM PON solution supports multiple wavelengths such as WiFi, ZigBee, UWB, WiMAX and UMTS over the same fiber infrastructure, but active components become necessary. Incorporating WDM in a PON allows the support of much higher bandwidth and scalability when compared to the standard PON, which operates in single-wavelength mode.

Regarding the wireless infrastructure, standard WiFi or WiMAX technology can be used for wireless mesh connectivity. These wireless access technologies have been employed worldwide. Several wireless routers provide multihop connectivity for user traffic delivery toward a few wireless gateway routers that are connected to the ONUs of the optical back end. An ONU can drive multiple gateways. An individual user scattered over such geographical area will associate with a nearby wireless router for Internet access. A mesh router can gain access to a gateway router through multiple paths. In the upstream direction traffic can be delivered to any of the gateways while in the downstream direction traffic is sent to a specific wireless router.

In such multi-radio networks each radio interface has the capability of switching over orthogonal channels and transmission or reception is possible at any channel at a time [21]. That is, considering a specific channel, only links that are located out of their mutual interference range can transmit at the same time. Consequently, a careful channel assignment becomes critical in such networks so that more simultaneous transmission occurs, leading to a global system capacity improvement [22].

E. Distance Controlled Power Efficiency

Multiple power efficient management schemes in wireless networks have been proposed in [23]. Lower transmission power leads to lower interference level and better end-to-end throughput. Power saving in multi radios has been studied in order to increase the mobile nodes operating time [24]. In a multi radio multi hops network, wireless network protocols can manage power consumption for each individual node and the total power distribution in the entire network. Figure 4.7a shows the source data is node (A), while destination is node (B) in a mesh domain.

In this case, the destination node (B) is still in communication range of the data source node (A), but it requires high transmit power to meet the necessary signal quality. Instead, the node (A) can use the multi-hop feature of ad hoc networks and build a route from (A) to (B) via an intermediate node (C), where (C) is located in midway between (A) and (B) as shown in Figure 4.7a. The decision to route data from (A) to (B) via (C) should take into consideration the battery level in both nodes (A) and (C) as well as link stability.

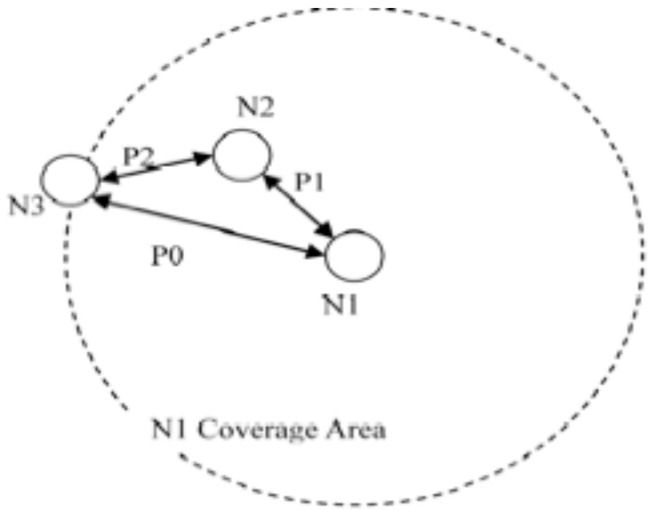

Figure 4.7a: Power Controlled Transmission.

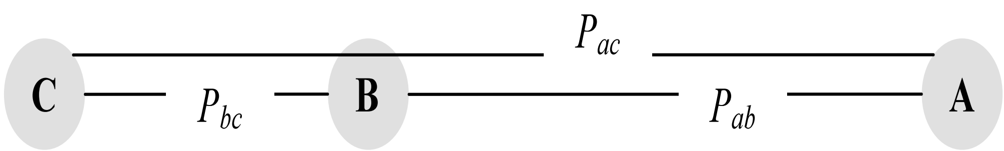

Figure 4.7b: Distance based Power Controlled Schema.

I. Power Saving using Multiple Hops

Power level is a scale for the minimum power required by the sender node to reach the next hop. If the next hop can be reached via another node by lower transmission power, then this new path should be adapted. Figure 4.7a illustrates this concept.

For node (A), less transmission power is required to reach the destination node (B) via intermediate node (C) instead of sending data directly from (A) to (B). The decision to change the route from direct link between (A) and the destination node (B) to an indirect route via (C) is taken by calculating the battery life of node (C) and the total throughput and efficiency of the new route.

In the source node:

1. When (battery / expected use time) = threshold: Then start transmission save mode
2. Check all the next hop neighbour nodes about a possible volunteer (the old destination node should be included in this message)
3. If a neighbour node can reach the old destination and source-neighbour required transmission power is less than the original; then a Volunteer Request message will be sent back to the source node
4. The route will be changed from the old destination to the new volunteered neighbour.

In the neighbour node:

1. When a Volunteer request message is received:
2. If the battery / expected use time > threshold: Then start Volunteer Process
3. If the old destination is in reasonable reach of transmission: Then send Volunteer Acknowledge message.

II. Transmission and receiving power

In Figure 4.7b, node "A" can reach node "C" directly with power P_{ac}. However, node "C" could be reached indirectly via node "B". The second path power is the sum of two parts (P_{ab} and P_{bc}). The wireless nodes transmit data to a certain range around the data source. The coverage range is a function of the transmission power and the medium coefficient. Equation (4.1) calculates the received power.

$$P_{rcv} = \frac{\varsigma}{d^4} \cdot P_{tx} \qquad (4.1)$$

where:

P_{rcv} : Received power.

ς : Log-normal coefficient

d : Distance between the source and destination

P_{tx} : Transmitted power.

Received power values (of transmitted signals from source nodes) are assumed to be equal at the destination nodes. Furthermore, the medium coefficient is the same for all data transmissions since it is the same ambience as shown in Equation (4.2).

$$K = \frac{P_{Tx}}{d} \tag{4.2}$$

where:

K is a constant value.

$$d_{AC} = d_{AB} + d_{BC} \tag{4.3}$$

where:

d_{AC} : distance between “A” and “C”

d_{AB} : distance between “A” and “B”

d_{BC} : distance between “B” and “C”

Based on these two assumptions, the transmission power of the two paths could be calculated as the following:

The direct path power:

$$P_{AC_{direct}} = K\left(d_{AC}\right)^4 \tag{4.4}$$

Based on Equation (4.4), d_{AC} could be replaced as:

$$P_{AC_{direct}} = K\left(d_{AB} + d_{BC}\right)^4 \tag{4.5}$$

$$P_{AC_{direct}} = K\left\{\left(d_{AB}\right)^4 + \left(d_{BC}\right)^4 + 4\left(d_{AB}\right)^3 d_{BC} + 6\left(d_{AB}\right)^2\left(d_{BC}\right)^2 + 4\left(d_{AB}\right)\left(d_{BC}\right)^3\right\} \tag{4.6}$$

The indirect path power:

$$P_{AB} = K\left(d_{AB}\right)^4 \quad \text{and} \quad P_{BC} = K\left(d_{BC}\right)^4 \tag{4.7}$$

From Equation (4.7), the required power for the indirect path between “A” and “C” is:

$$P_{AC_{indirect}} = P_{AB} + P_{BC} \tag{4.8}$$

$$P_{AC_{indirect}} = K\left(d_{AB}\right)^4 + K\left(d_{BC}\right)^4 \tag{4.9}$$

Comparing Equation (4.6) with Equation (4.9), the direct transmission power is higher by:

$$P_{AC_{direct}} - P_{AC_{indirect}} = K\left\{\left(d_{AB}\right)^4 + \left(d_{BC}\right)^4 + 4\left(d_{AB}\right)^3 d_{BC} + 6\left(d_{AB}\right)^2\left(d_{BC}\right)^2 + 4\left(d_{AB}\right)\left(d_{BC}\right)^3\right\} \tag{4.10}$$

From Equation (4.10) it is evident that the multiple-hops path requires less power than the direct path. The proposed mathematical model has been implemented to simulate the impact of power efficiency in a multi radio mesh environment.

4.5 Network Setup and Layout

The simulation model in OPNET [25] has been divided into three major scenarios (I) multiple radios in end-to-end wireless domain (wireless base model), (II) multiple radio over fibre network (III) power efficient mesh enabled multiple radio over fibre network (meshed multi radios over fibre). All three scenarios are simulated in parallel and compared on the basis of same parameters; the details are in the following sub sections.

The Figure 4.1 represents the multi radio mobile devices capable of WLAN, UWB, WiMAX, ZigBee and UMTS connectivity. The Radio Access Units (RAUs) supports all MAC and PHY layers of WLAN, WiMAX, ZigBee UWB and UMTS. The UWB model used here is 10 meters in range with a data rate up to 200 Mbps. This wide network was setup and simulated to analyse the scope of the simulation and to achieve reasonable simulation time of 60 minutes.

A. Wireless Base Model

In this scenario, the behaviour of five wireless technologies UMTS, WLAN, WiMAX, Zigbee and UWB were examined within the framework of a pure wireless domain. Firstly, the mobile device communicates to the remote server using a simple http application with UMTS infrastructure. The data traffic changed from HTTP to FTP and then to Video conferencing respectively. The WLAN, WiMAX and UWB were accessed via RAUs, which were connected to a wireless backbone server. An IP gateway (i.e. an enterprise router) connected the wireless network to an IP cloud used here to represent the backbone Internet connectivity. The remote server supports three kinds of traffic FMC such as HTTP, FTP and real time video calling/conferencing.

B. Multiple Radios over Fibre Model using ACH

In the second simulation scenario, setting and configurations are same as for the first one. The only addition is of the implementation of multi RoF. Mobile devices communicate with radio access points with no hoping. The RAUs are connected with Internet cloud using optical fibre (10 Gbps) simulating a real life environment [26]-[28].

C. Power Controlled Meshed Multiple Radios over Fibre Model

The third scenario keeps entire simulation, the setting and configurations same as for the second scenario. The functionality addition is that the mesh enabled multi RoF concept is introduced with proposed energy efficiency. Mobile devices communicate with radio access points with distance based hoping to minimize the power transmission.

Figure 4.8 is implemented and carried out. The technique in each multi radio node calculates the set of parameters for all possible destinations at periodic time intervals. In each node, the adjacent neighbour nodes are listed in a table stored with the minimum required power to reach next closest node. Source routing is used at the nodes according to a QoS set of requirements, which specifies the optimization function to be used for the selection of the paths. When a data packet is generated at the source node, the node applies the function to the cost vectors (check destination node, check battery and power threshold for transmission) of the paths to select the optimal path. If the source node battery power level is over threshold, the packet is transmitted to the destination in peer-to-peer mode. If the battery power is under threshold value, the algorithm looks for a lower cost node with minimum required power in neighbourhood and forwards it the data packet.

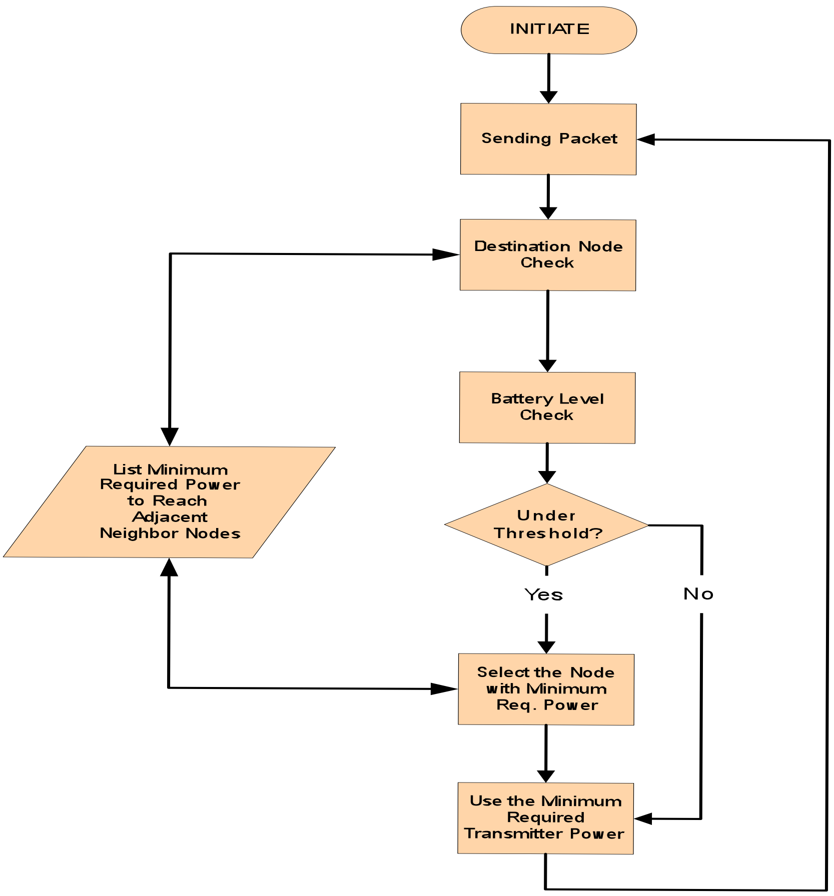

Figure 4.8: Power Controlled Mesh Work-Flow.

The proposed architecture made the data exchange very bandwidth efficient and enhanced system performance as discussed and presented in Section 4.6. The simulation network traffic type and parameters for three scenarios are described in Table 4.1 and Table 4.2 respectively.

Table 4.1: Network Application Traffic Profiles

Multi Radio Network Scenarios	APPLICATIONS H= Heavy L=Light		
	HTTP	FTP	Real Time-Video Conf.
Wireless Base Model	L	H	H
Multi Radio over Fibre	L	H	H
Meshed Multi Radio over Fibre	L	H	H

Table 4.2: Network Simulation Environment

Number of Nodes	25
Simulation Area	500 x 500 Meters
Simulation Time	60 Min
Fibre Channel bit rate	10 Gbps

4.6 Performance Evaluation and Discussions

This section carried out an imperative performance evaluation for mesh enabled multiple radios over fibre network with a special focus on the performance of the UMTS, WiMAX, WLAN, Zigbee and UWB when subjected to rich multimedia applications. Real time traffic was introduced in the network in the form of video conferencing. Video conferencing encompasses data, voice and images and adequately represents the ultimate heavy multimedia traffic. No extensive network management techniques were configured but the proposed architecture has been used to identify the effect of multiple radio interfaces on the performance of the optical fibre network.

The performance measurements that are relevant to network traffic, such as wireless and cellular link utilisation in terms of throughput were obtained and discussed. More specifically, the response times of applications (HTTP, Database and Video Conferencing) at the mobile devices were also compared to ascertain the user with expected QoS. Additionally, some critical network parameters such as media access delay, end-to-end packet drop, bit error rate and network power consumption have also been evaluated for both scenarios. A simulation time of one hour was set for both scenarios to achieve feasible results.

4.6.1. Network Throughput

The results showed that a higher network throughput has been achieved for the meshed multi radios over fibre. Figure 4.9 presents a comparison of average network throughput for same type data traffic of three scenarios. It shows meshed multi radio over fibre has 50% increase in the throughput of the networks because of multi-hoping and relay devices. The application controlled optical network has reached up to an average of 12 Mbps as compared to 5 Mbps by the network without mesh mode.

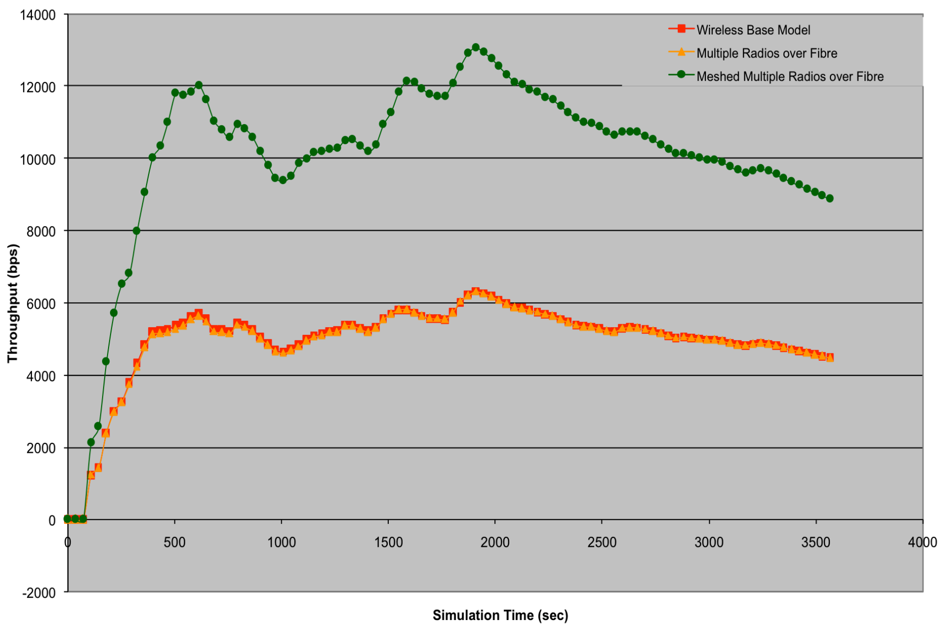

Figure 4.9: Network Average Throughput.

4.6.2. End-to-End Network Delay

Figure 4.10 presents the end-to-end network delay that indicates the comparison among wireless base model, multi RoF and meshed multi RoF models. The network average delay has been increased to about 50% when the proposed architecture is applied.

The base model performed best in comparison to multi RoF and meshed multi RoF model as compared to multihop communication, which lead to increased delay. This result is expected when the proposed approach is applied due to RAU's and multi hoping. The end-to-end delay for multi RoF and meshed multi RoF is 15 ms as compared to 1 ms delay in base model.

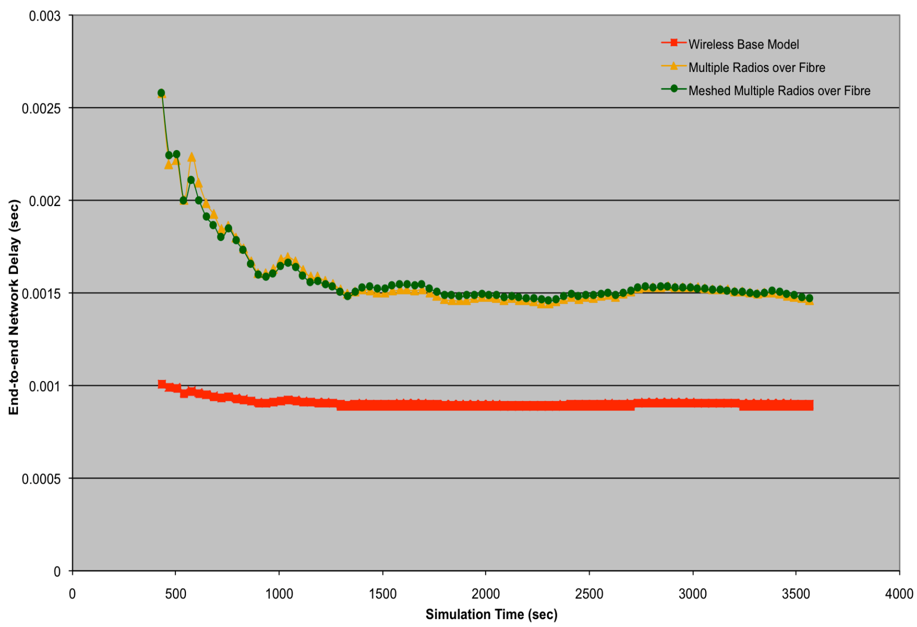

Figure 4.10: Network Average End-to-End Delay.

4.6.3. Network Multiple Media Access Delay

In previous results, it has been observed that wireless base model perform better in terms of end-to-end delay. The proposed architecture works on the transport, MAC and PHY layers. It reduces the medium access delay of the network because of availability of multiple air interfaces, whereas with base network it resulted in 0.8 seconds more delay as shown in Figure 4.11.

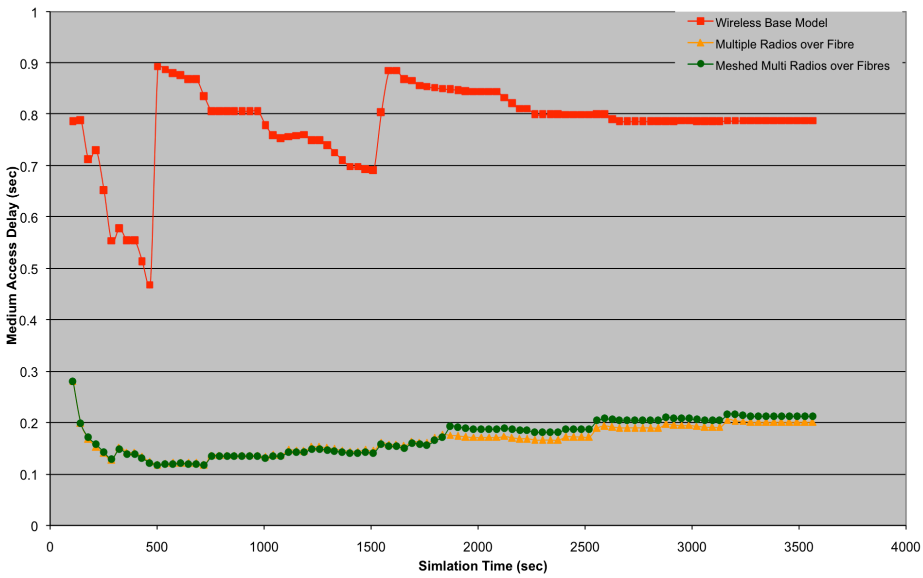

Figure 4.11: Network Average Medium Access Delay.

4.6.4. Packet Drop

Figure 4.12 shows the peak-to-peak network average packet drop comparison for the network scenarios. The base network shows very non- linear behaviour because of high variation in transmission. It has dropped up to 10 packets/second and gradually reduced to an average of 5 packets/second. On the other hand, meshed and multi RoF models behaved well by reducing the packet drop up to 53%.

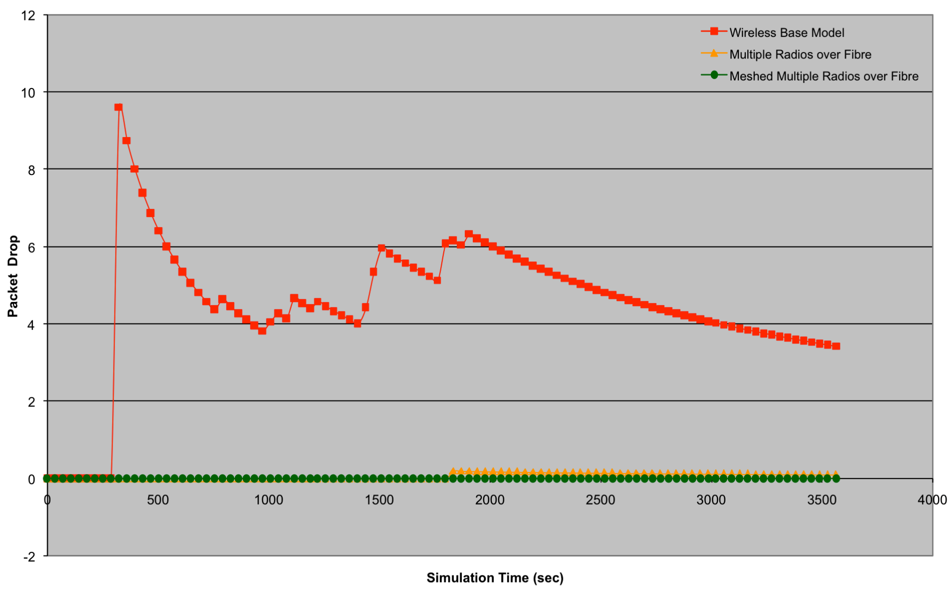

Figure 4.12: Network Average Packet Drop.

4.6.5. HTTP Response Time

There was great improvement in the HTTP response time when proposed architecture was applied as shown in Figure 4.13. The result shows that the meshed and multi RoF models can handle higher loads than the base model due to the higher bandwidth of fibre. It can be seen clearly from Figure 4.13 that both RoF network models performed well whereas, the response time reached 4.5 seconds for the base model.

The meshed and multi RoF performed excellently and reached an average response time of 0.4 to 1.3 seconds respectively.

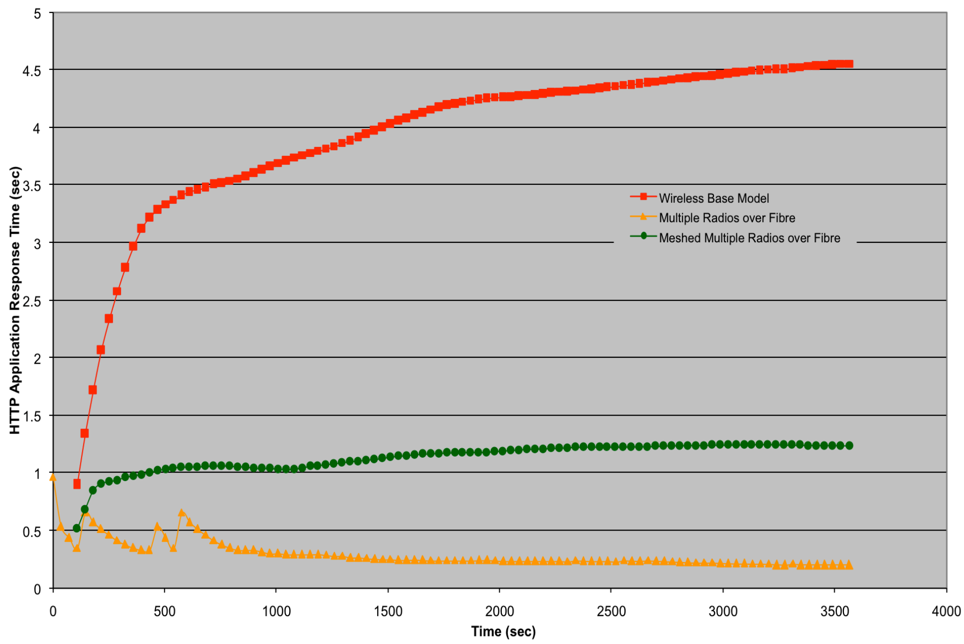

Figure 4.13: HTTP Average Response Time.

4.6.6. FTP Response Time

An improved performance is also seen in FTP during the simulation. A heavy FTP needs higher authentication and security information compared to a simple HTTP application. Therefore it enhanced the load on the network. The FTP response time reached upto 10 seconds for the base model as shown in Figure 4.14.

However, proposed RoF architecture reduced response time to an average of 0.2 and 0.3 seconds for multi RoF and meshed multi RoF respectively, which is 100% less then base model.

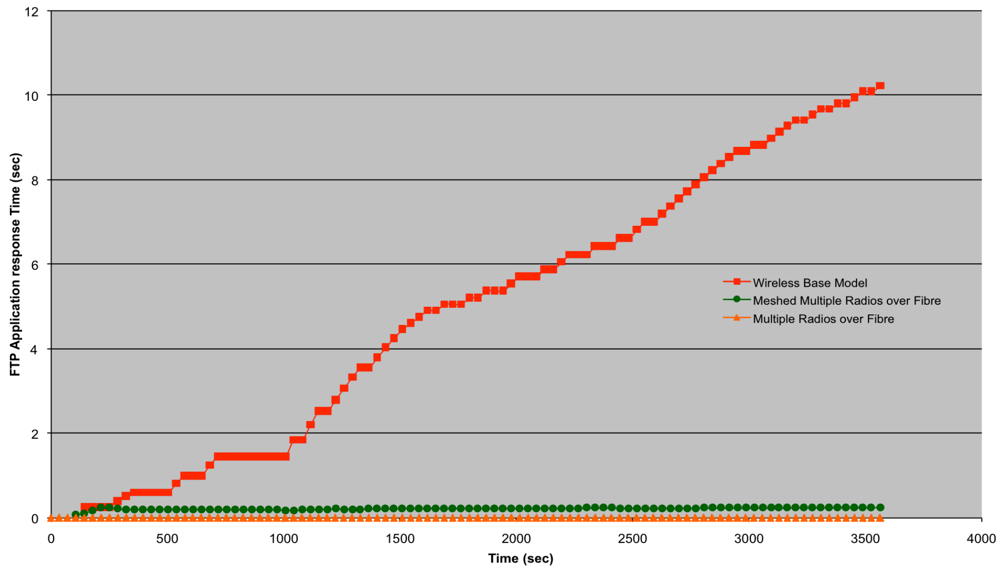

Figure 4.14: FTP Average Response Time.

4.6.7. Video Conferencing Response Time

The base model for real time video conferencing shows unacceptable response time of 27 seconds because heavy multimedia video transmission overloaded the radio link. The proposed RoF enhanced the response time from the video server. An average improvement of 23 packet/sec for video transmission has been seen in Figure 4.15, when proposed concept applied.

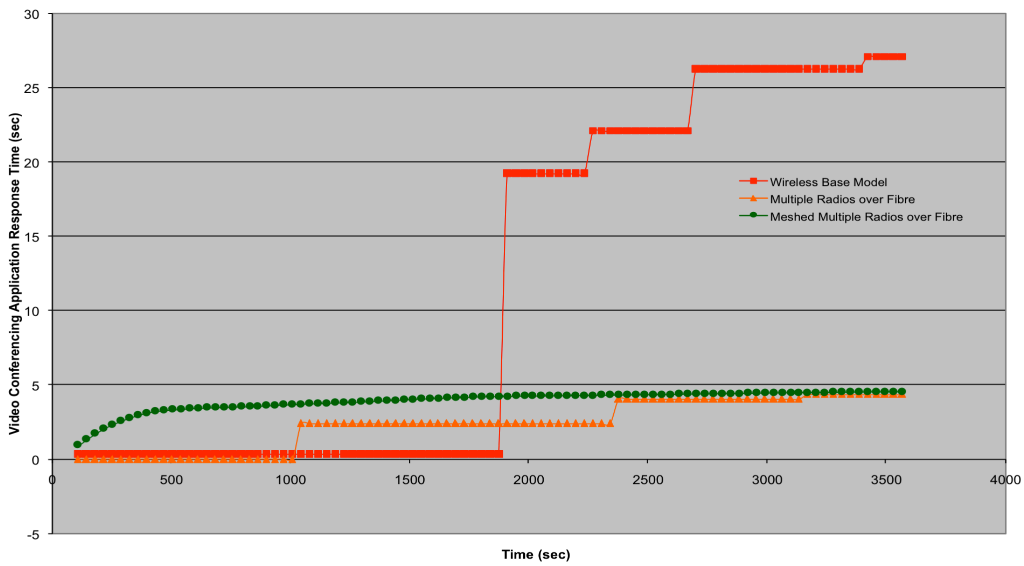

Figure 4.15: Video Conferencing Average Response Time.

4.6.8. End-to-End Power Consumption

The base network achieved higher power consumption. The glitches in the graphs are because of the variation in data traffic and the high bit rate on real time application demand. It can be seen that multi RoF has reduced the power consumption to 7% as shown in Figure 4.16. The proposed distance based power efficient mesh mode reduces the power consumption to 8% further as compared to multi RoF model. It has reduced an average of 10 mW power in comparison to the base model.

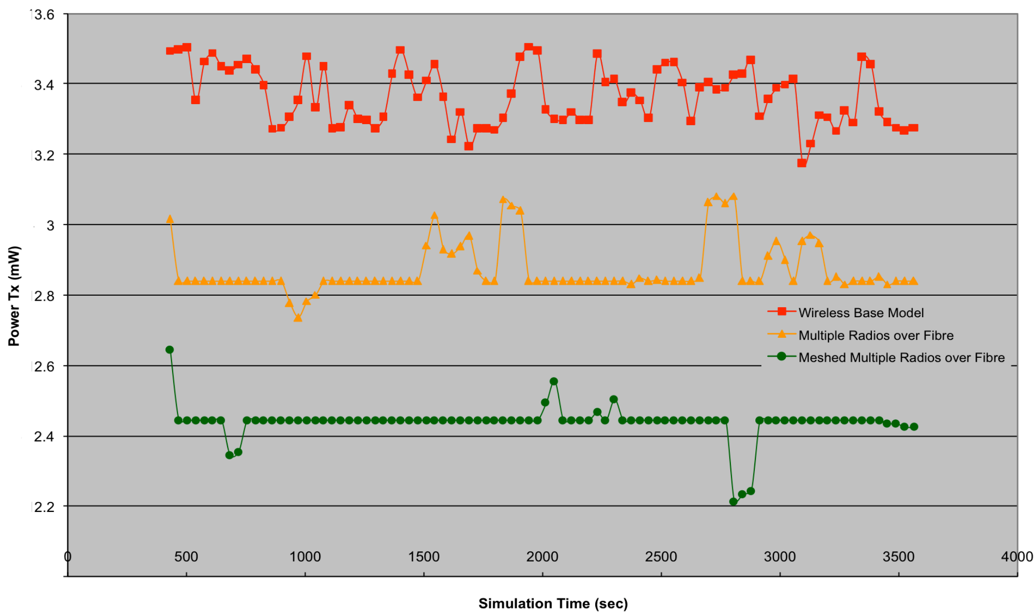

Figure 4.16: Network Average Power Consumption.

4.7 Conclusions

Power controlled meshed multi radio over fibre using ACH has been presented with a novel architecture for wired wireless synergy network. In this chapter, implementation of multiple radios with and without mesh mapping, has been successfully proposed, designed, implemented, discussed and simulated.

This chapter concludes that a meshed multi technique would act as a better convergence platform for future broadband network communication systems. In comparison to the traditional network base model, the proposed layout not only enhanced the network overall performance but also reduced packet drop upto 53%, application response time upto 100% and power consumption by 15%, which is very efficient for any wired wireless converged platform.

4.8 References

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Chapter 5

Intelligent Application Priority Assignment Mechanism for BWSN

Biomedical wireless sensor networks (BWSNs) need to guarantee reliable and timely transfer of data in emergency situations. This chapter presents a novel data transmission scheme based on Application Controlled Handover (ACH) mechanism, named as *Intelligent Application Priority Assignment Mechanism (IAPAM) for BWSNs. Current schemes use static/fixed priority assignment mechanism based on source of data and not on the criticality and importance of the data in different situations. IAPAM dynamically schedule different types of data flows based on their time critical nature. IAPAM smartly assigns priority to individual data packets rather to particular service or flow by continuously monitoring queuing delay providing end-to-end QoS without invoking any congestion control and avoidance mechanism. Experimental results show that IAPAM performs better than current standard of BWSN in terms of throughput and end-to-end delay for time crucial medical applications.

5.1 Introduction

During the last 5 years, various healthcare solutions have been proposed using information and communication technologies (ICT) [1]. Patient monitoring systems based on Biomedical Wireless Sensor Networks (BWSNs) and body area networks (BANs) has improved patients' health status during chronic care [2]-[4], thus enabling physicians to intervene more timely in emergency situations [5]. Patient monitoring in chronic cases demands pervasive healthcare for efficient response to treatment [6], [7].

*** Intelligent: The word "Intelligent" is used in the context of enhanced and smart proposed mechanism.**

A BWSN monitors important medical data such as body temperature (Temp), blood pressure (BP), electrocardiogram (ECG), electroencephalograph (EEG), electrooculography (EOG), electromyogram (EMG), heart rate, breathing rate and transmits it to a medical center, where this data is used for health status monitoring, medical analysis and emergency treatments [8]-[10]. A BWSN needs to guarantee that the packets having time critical data can be sensed and delivered to a medical center reliably and efficiently within the delay bounds. A routing protocol is an essential part of BWSN to route the time critical data with minimum end-to-end delays using congestion free intermediate nodes. BWSN requires further research on QoS issues realizing requirements of time critical data flows in medical scenarios.

Time critical data flows in medical scenarios handle data according to time constraints associated with the flow and the urgency of data. A BWSN requires an efficient data priority assignment and scheduling mechanism to accomplish this task. It also needs to continuously monitor network conditions to use an optimal path for data delivery.

In this chapter, an Intelligent Priority Assignment Mechanism (IAPAM) has been proposed by authors to increase throughput of time critical data packets. IAPAM decides at runtime which data flow is to be given high priority based on its urgency. The data generated by the source sensor nodes is compared with their respective threshold values. If the value of any type of sensed data is greater or close to its threshold value, priority is assigned to that data stream. At the intermediate sensor nodes a classifier is used. The task of the classifier is to classify different data flows and assign queues according to their priority and the source node identity. A scheduler adaptively schedule packets on the basis of the priority assigned by the IAPAM. At each intermediate node, an average queuing delay is calculated for both priority and non-priority queues. The calculated value is compared against threshold and appropriate action is taken in case the value is greater than the threshold. The proposed scheme is implemented and simulated in JSIM network simulator [11], [12].

Previous schemes [8]-[12] assign priority to the data flows on the basis of the source from which the data packet is generated. When there are different data flows and priority is to be assigned to the packets on the basis of their urgency, in that case a mechanism is needed which monitors QoS among different data flows and within those data flows. In IAPAM priorities are assigned to the packets on the basis of their data contents and not on the basis of source nodes as in other schemes.

The remainder of this chapter is organized as follows: Section 5.2 consists of contribution and related work from academia and industry. Section 5.3 presents the challenges, problem and methodology to develop the IAPAM. Section 5.4 provides related detailed description of IAPAM scenario in BWSN. Section 5.5 describes IAPAM functional components, enhancements in terms of intelligence and their working architecture. Section 5.6 presents performance analysis of IAPAM with brief discussion of all crucial parameters. The chapter is concluded in section 5.7.

5.2 Global Contribution and Related Work

Patel et al. present results evaluating possible use of wireless sensor networks for activity analysis of Parkinson's patients [13]. In this paper, motor fluctuations indicate the effectiveness and timing of medications for Parkinson's patients. In 14, authors use inertial sensors for monitoring of a distributed fall detection system.

Boyle et al. estimates the respirations rate using existing cardiac sensor reducing the number of sensors to enhance user's convenience [15]. This simplifies the cumbersome task of monitoring multiple physiological parameters in healthcare systems. Yoo et al. present a cardiac monitoring system with planner-fashionable circuit board shirt reducing number of sensor set [16].

I. Martı´nez et. al. presents an end-to-end based patient monitoring solution using ISO/IEEE 11073 (X73) in the bedside environment and EN13606. This plug-and-play sensor network communicates with a gateway that gathers medical information and sends the data to a monitoring server. The monitoring server transforms this information to an EN13606 extract to be stored on the electronic healthcare record (EHR) server. The system complies with the last X73 and EN13606 available versions providing end-to-end solution [17].

X. Liang and I. Balasingham [8] discussed cross layer QoS aware routing framework for biomedical sensor networks. Packets are classified as data packets and control packets having different priorities. When packets in a buffer reach a threshold, the proposed framework communicates with the user application to reduce the service rate. This scheme is not dynamically adaptive to the network changes, and it requires user intervention.

F. Xia and W. Zhao [18] presented a fuzzy logic based controller scheme to provide QoS management in wireless sensor networks. The idea is to regulate the flow of traffic by calculating the deadline miss ratio (DMR). DMR is the ratio of those packets that do not meet their deadline at the end of invocation interval. The operation is performed at the sink and at the end of every invocation interval the value of DMR is communicated to the source sensor node. At the source node, the sampling rate of packet for the next invocation interval is calculated on the basis of the previous DMR value. This scheme does not take into account intermediate sensor nodes. Decrease in sampling rate causes the decrease of overall throughput and thus results in low utilization of the network. There is no provision to handle flows with different priorities.

Different priority based scheduling schemes in [19] improve the packet delivery ratio of important data packets. This paper presents a scenario in which multiple sensor nodes send same type of data towards the sink. In the first scheme, the relative importance of the packet is determined on the basis of distance of the packet generating sensor node from the event. The nearer is the sensor node the higher the priority of the packet generated by that sensor node and vice versa. This scheme requires each node to determine its event distance in advance. In second scheme, the relative importance or priority of the packet is determined on the basis of signal strength of a sensor node to an event. The third scheme is based on timestamp and priority is assigned on the basis of how early an event is detected by the source node.

M.Younis et. al. [20] presented an analytical overview, which highlights important factors for extending the lifetime of WSN architecture. Many operational challenges to handle the QoS traffic in sensor networks are also discussed. This paper has reviewed many routing and MAC layer protocols that deal with the issues raised by the constrained and unattended sensor nodes. The paper presents an energy efficient protocol assuming data traffic with unconstrained delivery.

The mathematical expressions of queuing delay for real time and non real time flows have been derived in [21]. The queuing delays are calculated and the results are compared with the simulated results. The authors have implemented priority queuing (PQ) in a sensor node. The queuing delay for two different types of traffic is calculated by exploiting the M/G/1 queuing model. The purpose of using priority queuing is to avoid the drawbacks associated with FIFO queuing. In this scheme a priority queue is implemented which not only decreases the queuing delay but can also provides preferential treatment to time sensitive applications. The authors have not considered other QoS parameters such as packet loss, throughput, and end-to-end delay in their work.

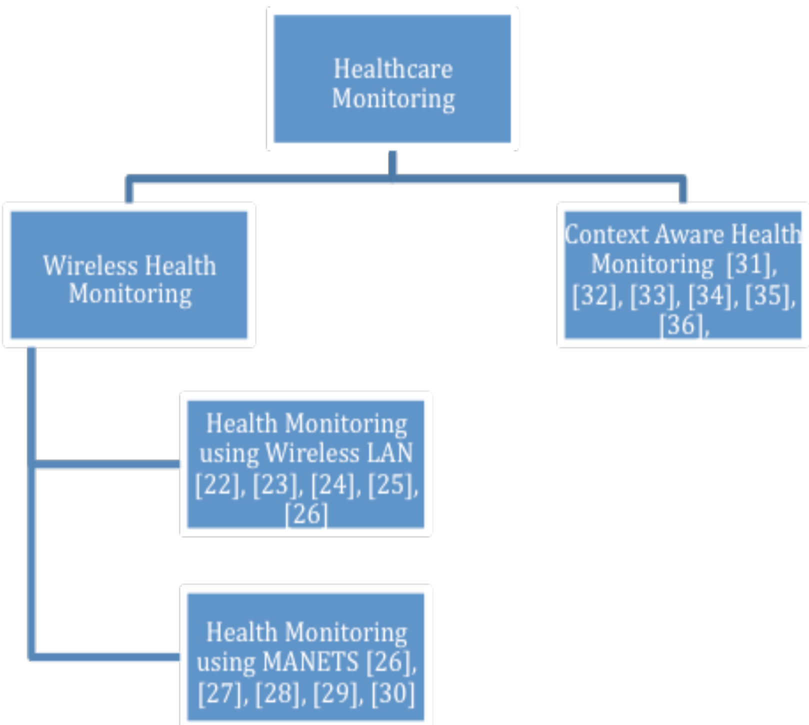

Figure 5.1: Classification of Health Monitoring Applications.

Figure 5.1 classifies health monitoring into wireless health monitoring and context aware health monitoring applications.

5.3 Challenges and Problem Statement

Following are the main challenges while providing quality of service in wireless sensor networks:

1. Wireless Sensor networks are normally resource constrained. Sensors are small devices and are usually low-cost, low-power and are equipped with limited data processing capability, transmission rate, energy, and memory. Because of the limitations in the available bandwidth, processing power, transmission power and the radio range of wireless channel are also limited.

2. WSNs are highly dynamic in nature. Most of the WSNs support mobility as most of the applications in the domain of the WSNs, requires sensor nodes to be mobile. The network topology can be changed over time due to exhausted battery energy, node failure, node addition, node mobility, and node failure. The capacity of channel may also change because of the dynamic adjustment of transmission powers of the sensor/sink nodes.

3. Heterogeneity is another important challenge of WSNs. In WSNs there could be a situation, which have different sensors node based on difference in functionality. Because of different functionality, sensors cannot share the same level of resource constraints. This coexistence of sensors and sinks makes WSNs fundamentally distinct.

4. WSNs are typically operated in unpredictable environments. As it is required to use wireless radio as the medium for data transmission when dealing with WSNs, due to this most WSNs suffer from diverse radio interferences. Also, query-driven and eventdriven applications can also cause the traffic load on the network to vary unpredictably.

5.3.1. Problem Statement

The introduction of real time data flows and time critical data flows specifically related to applications in medical scenarios, are required to handle data according to time constraints associated with the flow. In the past, we have seen many schemes in this domain which assigns priority to the data flows on the basis of the source from which the data is coming but when we have different data flows and we want to give priority to the packets on the basis of their criticality, then in that case we need a mechanism which handle QoS among data flows as well as within a data flow.

In this thesis an Intelligent Application Priority Assignment Mechanism is developed (IAPAM) which fulfils the mentioned requirements and thus helps to avoid congestion. The mechanism increases the throughput of data critical packets as compared to the normal packets. In order to prove its correctness and efficiency the system is implemented and simulated using the JSIM [12] network simulator.

5.3.2. The Methodology

In the proposed scheme, an intelligent system, which decides at runtime which data flow is to be given high priority based on its criticality, is developed. The data generated by the source sensor nodes is compared with their respective threshold values. If the value of any type of sensed data is greater or close to its threshold then priority is assigned to that data stream. Different priorities can be assigned which is based on data urgency.

At the intermediate sensor nodes a classifier is used. The task of the classifier is to classify different data flows and assign queues according to their priority and the source node identifier. A scheduler adaptively schedule packets on the basis of the priority assigned by the IAPAM. Also at each intermediate node, an average queuing delay is calculated for both priority and non-priority queues at the end of every specific interval.

The interval is selected at which the best throughput is obtained by maintain a threshold range TR for average queuing delay. The calculated value is compared against the TR and an appropriate action will be taken in case the average queuing delay is greater than the threshold.

5.3.3. Cross Layer Design for IAPAM

The Figure 5.2 demonstrates a cross-layer framework for wireless sensor networks to handle real time traffic. It demonstrates a typical communication stack and the parameters that could be shared among the layers. The design enables a higher layer to coordinate the behaviour of lower layers. The application layer could have parameters such as end-to-end delay and service differentiation priorities, which can be used at routing layer and the MAC layer to provide guaranteed QoS to a specific flow or time critical data packets.

Link Quality information that is generated at the link layer can be shared and communicated to the MAC and the application layer. The active/idle/sleep action at the MAC layer also helps in optimizing the performance of layers. So, it can be infer the cross layer designs though controversial because they do not follow the classic isolation model of layer which states that the different layers of the protocol stack cannot share information, but still are useful to provide quality of service to hard real-time data flows.

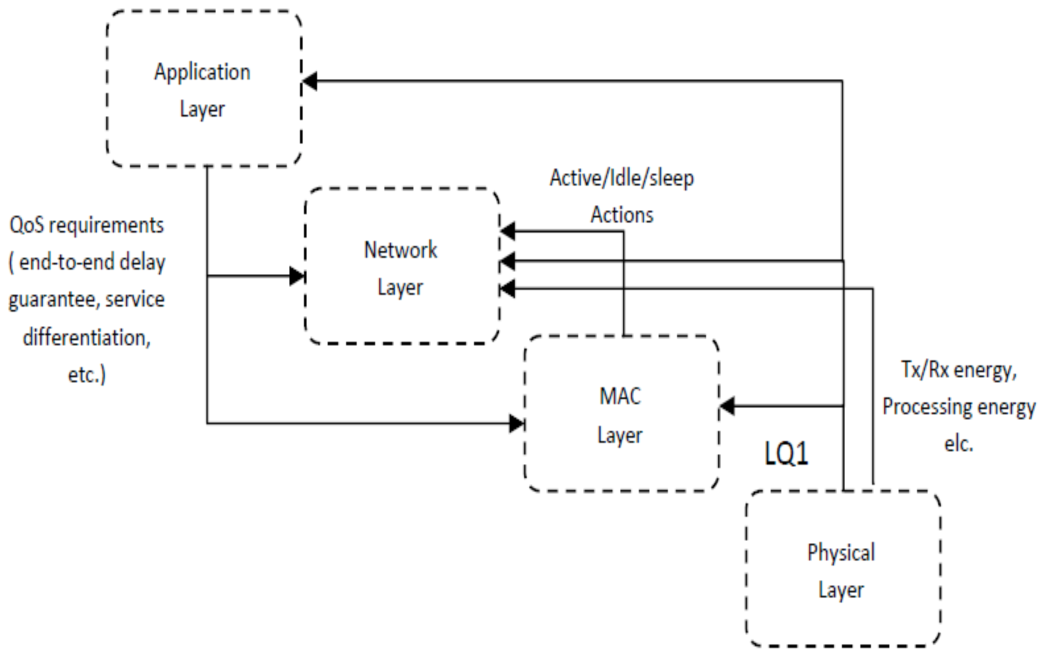

Figure 5.2: Cross Layer Design for IAPAM.

5.4 Intelligent Application Priority Assignment Mechanism

IAPAM provides prioritized scheduling to packets. In this mechanism priority is assigned to packets of different data flows on the basis of their importance and urgency. Scheduling is performed at the intermediate nodes on the basis of the priority assigned to the packets and source identity. Figure 5.3 shows a sample IAPAM scenario that contains target, sensor and sink nodes.

The target node is used to sense the data. The target nodes are moveable. These nodes send the sensed data in the form of target packet to the sensor nodes.

TargetAgent implements the target node. This involves generating signals (stimuli) and passing them to the lowers for transmission over the sensor channel.

TargetPacket implements the packet that represents the signal generated by a target node.

SensorPhy receives a signal generated by the TargetAgent to get up-to-date location of the target node and forward the generated stimulus to the sensor channel.

Sensor nodes consist of two protocol stacks. One is sensor protocol stack and the other is wireless protocol stack. The sensor node to communicate with the target node or to receive stimuli from the target node uses sensor protocol stack.

The sensor nodes to communicate with other intermediate sensor nodes and sink node use the wireless protocol. There exist a middleware, which is used to convert sensor packets into packets that are compatible with the wireless protocol stack and can be send on the wireless channel.

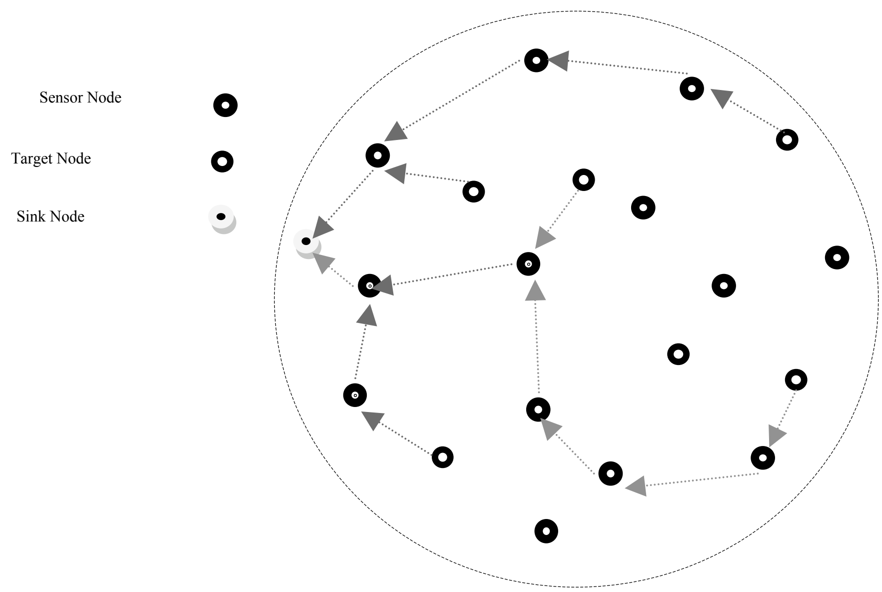

Figure 5.3: IAPAM Network Scenario.

A sink node is developed in a plug-and-play fashion using a sensor application layer (SensorApp), an interface layer (WirelessAgent) with the wireless protocol stack consisting of network layer (AODV), MAC layer (MAC 802.11), and physical layer. Some of the intermediate sensor nodes are congested because these nodes are common to multiple target nodes. The target nodes are sending different types of data with different priorities.

5.5 Functional Components of Application Priority Assignment

IAPAM priority assignment algorithm maintains minimum and maximum threshold values for each type of data stream. The thresholds are predefined which are in accordance with the values in real medical scenarios. If the data in the packet is greater or closer to the minimum and maximum threshold limits then the packet is considered a priority packet.

5.5.1. Packet Header Extension

The priorities are assigned at the initial level, the scheme requires a field in the target packet so that IAPAM assign the priority to that field and this field is further used to classify the packets. The second thing as mentioned above is that the proposed scheme is providing priorities on the basis of data urgency and the target node from which the data is coming (e.g. in real medical scenarios ECG data is considered more important than temperature data). So there is need of another field in the target packet header, which can identify the node from the data is coming. In order to fulfill the above requirements two fields, priority and target node id, are added in the header of target packet. The structure of the target packet used in IAPAM shown in Figure 5.4.

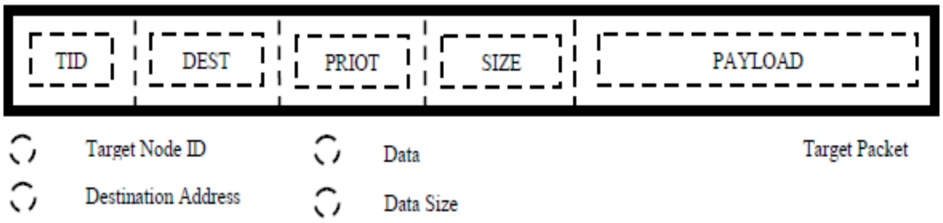

Figure 5.4: Structure of Target Packet.

In Figure 5.3, the target node communicates with the sensor nodes through sensor protocol stack. Sensor nodes only accept sensor packets. At the sensor node the target packet is encapsulated and tagged with the sensor packet header. So in order to communicate these two fields to the sensor packet, the sensor packet header is extended as well. In the sensor packet header the target node id field and the priority fields are added in order to identify the source target node and the priority of the sensor packet respectively. The structure of the sensor packet used in the proposed scheme is presented in the Figure 5.5.

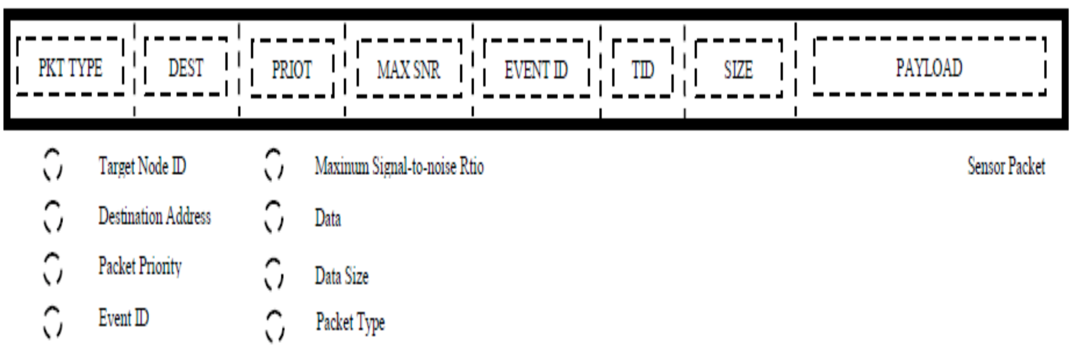

Figure 5.5: Structure of Sensor Packet.

Figure 5.6 shows that every packet is checked for three conditions. Firstly, the packet is checked for ECG, BP or Temperature target node. Second condition checks, whether the data the packet contains is greater than the minimum threshold and thirdly, whether it is less and equal to maximum threshold of the respective flow. If the packet fulfils all these conditions it is treated as a critical data packet otherwise as a normal packet.

In IAPAM, 2-bit prediction scheme has been used as an intelligent mechanism [37]. The 2-bit scheme is used to avoid branch hazards in pipelining. By using this approach, we store the result of the last two priorities of associated packets.

The prediction must be wrong twice before it is changed i.e. if the prediction is that the next packet will be a priority packet then the prediction is changed when two non-priority packets arrive consecutively.

There are two thresholds for each type of data stream considered, one is minimum threshold and the other is maximum threshold. The thresholds are predefined which are in accordance with the values in real medical scenarios. If the data in the packet lies between the minimum and maximum thresholds then the packet is considered as the priority packet.

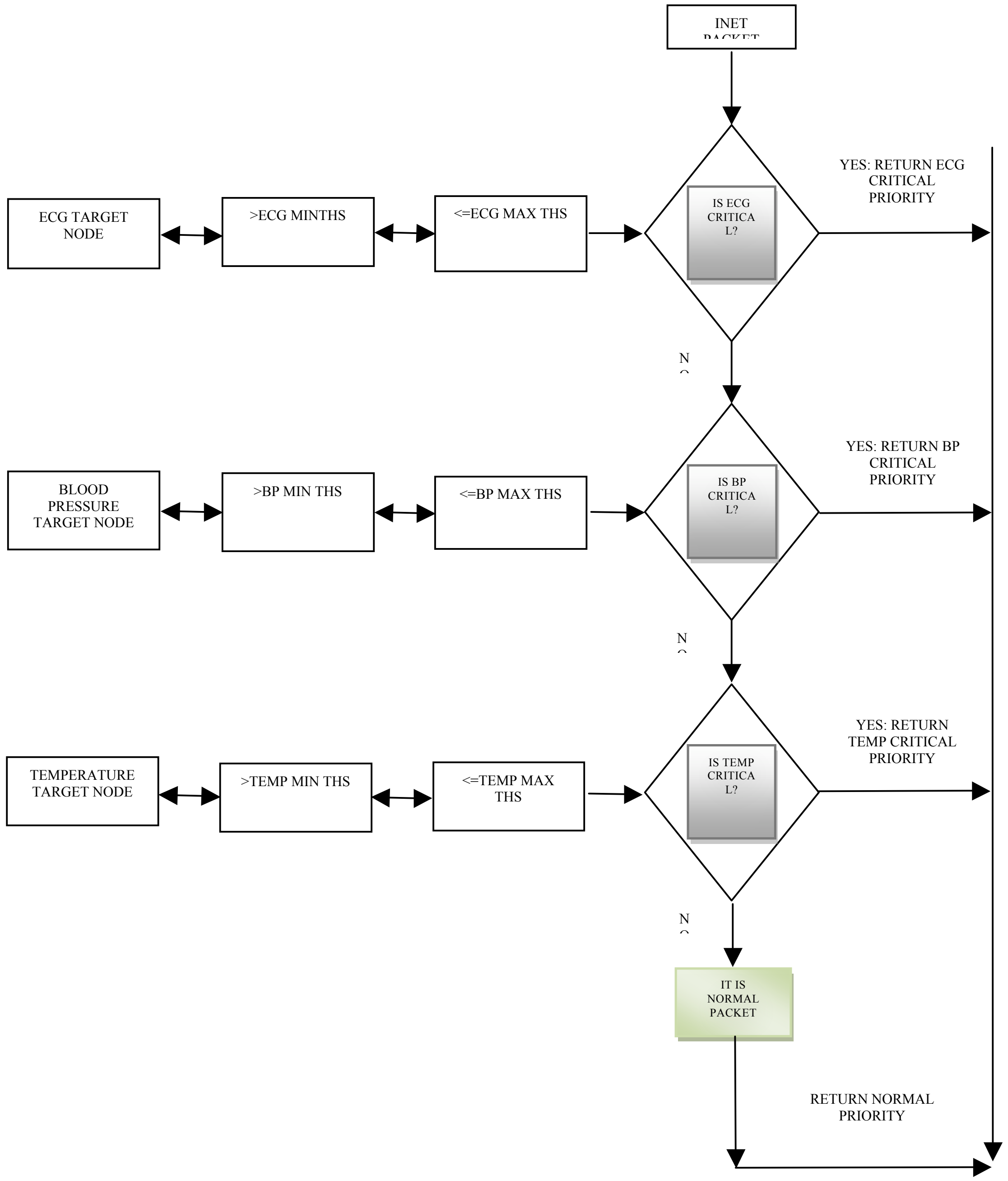

Figure 5.6: Priority Assignment Flowchart.

Let the minimum and maximum thresholds for the ECG, BP and Temp data are $(TH^{ECG})_{MIN}$ and $(TH^{ECG})_{MAX}$, $(TH^{BP})_{MIN}$ and $(TH^{BP})_{MAX}$, $(TH^{TEMP})_{MIN}$ and $(TH^{TEMP})_{MAX}$ respectively and the target node ids for these data flows are T_{ECG}, T_{BP} and T_{TEMP} .

The critical priority and normal priority are represented as C_p and N_p respectively and the upcoming packet is represented as IP where $(IP.\,C_p)_{ECG}$, $(IP.\,C_p)_{BP}$, $(IP.\,C_p)_{TEMP}$ and $(IP.\,N_p)_{NRM}$ are are representing prioritized packets of ECG, BP, Temp and normal packet from any of these nodes respectively. The equations below represent the prioritized packets from ECG, BP, Temp and normal packet from any of these nodes.

$$(IP.\,C_p)_{ECG} = (IP \in T_{ECG})\,\&\,(TH^{ECG})_{MIN} \geq IP < (TH^{ECG})_{MAX} \tag{5.1}$$

$$(IP.\,C_p)_{BP} = (IP \in T_{ECG})\,\&\,(TH^{BP})_{MIN} \geq IP < (TH^{BP})_{MAX} \tag{5.2}$$

$$(IP.\,C_p)_{TEMP} = (IP \in T_{ECG})\,\&\,(TH^{TEMP})_{MIN} \geq IP < (TH^{TEMP})_{MAX} \tag{5.3}$$

$$(IP.\,N_p)_{Nrm} = IP \in (T_{ECG}, T_{BP}, T_{TEMP})\,\&\,(TH^{ECG})_{MIN} > IP < (TH^{ECG})_{MAX} \tag{5.4}$$

The flowchart diagram for the priority assignment algorithm in IAPAM is shown in Figure 5.6.

The algorithm assigns the priority to the upcoming data packet by comparing the data with respective thresholds. If the data falls between the threshold than critical priority is assigned to the data packet.

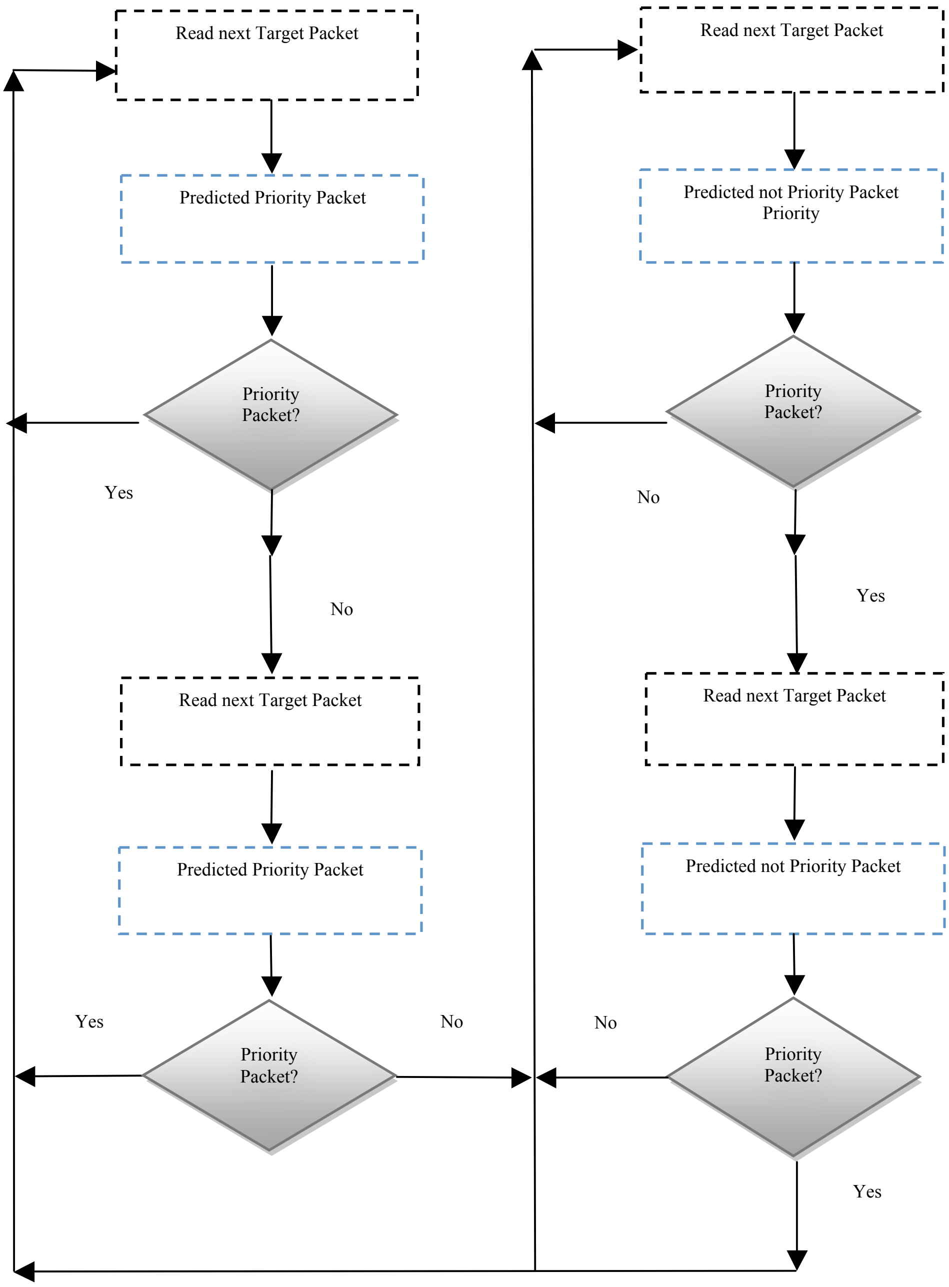

Figure 5.7: Application Priority Assignment Functional Block.

Figure 5.7 shows flow chart of the intelligence applied in the priority assignment mechanism. Each incoming target packet is first predicted as the priority packet. The packet is then checked whether it falls between minimum and maximum thresholds. In case, the packet is critical then the prediction is true. The process continues and the predicted value remains the same. But if the prediction for the two consecutive packets is not true then both packets are normal but the algorithm predicted these packets as critical. The value of the prediction bit is changed from priority to non-priority.

5.5.2. Modification to Classifier

The classification of data packets is based on two fields. First is the priority of the packet and the second is the target node id (source node of the data packet is ECG, Blood Pressure (BP) and Temperature. The flowchart diagram of the classifier algorithm is given in Figure 5.8.

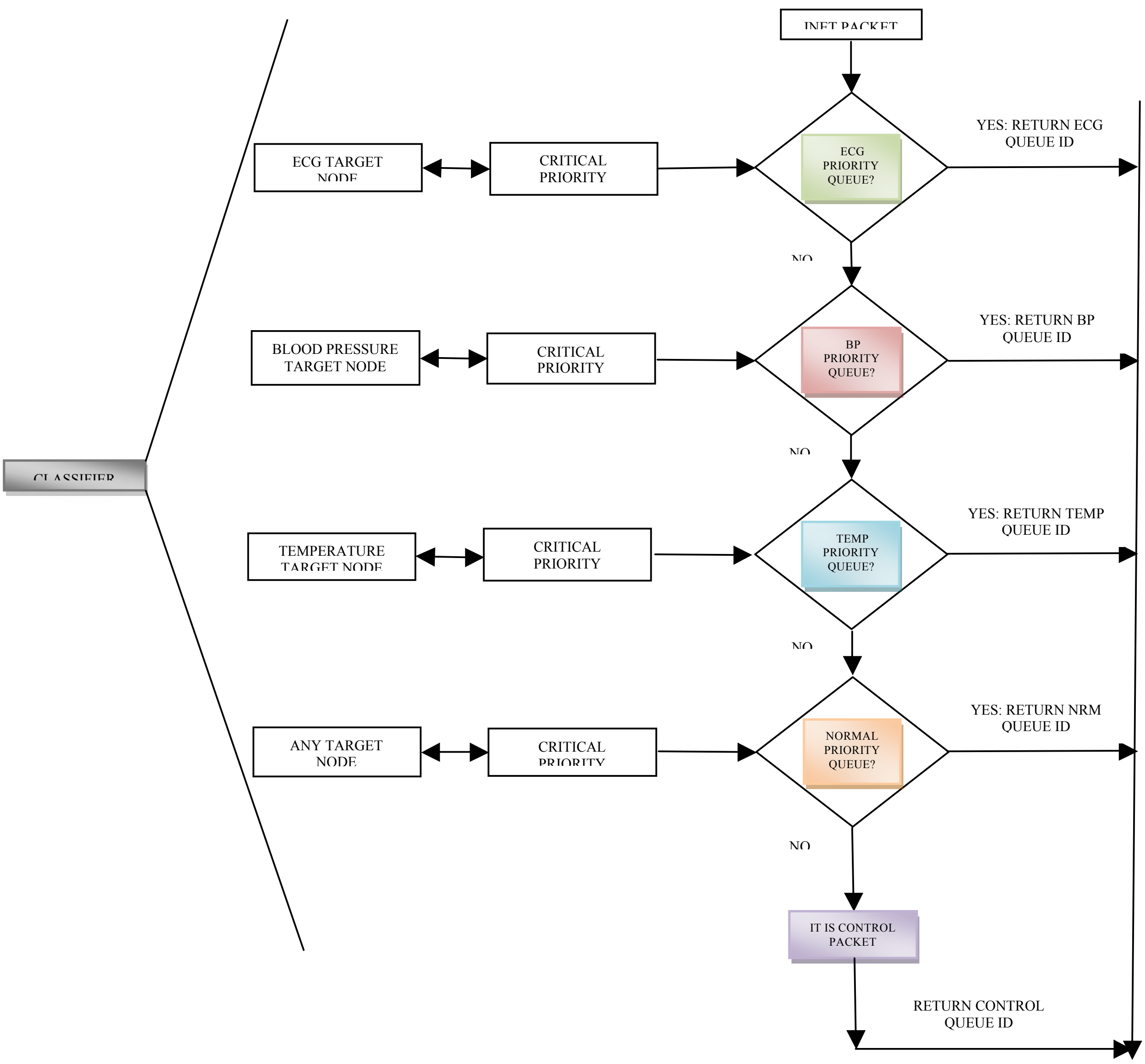

Figure 5.8: Classifier Algorithm Design.

Each packet is first checked for the ECG target node and for its priority, if both the conditions are satisfied then it is assigned to the highest priority queue next to the control queue else the packet is checked for the next data flow BP and its critical priority. The process continues and if the packet does not belong to any data flow and is not critical, it is treated as a control packet. The flowchart describes how the classifier selects the queue for the packets belonging to different data flows with different priorities.

5.5.3. Interface Queue Structure

In IAPAM, after assigning priorities to packets at the node level where the sensed data is generated, the packets are classified at each sensor node. Furthermore, the scheme maintains different priority interface queue for each data flow as shown in the Figure 5.9.

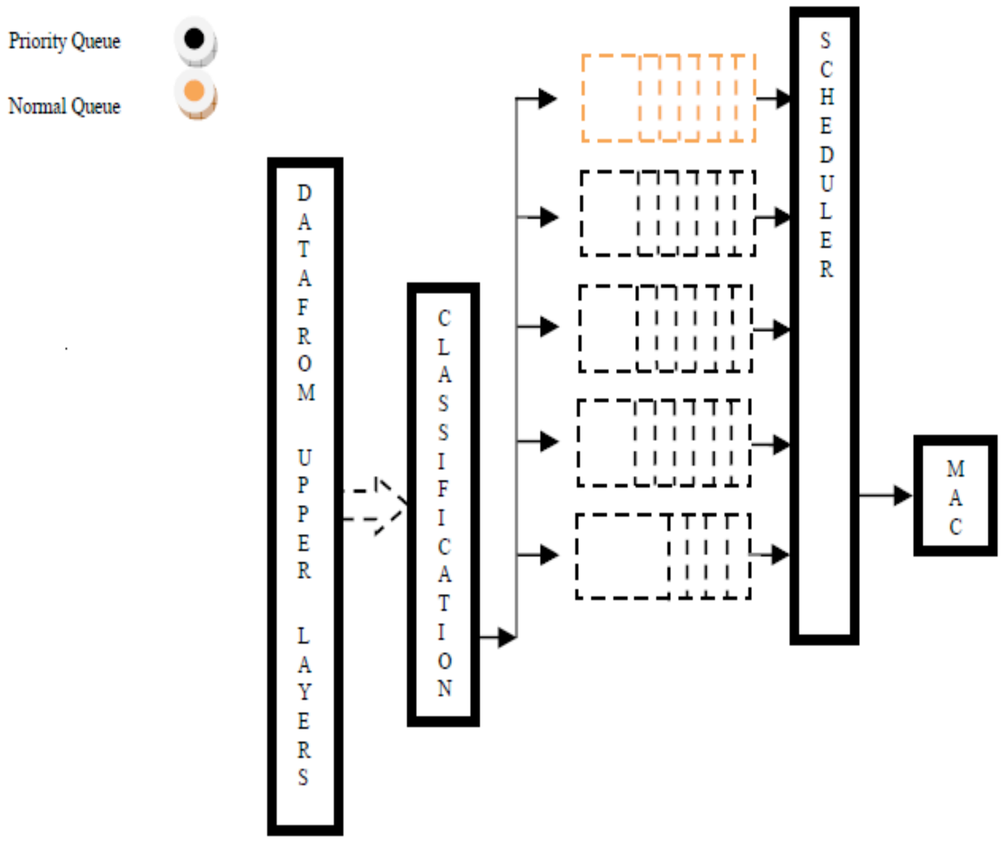

Figure 5.9: Virtual Queue Interface for IAPAM.

For example, if there are three data flows such as ECG, BP and Temperature of patients then five interface queues are maintained. Three priority queues for the priority packets of each data flow, one for control packets and the one for the normal packets of every data flow. ECG data is assigned highest priority queue among the data flows [38]. Control packets are given the highest priority among all packets of any type. Lowest priority queue is assigned to the non-priority data. The queue assignment to data flows is dynamic, if high priority data queue is empty then the low priority data flows are assigned to that empty queue in order to minimize the average queuing delay of the other data flows.

5.5.4. Queuing Delay

IAPAM calculates average queuing delay for a specific flow in a time interval T. The total queuing delay for that specific flow is calculated by adding the average queuing delays for all time intervals. The aim is to restrict the value of average queuing delay of N number of packets below a predefined threshold value in the time interval T for each specific flow. At the end of every interval the new calculated value of average queuing delay is compared with the threshold value. The value of time interval is chosen on the basis of the results obtained by taking different time intervals.

If the calculated average queuing delay of an interval is greater than the threshold then that specific flow is assigned to higher priority queue for the next interval so that the average queuing delay for that flow can be reduced. At the end of this interval the average queuing delay is calculated again and is compared with the threshold. In IAPAM, if there is an increase in the average queuing delay of ECG data flow then the ECG data is assigned to the control queue, which has the highest priority and the control data is assigned to the ECG queue. In the same way other data flows can be assigned higher priority queues if their average queuing delay is higher than the threshold.

IAPAM is using five interface queues, which can be assigned dynamically to any data flow on the basis of the average queuing delay of each flow. The scheduler first de-queue packets from the highest priority queue and if highest priority queue is empty then the scheduler goes to the second highest priority queue and de-queue packets. This dynamic assignment of queues among different data flows not only reduces the average queuing delay for each specific flow but also increases overall throughput of the network.

There are N number of packets are currently present in the queue, which has the total size S. The T_{Diff} is the time spent by each packet in the queue which is the difference of the T_{OUT} and T_{IN}, where T_{IN} is the time when the packet enters the queue and T_{OUT} is the time when it leaves it. The difference of these will give the queuing delay for that particular packet.

$$T_{Diff} = T_{OUT} - T_{IN} \tag{5.5}$$

The total queuing delay of the N number of packets left the queue in a specific time interval T is given as:

$$T_{QD} = (T_{OUT} - T_{IN})_1 + (T_{OUT} - T_{IN})_2 + (T_{OUT} - T_{IN})_3 ....(T_{OUT} - T_{IN})_N \tag{5.6}$$

Equation (5.6) can be written as:

$$T_{QD} = \sum_{i=1}^{N} (T_{OUT} - T_{IN})_i \tag{5.7}$$

The total queuing delay incurred by N packets in an interval T. By using Equation (5.7) the average queuing delay can be computed which is given as:

$$A_{QD} \text{ at time interval } T = \frac{1}{N} \sum_{i=1}^{N} (T_{OUT} - T_{IN})_i \tag{5.8}$$

Where A_{QD} gives the average queuing delay for a specific flow in a time interval T. The total queuing delay for that specific flow at a node can be calculated by adding the average queuing delays of all the time intervals. Suppose, have m time intervals then the total queuing delay for a specific flow during m time intervals is given as:

$$TA_{QD} = A_{QD_{at\ T1}} + A_{QD_{at\ T2}} + A_{QD_{at\ T3}} + A_{QD_{at\ T4}} \ldots\ldots A_{QD_{at\ Tm}} \tag{5.9}$$

The Equation (5.9) can be written as:

$$TA_{QD} = \sum_{m=i}^{N} A_{QD \to atT_m} \tag{5.10}$$

The aim is to restrict the value of average queuing delay of N packets below some predefined threshold value in the time interval T for each specific flow. At the end of every interval the new calculated value of average queuing delay is compared with the threshold value.

The value of time interval is chosen on the basis of the results obtained by taking different time intervals. The scheme is taking 0.2 sec as the value of the time interval because at this value the scheme is getting the best results in terms of throughput and delays. If the calculated average queuing delay of an interval is greater than the threshold then the queue for that specific flow is changed to higher priority queue for the next interval so that the average queuing delay for that flow can be reduced. Again at the end of this interval the average queuing delay is calculated and compared with the threshold. In IAPAM, if there is increase in the average queuing delay of ECG data flow then the ECG data is assigned to the control queue, which has the highest priority and the control data is assigned to the ECG queue. In the same way the BP queue is interchanged with ECG queue, the Temp queue is interchanged with BP queue and the queue for the normal flow is interchanged with the Temp queue.

IAPAM is using five interface virtual queues, which can be assigned dynamically to any data flow on the basis of the average queuing delay of each flow. Among the five queues the queue zero is considered as the high priority queue because the scheduler first de-queue packets from that queue and will face the minimum queuing delay. If the first queue is empty then the scheduler move to the second queue and de-queue packets. This dynamic assignment of queues among different data flows not only reduces the average queuing delay for each specific flow but also puts an healthy effect on the overall throughput of the network.

5.6 Performance Evaluation and Discussions

In this section, the performance of IAPAM has been evaluated. A typical patient monitoring sensor network is simulated in JSIM [6], [12] as shown in the Figure 5.10. Twenty sensor nodes and one sink node are distributed uniformly in a 500 × 600 square meters terrain. Six of the nodes are moving with walking speed in random directions, while other nodes are stationary. The network consists of three different kinds of data flows of ECG, BP and temperature generated by the sensors. Out of twenty, six nodes are target nodes, which are generating signals or sensed data related to the mentioned type of traffic. There are thirteen sensor nodes, which are used to collect data from the target nodes and send it to the sink. The simulation time is 500 sec.

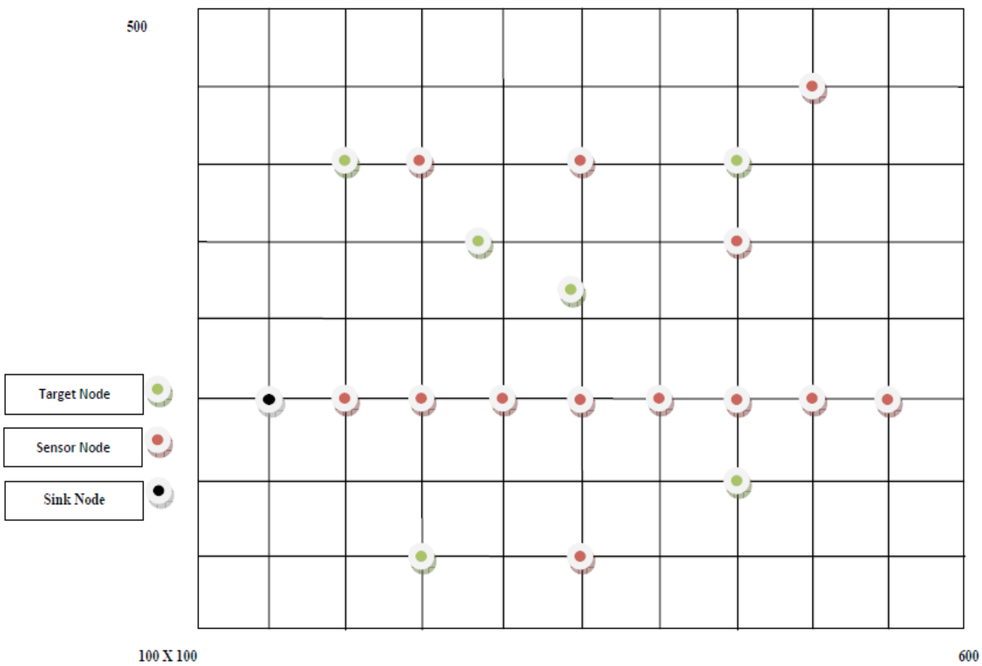

Figure 5.10: Network Simulation Scenario.

5.6.1. Network Throughput

Figure 5.11 shows a comparison of the BWSN throughput with and without IAPAM. The throughput of IAPAM enabled BWSN is stable and greater than the throughput obtained in the simple scenario without IAPAM. The variance of IAPAM enabled BWSN is 954270.1 and variance of BWSN without IAPAM is 1008683. The mean of IAPAM enabled BWSN is 8744.5 and mean of BWSN without IAPAM is 4740.5. The small variance and mean in IAPAM enabled BWSN is because of packets prioritization based on the urgency of the data ensuring minimal required throughput.

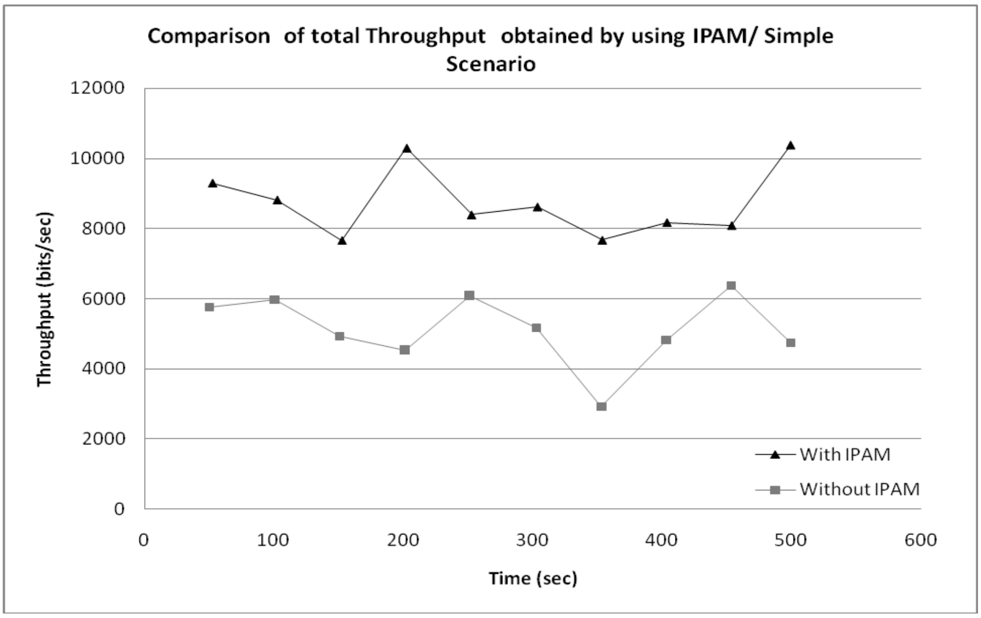

Figure 5.11: Network Average Throughput Comparison.

5.6.2. Network Queuing Delay

Figure 5.12 shows average queuing delay at intermediate node near the sink. The average queuing delay of IAPAM is varying less as compared to the simple scenario without IAPAM. The threshold value of the average queuing delay is taken as 0.015sec. It can be observed from simulation results that the average queuing delay in IAPAM is below 0.015sec. So, it can be inferred that the system is performing well in terms of queuing delay. The mean of IAPAM enabled BWSN is 0.014616 and the mean of BWSN without IAPAM is 0.01593.

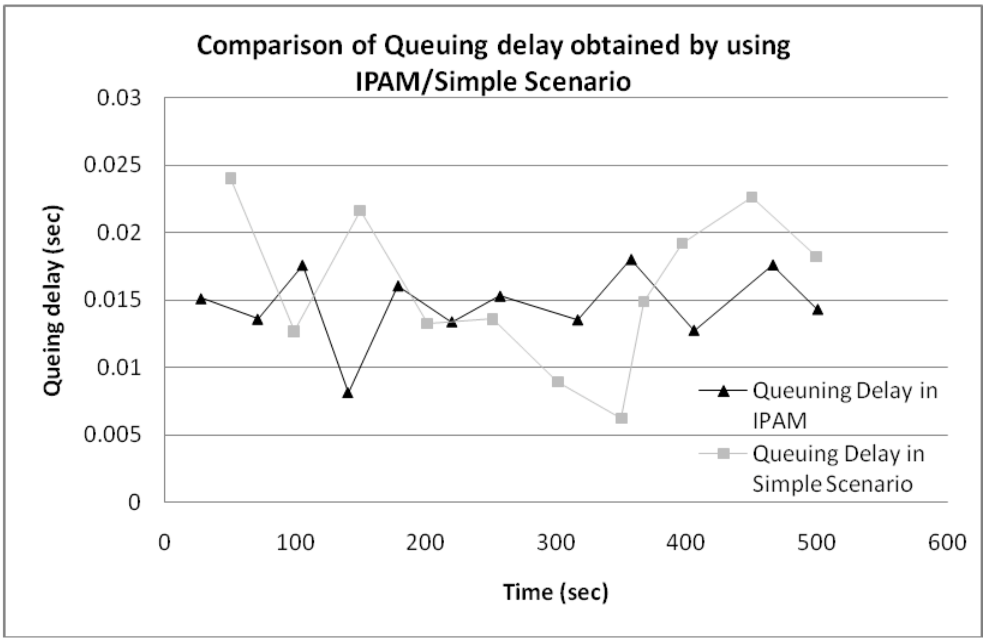

Figure 5.12: Network Average Queuing Delay.

The variance of BWSN without IAPAM is 3.26302E-5 and the variance of IAPAM enabled BWSN is 7.48342E-06. The small variance and mean in IAPAM enabled BWSN is because of priority and scheduling mechanisms of urgent data packets.

5.6.3. Network Queuing Delay for Multiple Applications

Figure 5.13 shows the queuing delay of different types of data flows of ECG, Blood Pressure and Temperature. The packets from the ECG nodes are incurring the lowest average queuing delay than blood pressure and the temperature because in hospitals ECG data is given the highest priority.

The Figure 5.14, Figure 5.15 and Figure 5.16 compare average queuing delay for ECG, BP and Temperature respectively in BWSN with and without IAPAM. The results clearly show that queuing delays obtained for ECG and BP are much lower than simple scenario because ECG and BP data has higher priority as compared to other data. Queuing Delay obtained for temperature is higher in IAPAM as compared to simple scenario because the priority of temperature flow is low in IAPAM.

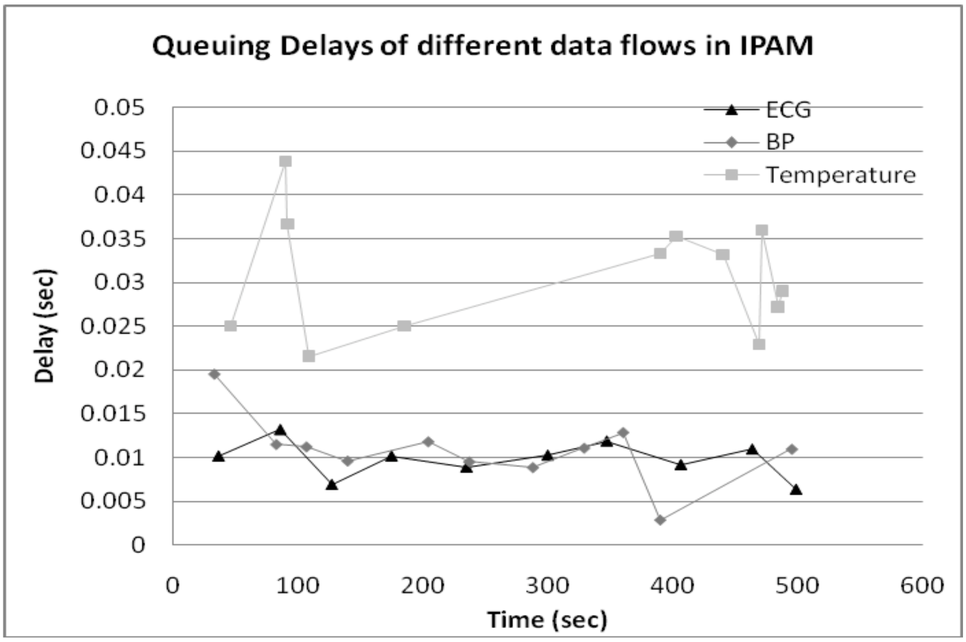

Figure 5.13: Comparison of Queuing Delay of Multiple Applications.

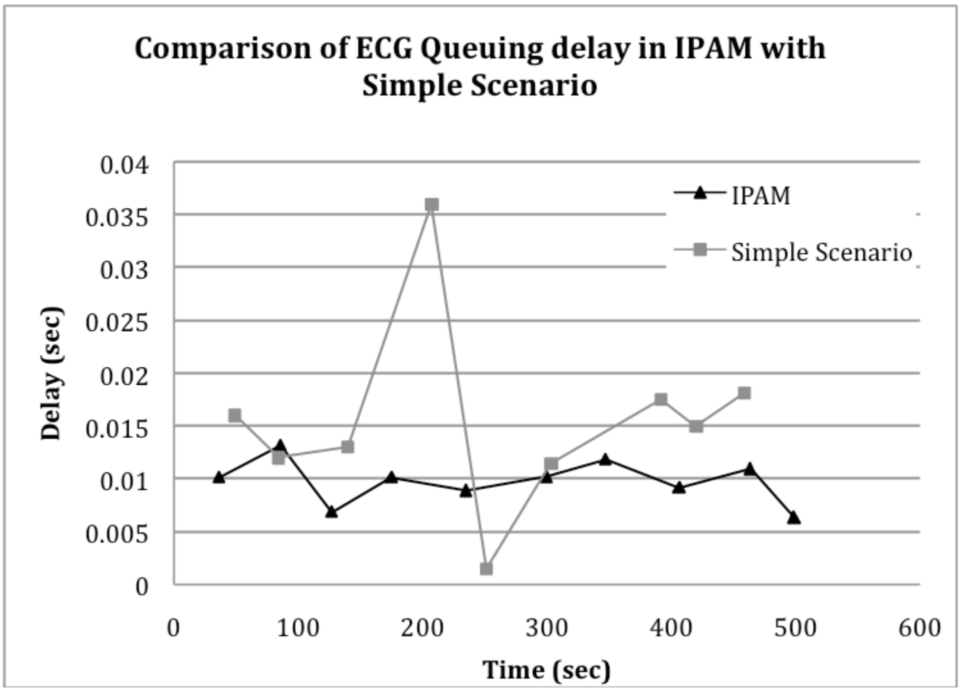

Figure 5.14: Comparison of ECG Queuing Delay.

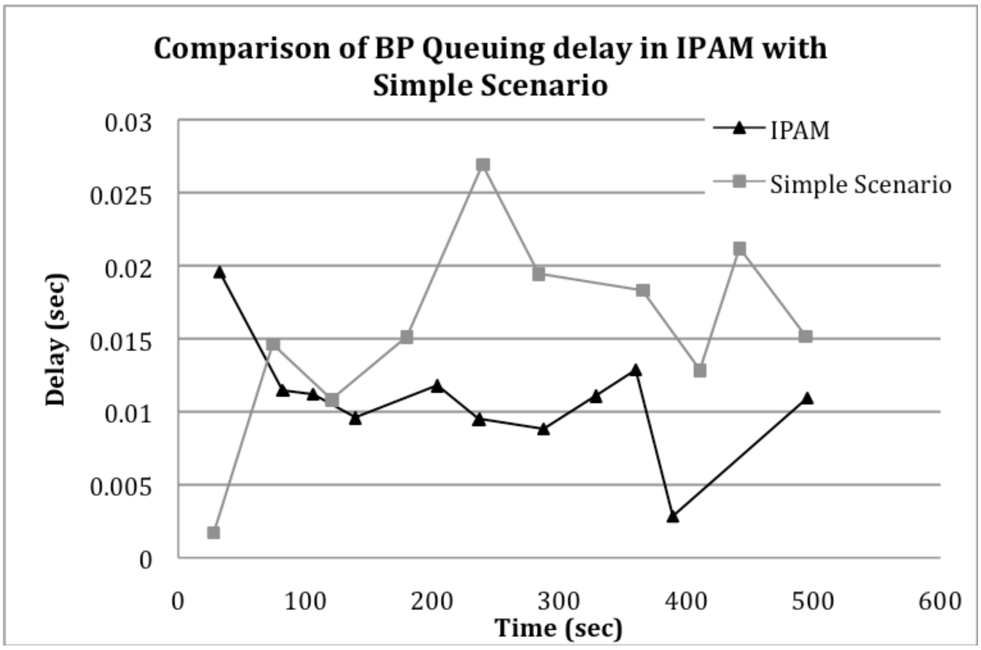

Figure 5.15: Comparison of BP Queuing Delay.

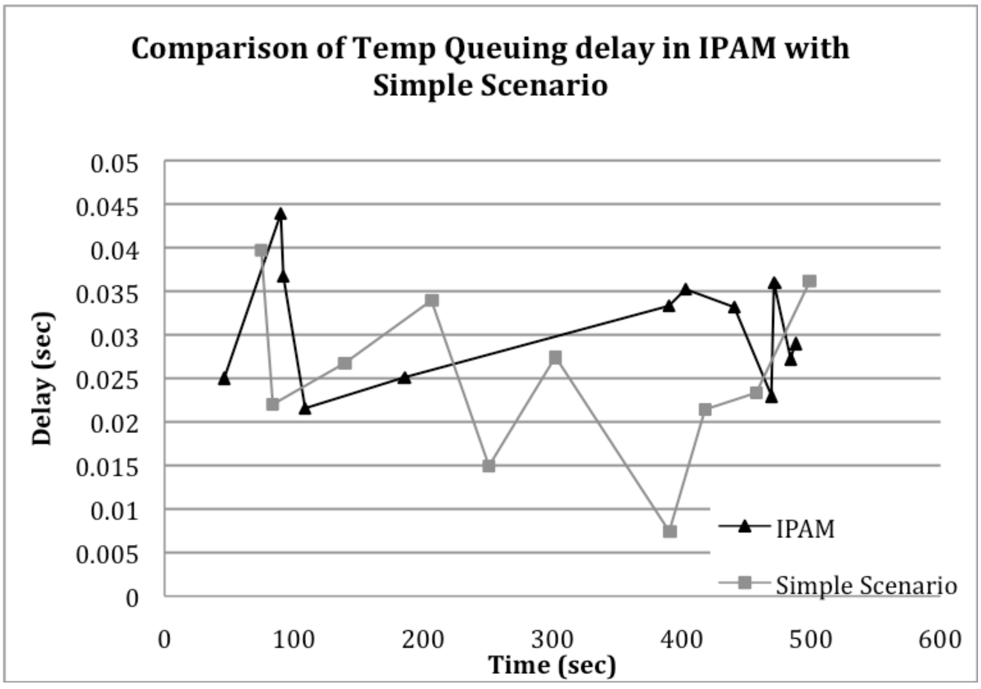

Figure 5.16: Comparison of Temperature Queuing Delay.

5.6.4. Network Data Loss

Figure 5.17 shows the byte loss rate in IAPAM is less than the simple scenario. This shows that the network is behaving reliably when using IAPAM. The bytes loss ratio is greater in simple scenario as compared to IAPAM because the priority of ECG, BP and Temp data is higher than other data and prioritize data is scheduled with no delays and normal data is passed to normal queues resulting fewer losses. The proposed IAPAM scheme has multiple virtual queues with different priority levels as compared to simple scheme with one queue resulting in higher byte loss rate. IAPAM routes the acquired data based on the urgency of the data packets.

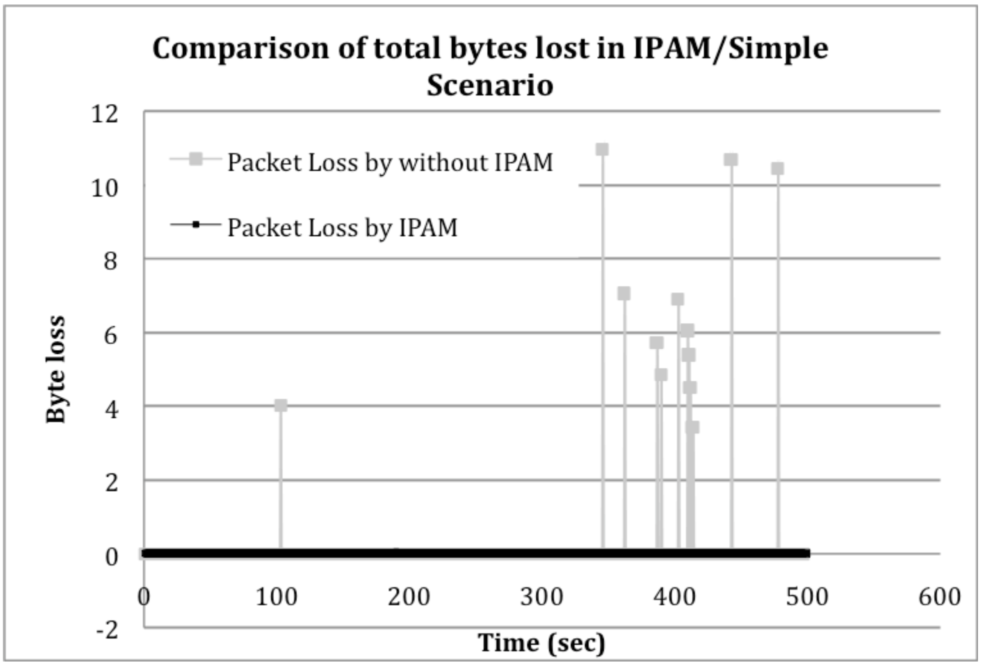

Figure 5.17: Network Average Data Loss (Bytes).

5.6.5. Network End-to-End Delay

Figure 5.18 compares the end-to-end delay of packets for IAPAM and of simple scenario. In IAPAM the end-to-end delay is very lower as compared to simple scenario because of IAPAM enabled intermediate nodes.

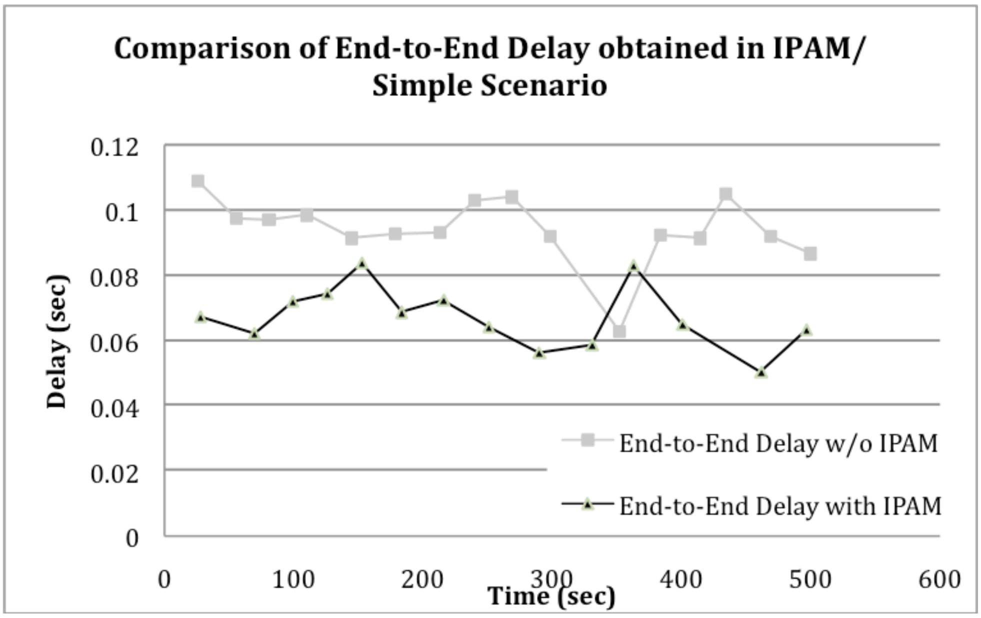

Figure 5.18: Network Average End-to-End Delay.

5.6.6. Geometric Mean of the Queuing Delay

Figure 5.19 compares the geometric mean of queuing delays at different nodes in IAPAM enabled BWSN and simple scenario. The node n1 is near to the sink and is congested because all traffic to sink passes through it.

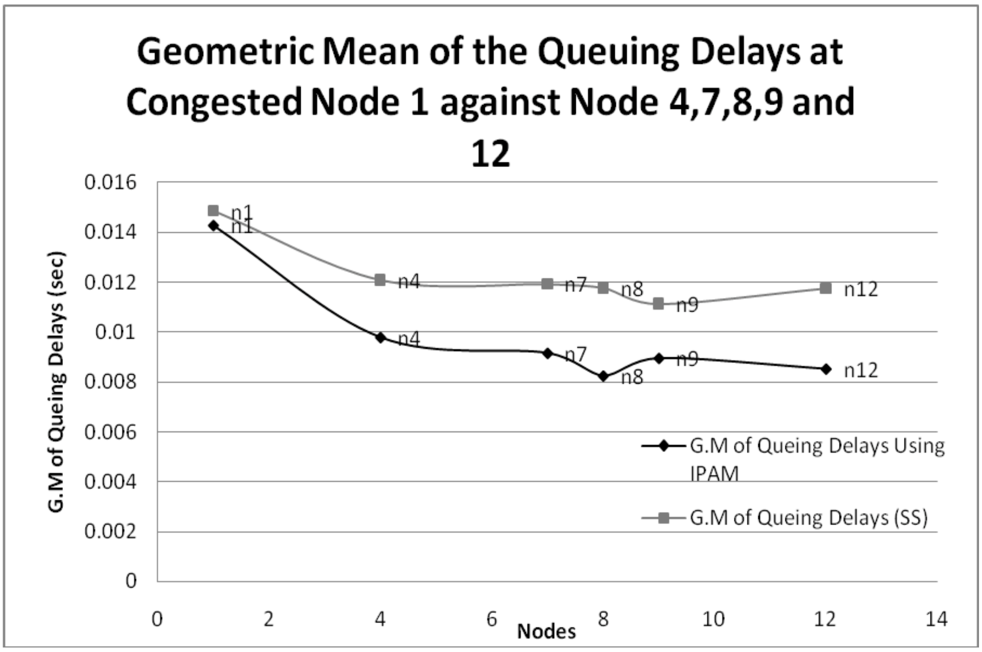

Figure 5.19: Geometric Mean of the Queuing Delay at Intermediate Nodes.

Figure 5.12 shows the average queuing delay of node n1. The average queuing delay in IAPAM enabled BWSN at node n1 is close to the one in simple scenario but it is still better in IAPAM. The average queuing delays at other intermediate nodes (4, 7, 8, 9, and 12) that are away from the sink in IAPAM enabled BWSN is less as compared to simple scenario resulting less end-to-end delay as shown Figure 5.18.

5.6.7. ECG & TEMP Queuing Delays Comparison

Figure 5.20 presents IAPAM dynamically adjust queuing delays based on the urgency of data. It shows that ECG has lower queuing delay & temperature has higher queuing delays till 250 sec. After 250 sec priority of ECG data becomes normal but the priority of temperature data increases resulting in higher delays for ECG and lower delays for temp data.

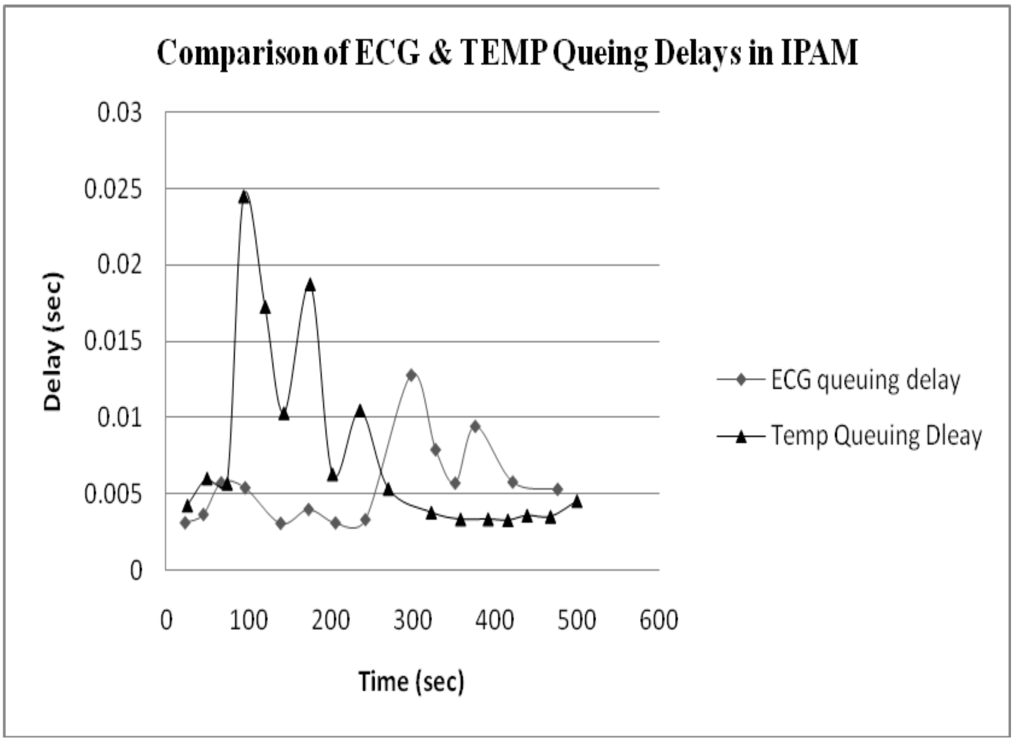

Figure 5.20: Comparisons of ECG & TEMP Queuing Delays.

5.7 Conclusions

In this chapter a new data transfer scheme, called intelligent application priority assignment mechanism (IAPAM) for biomedical wireless sensor networks (BWSN) has been proposed, discussed, developed and simulated. IAPAM dynamically assign priorities to individual data packets rather to a particular service or flow by continuously monitoring queuing delays without any invoking congestion control and avoidance mechanism. The proposed modified classifier in IAPAM assigns data level and node level priorities to data packets.

Multiple virtual queues have been assigned to implement node level priority. Finally, JSIM simulation model has been implemented to prove the conceptual model of implementing the Application Controlled Handover Extension for the IAPAM in the medical urgency scenario.

The simulation results have shown that IAPAM offers better performance than current standards of BWSN in terms of queuing delays, end-to-end delays and throughput. The end-to-end delay in IAPAM enabled BWSN is improved by 37.5% as compared to the simple scenario and throughput in IAPAM enabled BWSN is 70% higher than simple scenario. Future work will consist of implementation of a cross-layer design that will use lower layer parameters at the routing layer so that if there is some urgent data from different flows, it can be assigned the routes that are reliable and congestion free.

The scheme can also be enhanced to deal with the multimedia traffic. Sending and receiving voice and video traffic over the network and maintaining the desired throughput and delay levels for urgent data flows is a challenging task.

5.8 References

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Chapter 6

Mobility in IEEE 802.15.4 Based IAPAM Enabled BWSN

IEEE 802.15.4 is specifically designed for low rate wireless personal area network (LR-WPAN). It is very useful to obtain the low data rate, low power consumption, low complexity and low cost wireless networks. It is a new technology that has great potential for biomedical wireless sensor networks (BWSN) application in real time such as online wireless game, mobile patient health monitoring etc. The standard operates in two modes: one is beacon-enabled and other is non-beacon enabled. In this chapter, (1) the performance study of non-beacon enabled modes of IEEE 802.15.4 using IAPAM from small to large scale BWSN is evaluated, (2) the impact of mobility on remote patient equipped with IAPAM based sensors at variable speeds.

6.1 Introduction

Wireless sensor networks (WSNs) have gained worldwide attention in recent years, particularly with the proliferation in Micro-Electro-Mechanical Systems (MEMS) technology, which has facilitated the development of smart sensors. The sensors are small with limited processing, speed, wireless communication and resources. A wireless sensor network (WSN) is a special kind of ad hoc network that comprises of a large number of cooperating small-scale sensors that are geographically distributed and interconnected by wireless networks. Each sensor has wireless communication capability and sufficient intelligence for signal processing and networking of data. A wireless sensor network (WSN) consists of distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. The sensor nodes can sense, measure gather information and communicate with each other. So that sensor nodes must have the abilities of sensing, computing and communicating. Sensor nodes are expected to have lower power consumption and simple structure characteristics. The basic mode of operation is different and also very inexpensive from traditional networks. WSNs used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control [1]-[3]. An example of BWSN is shown in Figure 6.1.

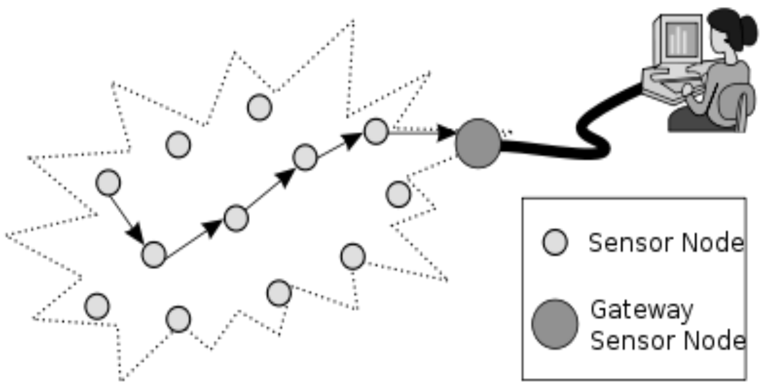

Figure 6.1: BWSN Proposed Architecture.

BWSN is classified into two major classes such as structured BWSN and unstructured BWSN [1], [3]:

Structured: In a structured BWSN, all or some of the sensor nodes are deployed in a pre-planned manner. The advantage of a structured network is that fewer nodes can be deployed with lower network maintenance and management cost. Fewer nodes can be deployed now since nodes are placed at specific locations to provide coverage while ad hoc deployment can have uncovered regions.

Unstructured: An unstructured BWSN is one that contains a dense collection of sensor nodes. Sensor nodes may be deployed in an ad hoc manner into the field. Once deployed, the network is left unattended to perform monitoring and reporting functions. In an unstructured BWSN, network maintenance such as managing connectivity and detecting failures is difficult since there are so many nodes.

6.2 Components of BWSN

The typical architecture of the biomedical sensor node is classified in two main components as shown in Figure 6.2.

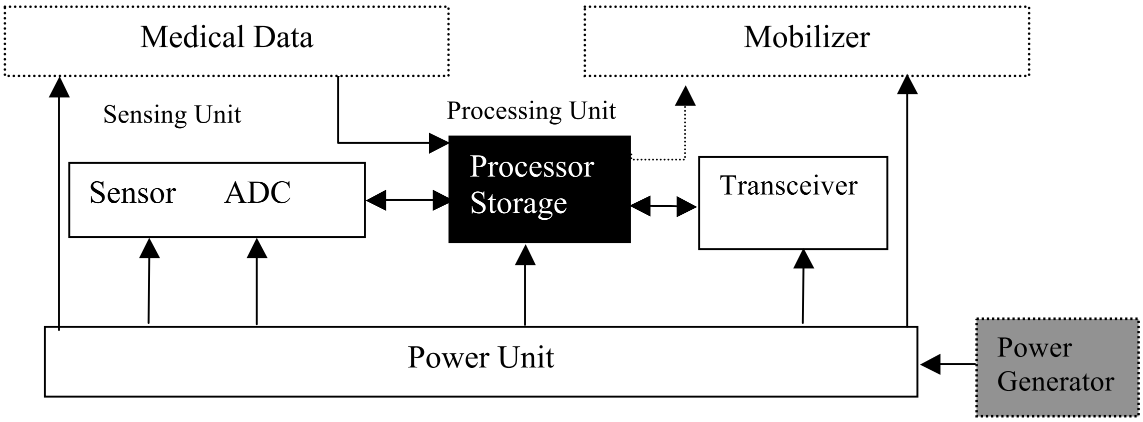

Figure 6.2: Biomedical Sensor Node.

6.2.1. Components of Sensor Node (Hardware)

The major hardware components of a sensor node are sensors with ADC (Analogue Digital Convertor) unit, power resource (battery), low power embedded microprocessor, memory and radio transceiver. The microprocessor works like a coordinator among the components of WSN. One or more sensors are used to collect the data from environment. In BWSN the battery is used to store the temporary data. In the context of battery there are two types of sensors such as active sensor and passive sensor [4]:

Active Sensors: The active sensors sense the data with actively probe the environment. They require continuous energy from a power resource.

Passive Sensors: The passive sensors sense the data without manipulating the environment by active probing. They are self-powered to amplify their analogue signal.

Components of Sensor Node (Software)

The major software components of a sensor node consist of five subsystems such as Operating System Microcode, Sensor Drivers, Communication Processors, Communication Drivers and Data Processing Mini Applications. Operating System

Microcode is also referred as middleware. It is a high-level software module for supporting a variety of functions. The middleware covers the software from the machine level functionality of the processor. Most commonly used Operating System for WSN is Tiny OS.

Sensor Drivers are also software modules that manage the basic function for sensor transceivers. Communication processors manage the communication functions. The main communication functions are routing, packet buffering and forwarding, topology maintenance, medium access control and encryption. Communication drivers are the modules which operate the radio channel transmission link, clocking and synchronization, signal encoding, bit recovery, bit counting, a signal levels and modulation. Data Processing Mini Applications are the basic applications such data processing, signal value storage etc. these application are supported at node level for in-network processing. This layer is responsible to handle the low level operation such as message transmission, message reception and addressing. The application layer stays at top level. The physical (PHY) and data link layer (MAC sub-layer) is based on IEEE 802.15.4 wireless network standard. The basic architecture is shown in Figure 6.3.

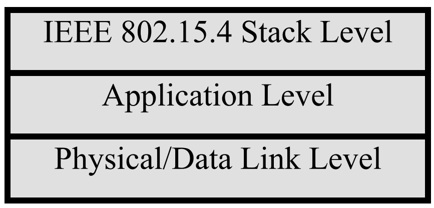

Figure 6.3: Network Layers of IEEE 802.15.4.

6.2.3. The Media Access Layer (MAC)

In the IEEE 802.15.4, there are two types of devices such as full-function devices (FFD) and reduced-function devices (RFD). The FFD can talk to other RFDs and other FFDs. FFD can operate in three modes serving as PAN coordinator, coordinator or a device. The RFD can only talk to a FFD. In IEEE 802.15.4 standard the LR-WPAN is consisted of a PAN coordinator and other set of devices. PAN coordinator is the main controller of network. PAN coordinator is responsible for initiating, maintaining and joining the network.

There are two main operational modes are available in the IEEE 802.15.4 network: beacon-enabled mode and non beacon- enabled mode. In the non beacon-enabled network the beacon frames are not transmitted periodically. The beacon request command frame is requested by device explicitly. In non beacon-enabled mode the non-slotted CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) is employed in the mac sublayer.

In the beacon-enabled network the beacon frames are transmitted periodically by PAN coordinator and all communication between devices and coordinator are based on a superframe structure. The beacon provides two services for the PAN coordinator: PAN coordinator for synchronization with nodes uses beacon frame. The time duration between two consecutive beacons is called Beacon Interval (BI).

In the beacon interval time, not all the time nodes can transmit data. The beacon interval contains the active and inactive period. The active period is termed as superframe and nodes can transmit data only during the active period (superframe).

In beacon-enabled mode the medium access is controlled by slotted CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) technique. The active part is divided into two periods, a contention access period (CAP) and an optional contention free period (CFP). The optional CFP may accommodate up to seven guaranteed time slots (GTSs) and a GTS more than one slot period. However, a sufficient portion of CAP shall remains for contention-based access of other network devices or new devices wishing to join the network.

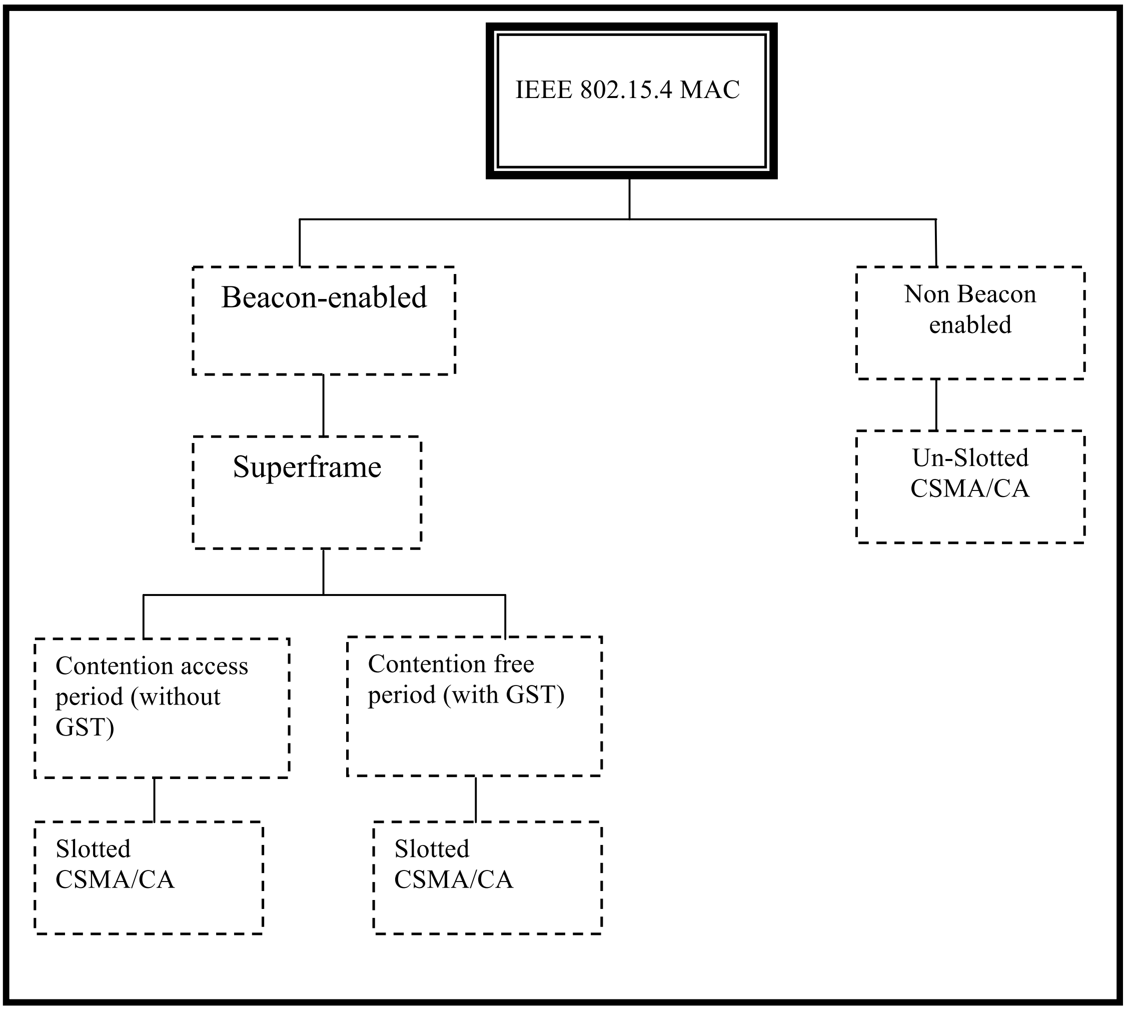

Figure 6.4: IEEE 802.15.4 MAC Operational Modes

To access a channel during CAP a slotted CSMA/CA technique is used. All contention based transactions must be completed before the beginning of CFP. All transactions, which are using GTS, must be completed before the time of the next GTS or the end of the CFP. In the superframe the network can also have GTS (Guaranteed Tim Slot) where a time slot is dedicated to a particular node.

The CFP portion of the superframe is also call GTS. CFP can grow and shrink depending on the number of GTSs assigned by the PAN coordinator. In GTS there is no competition among the nodes for gaining the time slot. GTS is assigned to critical time sensitive nodes. Figure 6.4 shows the IEEE 802.15.4 MAC operational modes.

6.3 Global Contribution and Related Work

In wireless sensor network the performance evaluation has been always a challenging task. The performance evaluation techniques can be classified on different parameters. The outdoor scenario can be different from indoor scenario. The lowest layers of wireless sensor network use the IEEE 802.15.4 standard, but there is different implementation of upper layers (like ZigBee).

The IEEE 802.15.4 standard [5] is most commonly used in wireless sensor networks that exist today. The main reason of using this standard is that it uses low power consumption, short range wireless networks, an efficient wireless connectivity between devices, self-forming wireless communication, flexible network routing, and unlicensed radio bands. This standard is very suitable and having attractive properties. The IEEE 802.15.4 standard supports two layers:

- MAC(Media Access Control) sub-layer
- PHY(Physical) layer

The lower layers of the communication protocol stack are provided by IEEE 802.15.4 standard. The network administrator of wireless sensor network can define the upper layers of the communication protocol stack. The network administrator most commonly uses the existing standard for upper layers such as ZigBee. The ZigBee software layer stays on the top of physical and mac sub-layer that is provided by IEEE 802.15.4 standard. ZigBee wireless technology is most commonly used in short-range communication system such as low-rate wireless personal area network (LR-WPAN).

The ZigBee wireless technology is the most popular worldwide open source standard for wireless radio sensor networks in the control and monitoring fields. In our discussion the performance evaluation of ZigBee based wireless sensor network are all based on the IEEE 802.15.4/ZigBee standard. There is a large number of research papers related to the performance analysis of WSNs. Some of which will be briefly discussed below.

In [6] it has been investigated that using on site PER (Packet Error Rate) measurement, the performance of non-beacon and beacon enabled models. In additionally, the Bluetooth interference impact over IEEE 802.15.4 is evaluated. It is clear from results that there were losses of mode selected and Bluetooth over the PER. Furthermore, the PER doesn't show significance distance dependency for distances between 3 to 10 meters.

In [7] an analytical model for the non beacon-enabled mode of the IEEE 802.15.4 medium access control (MAC) protocol is presented. A wireless sensor network (WSN), which is, consisted of sensors nodes. These nodes transmit data to a sink by direct links. The author reveals that by using the carrier-sense multiple access (CSMA/CA) with collision-avoidance algorithm that is defined by IEEE 802.15.4. The nodes transmit their packets upon reception of a query from the sink.

The evaluation of the distribution of the traffic, which is generated by the nodes, is allowed. In particular, the probability of a node successfully accessing the channel and the probability of a packet arriving at the sink are derived. Beside this the evaluation of the optimum size that a packet should have allowed by the model to maximize the success possibility for its transmission. Through simulations results are validated. The type of channel access mechanism is allowed by the 802.15.4 standard regarding MAC: non-beacon and beacon-enabled mode. The unslotted carrier-sense multiple access with collision avoidance (CSMA/CA) can be used. To access the radio channel each time a device waits for a random backoff period. After its end it senses the channel. The device transmits the data if the channel is found to be idle, if channel is not found to be idle then before trying to access the channel it waits for another random period. A slotted CSMA channel-access mechanism is used by implemented which is managed by the PAN coordinator send at regular intervals bound the superframe.

The mobility of the sensor nodes, which is an important feature in WSN is examined in [8]. A major challenge is to provide energy efficient and reliable operation taking into consideration various mobility strategies. In particular due to multi-hop nature of many WSN, local contention can reduce both the lifetime and efficiency of the network and can load network and can load network-wide congestion.

Thus in [8] the interdependence between local contention and end-to-end congestion is shown. The work is mainly based upon the slotted CSMA/CA medium access control method, which is adopted in IEEE 802.15.4 protocol specification for LR-WPAN. It also covers the beacon-enabled mode under various mobility scenarios and evaluation of the beacon-enabled adopted by IEEE 802.15.4 protocol and comprehensive performance analysis has been done. The effect of full active period and half active period on packet delivery ratios is studied by changing the superframe order and beacon order. The relation between congestion, mobility and local contention is examined by changing the network traffic load. It is proved by the results that mobility can be used to increase the performance of sensor network. The author of the paper sys that by regulating the superframe order and beacon order to nodes into sleep does not reduce the number of packets significantly which are delivered to the sink in many-to-one model of communication.

In [9], several metrics, three different access schemes are evaluated and considering the coexistence of contention free period (CFP) and contention access period (CAP). The author is also studied the mutual influences of these two traffics. It is shown by the results that the cost of much power consumption in terms of latency and throughput the unslotted mode have better performance than slotted mode. Moreover without sufficient GTS allocation the successful transmission of the CFP frames cannot be guaranteed by the guaranteed time slot (GTS) in CFP.

In [10] the authors investigate the challenges and advantages of deploying a single mobile sink in IEEE 802.15.4 ZigBee wireless sensor networks (WSNs). The first part of the paper reveals the most modern research on sink mobility in WSNs. It places a special emphasis on various types of sink mobility (controlled, random and predictable) in WSNs. It also discusses the application scenarios, which are most suitable for their respective development. In the second part of the paper author presents a ZigBee-based/IEEE 802.15.4 wireless sensor network model is presented for simulation of large scale networks. The model enables the forms of routing in the underlying ZigBee WSN, evaluation of predictable and random sink mobility under different conditions. The use of mobile sink has been recently proposed in the literature [11]-[20]. A mobile sink consists of a wireless electronic device, which is mounted on the top of the robot. It has the ability to move around the sensing area of the network. The movement can be controlled or pre-programmed remotely. Generally many advantages of deploying mobile sinks are reduced probability of sink isolation and more balanced consumption of energy across the network (i.e. among static nodes). The IEEE 802.15.4/ZigBee suite of standards is generally recognized as technology of choice for applications because of their ability of cost-effective, low power and reliable communication. The author [16]-[18] compares predictable and random forms of sink mobility in ZigBee WSNs. The performance comparisons of two types of ZigBee topologies and two types of sink mobility are presented in [16]-[18]. This comparison is based on the packet loss, observed energy consumption and packet delivery delay. The results obtained and presented suggests that generally random sink mobility can provide better performance than predicable sink mobility, particularly from the irrespective of average packet delay and overall energy consumption.

In [21], a burst traffic adaptation algorithm for IEEE 802.15.4 beacon- enabled networks is presented. The proposed algorithm is designed to accommodate the burst traffic and to dynamically extend the active periods. The proposed algorithm is designed for the performance enhancement in terms of energy consumption per packet transmission and end-to-end delay. The adjustment of duty cycle is the main aim of this algorithm in order to deal with intermittent traffic bursts. The adjustment is made possible in an on demand manner. The device requests the extension of active period by transmitting a busy tone, whenever it cannot transmit a packet in a given active period at all. End-to-End delay can be shortened by the algorithm, as there is extension of active period until the entire devices come to succeed. Due to busy tone transmission more energy is consumed and this is also amortized by the reduction of wastage incurred by packet collision. This work is also validated by the simulation results in paper.

In [22], the impact of sinks mobility in WSNs is evolved. The IEEE 802.15.4 provides the mechanism to form the topology. In particular, a WSN is deployed in a museum for monitoring the localization. In this work, authors analyze how a sink's mobility affects the connectivity and energy consumption that is used for the network reconfiguration and formation. When a sink moves in IEEE 802.15.4, the sensors, which are connected to it, can lose their association. The sink movement measures the percentage of nodes connected to the network. They showed that network connectivity can be heavily affected on it. Due to sink mobility, the loss of the association has an impact on the network energy consumption because to restore the association the nodes have to send energy. To avoid the performance worsening, it is important to suitably manage the variation of connectivity and energy consumption. The author is recommended to provide nodes with buffers suitably to prevent loss during lack of connectivity. The IEEE 802.15.4 beacon-enabled network is sensitive to sink mobility (mobile node) than non-beacon enabled network. When data traffic is considered the performance of the non-beacon enabled networks must be evaluated. In this case the mobility affects the data transfer delay and loss of packets. They showed that when beacon-enabled networks are used, it is important to choose a suitable value of BO (Beacon Order). This parameter affects the performance concerning formation and reconfiguration of the network.

In [23], the authors have investigated local contention and end-to-end congestion and their relation to mobility in WSN. A comprehensive performance evaluation of a beacon-enabled mode adopted by IEEE 802.15.4 standard under the different mobility scenarios. The author is studied the effect of full-active period and half-active period on packet delivery ratios by changing the superframe order and the beacon order. The author is also examined the relation between the local contention, congestion and mobility by changing the network traffic load. The simulation results prove that utilizing the mobility can increase the performance of the sensor network. On the other side, by regulating the superframe order and beacon order to put the nodes into sleep does not significantly reduce the number of packet delivered to sink.

In [24], a new algorithm has been proposed for beacon order adaptation in IEEE 802.15.4 star topology network. In particular, the coordinator determines the required duty cycle and adapts the beacon interval by observing the communication frequency.

In [25], the effect of mobility is examined and the interaction between various input parameters on the performance evaluation by using protocols designed for wireless sensor networks. An important goal in this study is the interaction of the MAC layer and routing protocols, which involve different mobility parameters. In [26], the authors show that a static sink gives the best network performance. The author has proved that if a trajectory has to be chosen for other reasons, then the trajectory should give reasonable amount of time for each route that is a link route for a segment of network. In case of diagonal trajectory the throughput is very low. There are many major factors such as traffic and the type of trajectory along with node density.

In [27], the authors have evaluated the performance of slotted CSMA/CA in order to understand the impact of some major protocol attributes (beacon order, superframe order and back-off exponent) on the network performance. Furthermore, the authors have studied the application of slotted CSMA/CA for broadcast transmission in wireless sensor networks. For large scale sensor network the backoff algorithm of slotted CSMA/CA is not flexible. It lowers limit of the backoff delay is always 0. This paper paves the ways to understand the slotted CSMA/CA mechanism and its efficient used in wireless sensor networks. By introducing priority mechanism to improve the performance of this mechanism and to turn slotted CSMA fair and more flexible for large scale network.

In [28], the authors have investigated the performance capabilities of OPNET Modeler [31] in simulating WSNs. The presented results show consistency with other simulator softwares of WSNs. The author has concluded that OPNET has good potential in simulating WSNs. Simulators can provide a vast variety of statistics and reports at different network layer for the entire network or for an individual node.

6.4 Proposed Network Scenarios for BWSN using IAPAM

An IEEE 802.15.4 wireless sensor network (WSN) based on BWSN equipped with IAPAM is composed of a PAN coordinator and set of sensor nodes. The proposed BWSN scenario is based on PAN, which is named as Patient PAN. Each PAN consists of one PAN coordinator and set of 50 mobile sensor nodes. In PAN the one mobile node assumed to be a sensor attached to the patient moving at variable speeds (5m/s, 10 m/s and 20 m/s), which is presenting a remote monitoring of a patient at home. In the proposed network scenario the patient also moves randomly using random waypoint mobility model. The following section briefly outlines the scenario in detail.

6.4.1. Network Model Mobility Strategies

In our proposed IAPAM enabled BWSN the mobile node adopts the following three main strategies:

1. Random mobility [13], [18]
2. Directed mobility [15]
3. Controlled mobility [18]

The model of BWSN can be either continuous or event based. In continuous model the sensors periodically transmit medical data to the sink (e.g medical monitoring application). In event-based BWSN, only a subset of sensors transmits data to the sink at different instances of time (e.g history of blood pressure). The selection of mobility type is very important in BWSN. The details of these mobility strategies are discussed.

A. Random Mobility

It is assumed that random walk mobility is independent of network topology and traffic flows. In this strategy the mobile node randomly select the length and direction of its path segment. In this type of mobility the mobile node randomly selects the traversal time of segment and pause between the movements of two different segments. The speed, pause time and direction are randomly selected. There is no overhead for navigation and mobile node does not depend on the network parameters. The randomized mobility is very effective to overcome the sink neighbourhood problem. Due to continuous and random changes of mobile node the energy consumption is more balanced and ultimately prolonged the lifetime of network. From the resulting point of view the random mobility is suited for continuous monitoring sensor networks. The mobile node in our proposed BWSN used the Random WayPoint Model for random mobility.

B. Directed Mobility (predictable)

In this type of mobility the mobile node always follow the same deterministic path through the network. In this strategy, the selected path is enforced by artificial or network obstacles in the environment. From the application point of view the predictable mobility is suited for continuous and event based BWSN with known area of activity. In both random and directed mobility the speed of mobile node influence the amount of control data generated in the network and it is possibly limiting the benefits of mobility. For example a faster mobile node moves, the more frequently it will have to:(i) change in association of network; (ii) inform to other nodes (fixed) for its current location, so that more overhead traffic.

The benefits of mobile node are also affected by different data rates and periodicity of data transmission in case of random and directed mobility.

C. Controlled Mobility

In this type of mobility, the path of mobile nodes becomes a function of the current state of node's energy consumption, network flows and to ensure optimal network performance for all times. The speed and pause times are two other optimization parameters for this strategy. From application point of view the controlled mobility strategy is used in both continuous and event-based BWSN. Only a few traffic flows are exist in event-based BWSN. The data generation is distributed throughout the network in the continuous network. By a particular traffic flow the location of the mobile node may not be influenced.

6.4.2. Mobility Challenges in Proposed BWSN

The use of mobile node could also impose a number of challenges towards the network, which are:

- Due to changes in location of mobile node the routing paths need to be updated periodically. It may causes to increase the data latency.

- In case of extreme mobility of mobile node may cause of increasing the packet loss. Sometimes packet may be dropped due to outdated location.
- Due to periodic repetition of association request for reconnection may cause of increasing the control overhead.

6.4.3. Random Mobility Model for Proposed BWSN

In this proposed work the Random Way Point (RWP) has been chosen as mobility model. Now a detailed model is discussed in detail. A node selects its speed from 0 to Vmax and its destination in the RWP model. The node is moving at that speed until it reaches its destination point. After reaching at destination or immediately starts the traveling to the next destination if the time is zero. If the speed is low and it selects a very remote location, it takes too much time to reach at the destination and if the speed is high, it selects a place too close to its location, it takes a very limited time to reach the destination. This is very important point when it is considered the length of simulation. The movement of the nodes is relevant to the chosen location and its speed. A more suitable network is obtained for slow moving with less pause time and the opposite is true for fast moving nodes with a relative high pause time. If the time is equal to zero than this model is quite similar to Random Walk (RW) mobility model. A memory less mobility pattern is represented by RW mobility model because each step is calculation without any information of the previous step; at regular time intervals both the speed and direction of the node are updated such as sudden, sharp turns or sudden stops which can cause very unrealistic behaviour.

In simulation area the mobile nodes are distributed random in the beginning of simulation. In the center point of the simulation area the nodes have high probability of moving in the smaller simulation areas, which can cause localized high-density areas. Random Way Point model is very suitable for the simulation of BWSN and this also widely used in Mobile Ad hoc Networks.

In the mobility of the mobile node an important modelling assumption that differentiates our approach from most standard models [29]. The mobile node moves driven by a high level mobility function, which symbolize by M. If pos is the position of the mobile node in a given moment then M(pos) will return a new position pos+1 towards which the mobile node should move. This defines a trajectory for the mobile node as a series of points pn0, pn1 = M (pn0), pn2 = M (pn1), . . . , pos = M(pos−1). Also, the function M defines the speed sp = M (sp−1) by which the mobile node moves from position psn −1 to position pn, the speed is bounded by a maximum value which is depended on the scenario and models the mobility capacity of the mobile node; this limit smax. A valid definition of M returns positions that are within the network area and s ≤ smax. The mobility function for the mobile node can be invoked at anytime even before reaching the designated point. The actual mechanism that moves a mobile entity from position pn−1 to position pn it can be a human driver or an automated navigation system.

6.4.4. GTS and CAP traffic support in BWSN (beacon enabled mode)

The proposed BWSN is also customized to include the two data traffic generator at application layer such as Traffic Source (CAP), GTS Traffic Source (CFP) and a Traffic Sink. The Traffic source generates acknowledged and unacknowledged medical data during the CAP in the beacon enabled mode. The GTS Traffic Source can produce acknowledged or unacknowledged time critical data frames by using GTS (Guaranteed Time Slot) mechanism. The traffic sink process module performs network statistics by receiving frames forwarded from lower layer. The physical layer consists of IEEE 802.15.4 radio receiver (Rx) and transmitter (Tx), the operating frequency band is 2.4 GHz and bit rate is 250 Kbps.

6.5 Simulation Environment

In order to investigate the performance analysis and impact of mobility on remote node at variable speed in IAPAM enabled BWSN. A simulation based extensive simulation based experimentation is conducted. Our simulation are modelled and performed in JSIM [30] and OPNET [31]. The layout of network scenario is captured in Figure 6.1.

In all scenarios the key simulation parameters, which are configured in simulations, are shown in Table 6.1.

Table 6.1: The Simulation Parameters

Simulation Parameters	
Simulation Area	1000m x 1000m (square shaped)
Simulation Time	60 minutes (3600 seconds)
MAC Layer Parameters	
Maximum number of retransmission	5
Acknowledge wait duration(sec)	0.05
Minimum value of the back-off exponent in the CSMA/CA	3
Maximum number of back-off the CSMA/CA algorithm will attempt before declaring a channel access failure	4
Channel sense duration (sec)	0.1
Physical Layer Parameters	
Data rate(kbps)	250
Receiver sensitivity(dB)	-85
Transmission band(GHz)	2.4
Transmission power(W)/Range	0.002 / 249m
Application Layer	
Packet interval time (sec/constant)	2
Packet size (bits/constant)	1024

6.6 Performance Evaluation and Discussions

This section compares the results of fixed nodes against mobile node in BWSN. 10, and 50 network nodes are introduces in fixed BWSN scenario. In comparison to that 10 and 50 mobile nodes at speed of 5 m/s, 10 m/s, 20 m/s and random mobility are presented in second scenario. To measure the network performance various parameters are compared:

1. Average Network Throughput
2. Average Network Delay
3. Average Network Power Consumed

6.6.1. Average Network Throughput

Figure 6.5 shows average network throughput of 10 nodes for both fixed and mobile scenarios. It can be seen that 10 nodes (fixed) have the least network throughput in comparison to 10 mobile nodes scenario. Random mobility scenario produces highest throughput reaching an average of 80 Kbps.

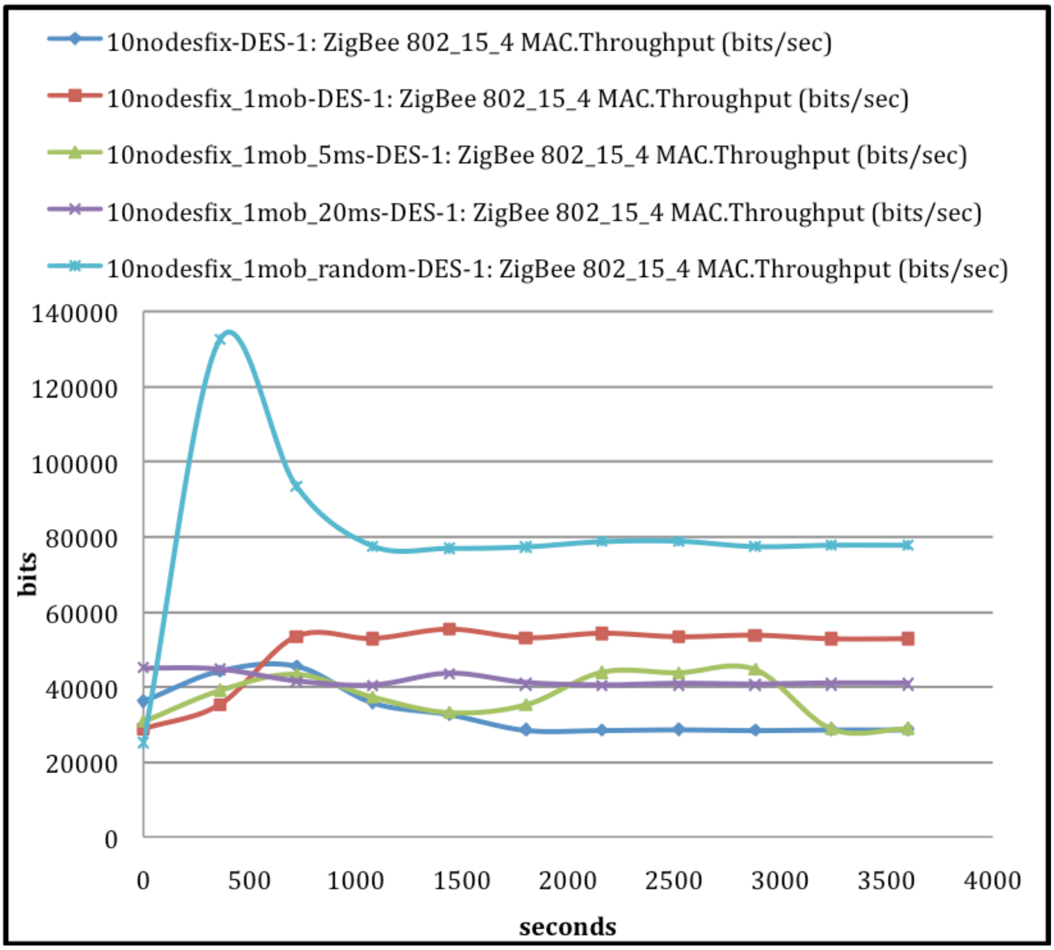

Figure 6.5: Average Network Throughput (10 Nodes).

Average network throughput of 50 fixed nodes in comparison to 50 mobile nodes with various mobility patterns is shown in Figure 6.6. 50 fixed nodes achieved the minimum throughput of 5kbps. The highest throughput has been noticed from 50 nodes moving with 20 ms. High mobility caused the high throughput in the results. 50 nodes with 5 ms and 50 nodes with controlled mobility shown a linear behaviour in results.

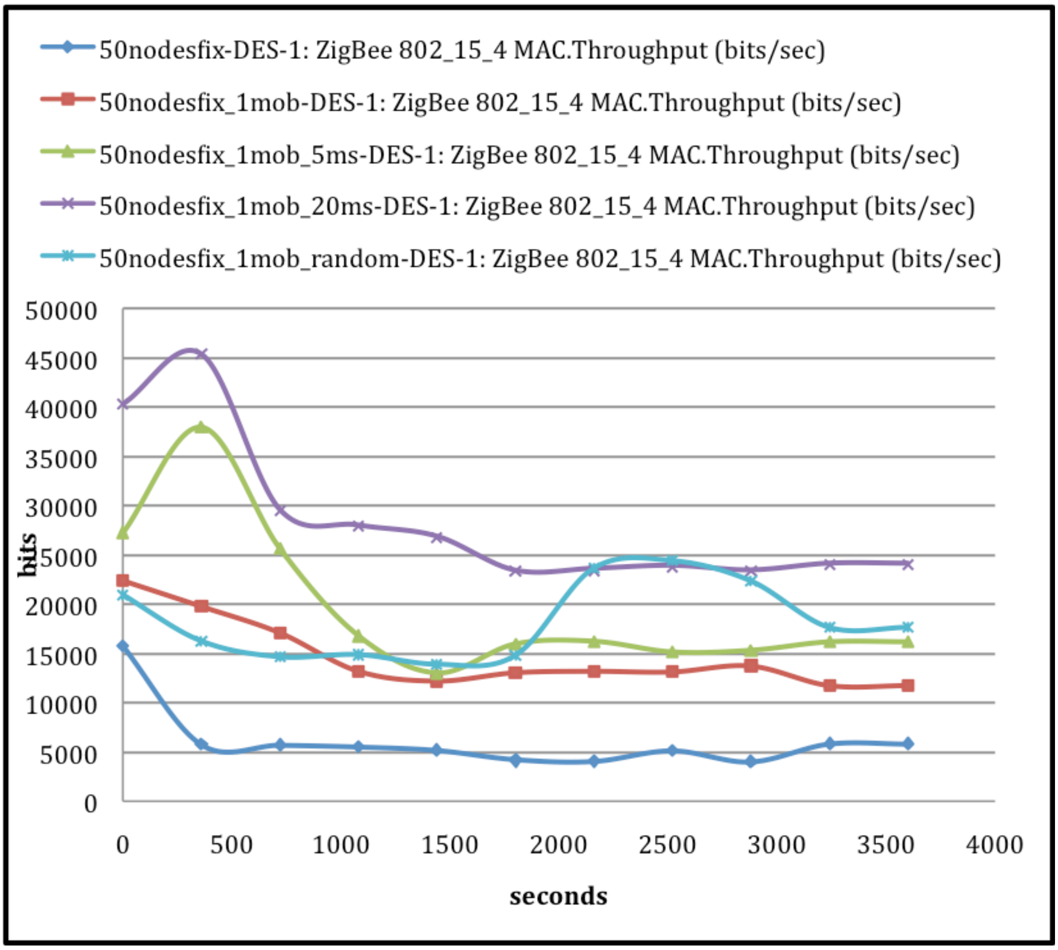

Figure 6.6: Average Network Throughput (50 Nodes).

6.6.2. Average Network Delay

Figure 6.7 shows average network delay of 10 nodes for both fixed and mobile scenarios. It can be seen that 10 nodes (fixed) have the least network throughput in comparison to 10 mobile nodes scenarios. Random mobility scenario produces highest delay reaching an average of 0.2 seconds. Fixed nodes achieved 0.07 seconds average end-to-end delay. Mobility scenarios with 5 ms and 20 ms showed an average of 0.1 seconds and 0.12 seconds respectively. Random mobility is the most realistic approach to real life mobility patterns. Deploying random mobility pattern over proposed IAPAM enabled BWSN scenario suggests that random mobility shows highest network delay as shown in the Figure 6.8.

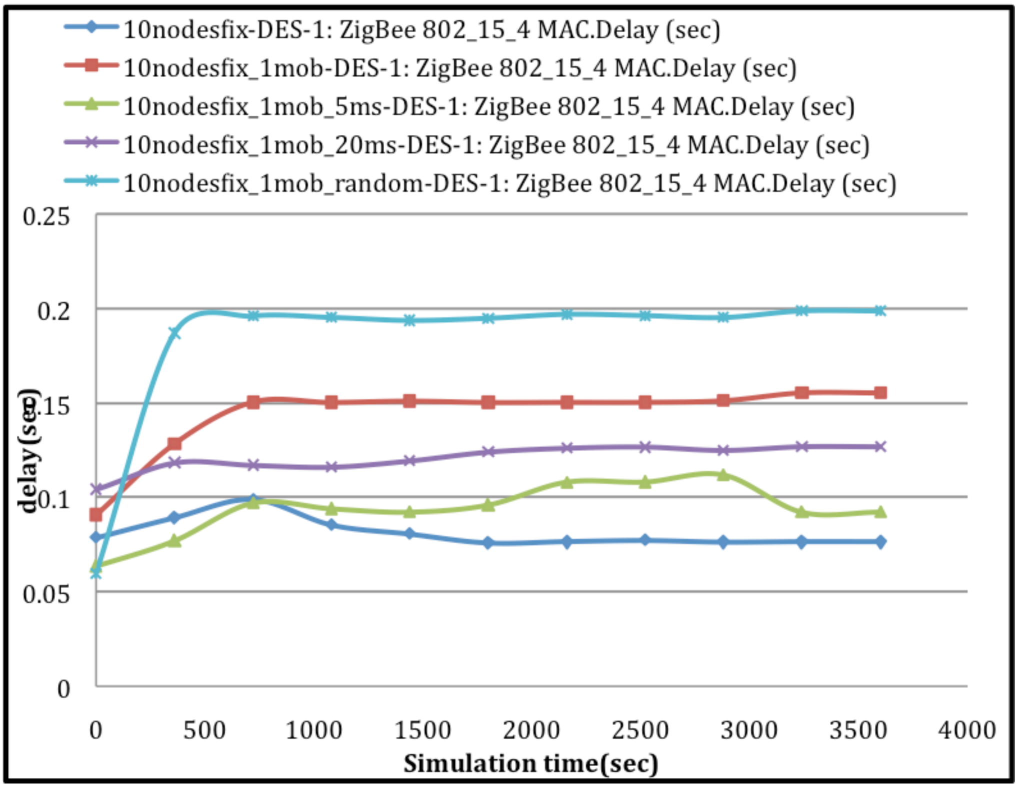

Figure 6.7: Average Network Delay (10 Nodes).

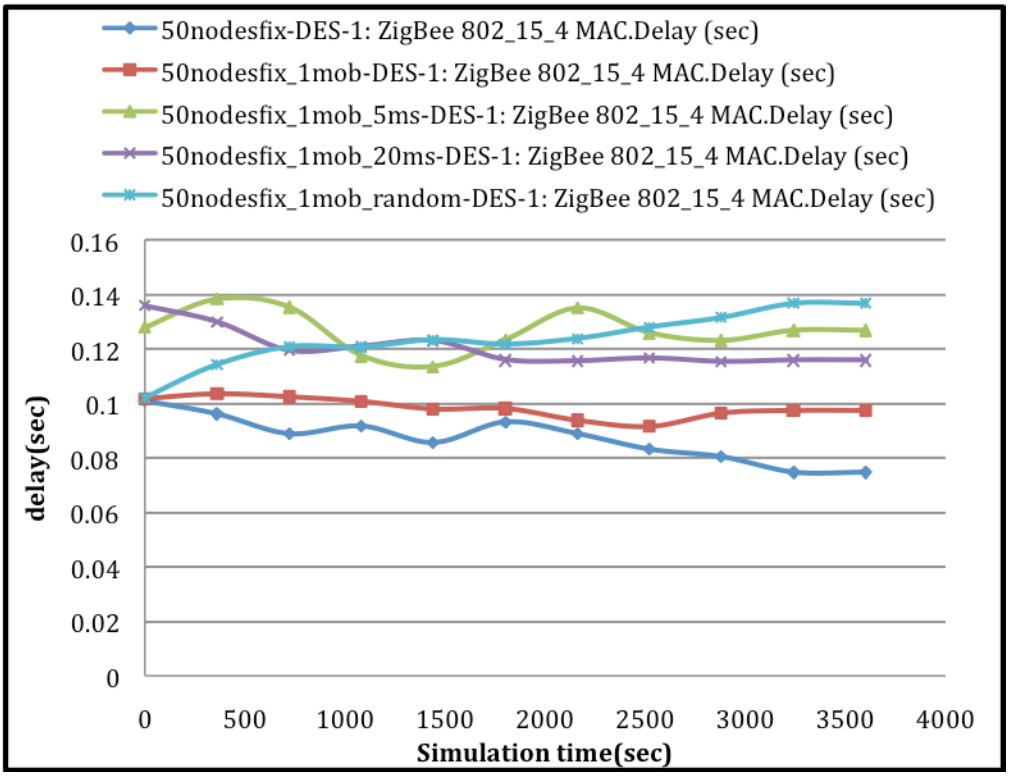

Figure 6.8: Average Network Delay (50 Nodes).

6.6.3. Average Power Received

Figure 6.9 shows average network delay of mobile nodes scenarios. It has een assumed the fixed nodes have constant power source so only scenarios based on various mobility models has been simulated for the wireless power consumed and received. Power is a critical issue for mobile nodes.

It can be seen that random mobility scenario received minimum power an average of 0.06 mJouls. Mobility scenarios with 5 ms and 20 ms showed an average of 0.1 mJouls/sec respectively.

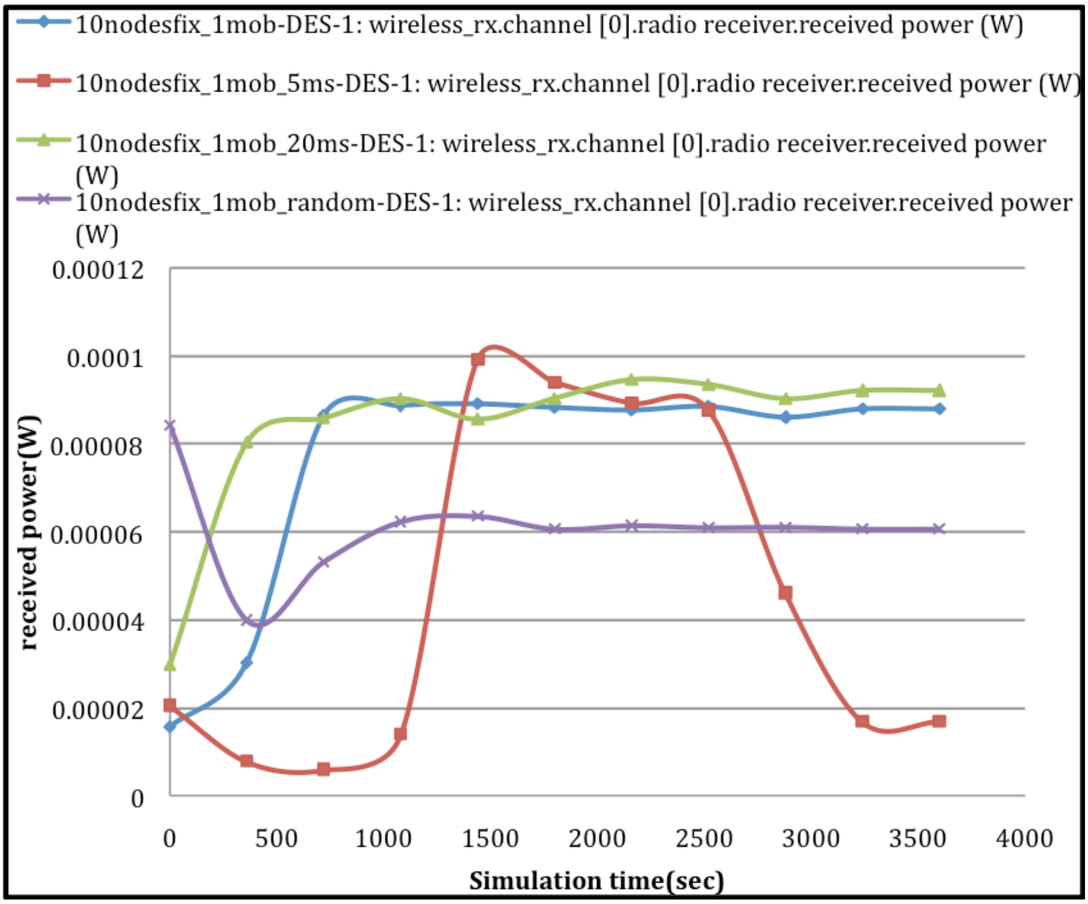

Figure 6.9: Average Rx Power (10 Nodes).

Average network power received for 50 mobile nodes with various mobility patterns is shown in Figure 6.10. Higher power received is directly proportional to high volume of data sent by mobile sensor nodes. The highest power used has been noticed from 50 nodes. High mobility caused the high throughput in the results. A linear behaviour can be seen in results.

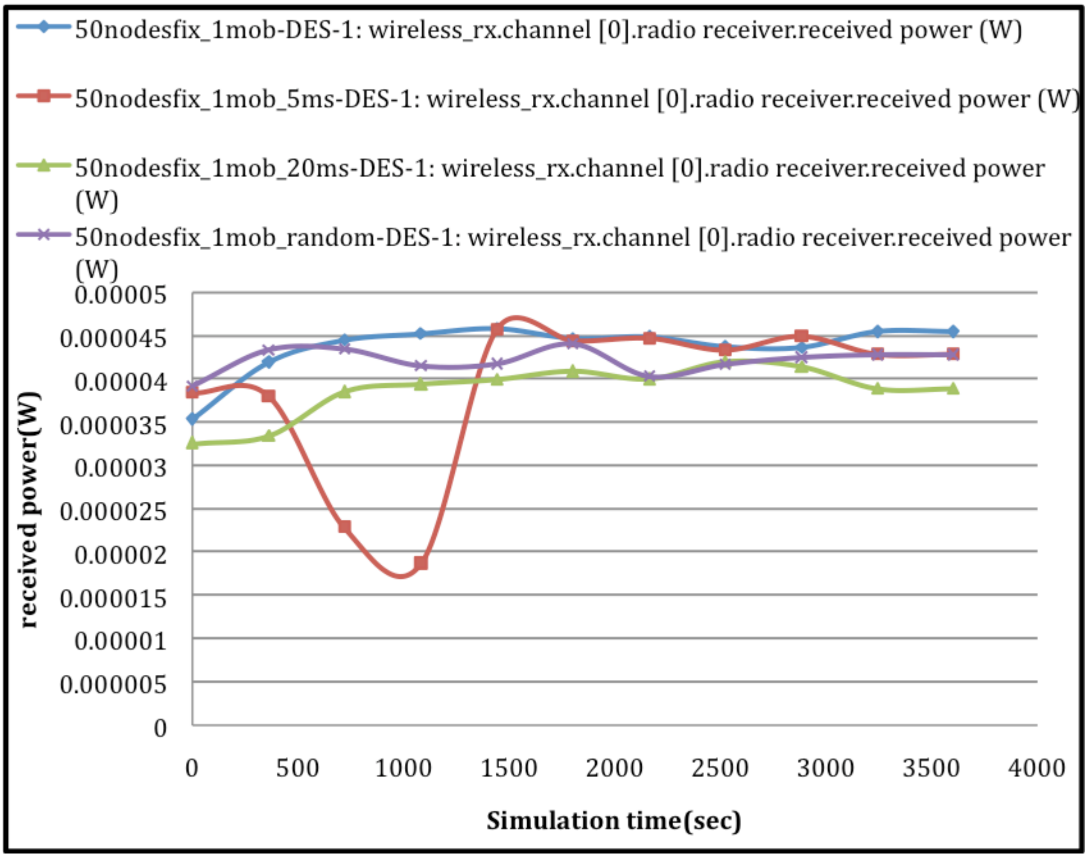

Figure 6.10: Average Rx Power (50 Nodes).

In the proposed study, a comparison of the scalability of the BWSN has been conducted. 10 to 50 numbers of nodes has been simulated. The simulation results show that increase the number of nodes increases the network throughput and increases the network delay of the network. A comparison of impact of directed and random mobility on mobile sensor node has been observed too.

6.7 Conclusions

A comparative study of different mobility patterns and their impact over IAPAM enabled BWSN has been presented. The issue of transmitting medical data traffic by mobile nodes has been studied and the consequences of using controlled, directed and random mobility have been described. The simulation results have shown that applying mobility over BWSN leads to high traffic throughput at the mobile nodes, which causes higher average delay in the network and more power consumed. The simulation results have shown that mobility decays the network performance. In particular the simulation results presented in this chapter show that the average network throughput for directed mobility network is 6 times more than the average network throughput for random mobility enabled network. Furthermore, the average network delay for directed mobility network is 2 times more then the average network delay for random mobility enabled network

The results provide strong evidence that the variation in speed has a great impact on the performance of the BWSN. On the basis of results obtained and presented in this chapter it can be concluded that the random mobility of a node can be expected to provide a better performance than directed mobility especially from the perspective of network throughput and network delay.

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Chapter 7

Conclusions and Future Work

This work has proposed an intelligent application controlled handover to improve optical wireless converged network framework and application priority assignment mechanism for biomedical wireless sensor networks. A new scheme for wired wireless integrated network has been proposed in order to enhance the end-to-end network performance. Simulation results have shown that the proposed concepts of switching wireless interfaces, application controlled handover and interface selection criteria have improved the performance.

7.1 Main Challenges and Solutions

The intelligent switching of radio access technology is an efficient proposed protocol for cellular and wireless network applications. However, there are some technical challenges required to resolve and improve this intelligent handover mechanism. After presenting the optical wireless converged network limitations and the existing challenges caused by applications of the current technology, this thesis has proposed the following enhancements for the WWIN:

1. **Interface Selection Process and Capabilities:** In the original network framework, the network capabilities are a set of potential features of the device. This is not enough for a changeable interface access network such as UWB, WiFi, WiMAX, WPAN and UMTS because these interfaces have their set of capabilities. The type of application is a criteria required for better interface selection process.

   Proposed solution: New set of selection criteria is proposed, developed and simulated. These criteria; such as the network coverage and application requested, are proven to enhance the network functionality in the aspects of continues function and soft handover process as described in Chapter 3.

2. **Cross Layer Application Controlled Handover:** The network standards do not consider the application type and the user-network interfaces.

   Proposed solution: Introduction of the concept of cross layer to the multiple air interfaces over fibre. This concept is based on the fact that the APP, Transport, MAC and PHY layers communicate to enhance network performance that is only activated by the application controlled handover on wireless clients. In this concept, the wireless network would be considered as a collection of high rate, low rate wireless mobile devices surround the user at home or work.

3. **Power and Application Controlled Framework.**

   Proposed solution: Develop the feature of distance based power management to the network using the power control handover. Enhanced the application controlled handover development by introducing traditions power management scheme in the formation of network. Wireless devices always have battery lifetime constraints. In Chapter 4, this technology is used to introduce in parallel to intelligent application handover to enhance network devices for longer usage and enhancement.

4. **Mesh Formation and Network Scalability and Integration.**

   Proposed solution: Introduce the mesh based infra for multi radio over optical network integration features. Wireless gives you mobility, optical fibre is more secure, and have terahertz of bandwidth. WiFi and WiMAX have been used for mesh connectivity to router traffic through mesh routers with a functionality of radio access units. Multihop power controlled connectivity for requested application traffic enhances the end-to-end network features.

5. **Application Priority Assignment for BWSN.**

   Proposed solution: This work has studied the BWSN application priority issues and the critical consequences of medical applications. An intelligent application priority assignment mechanism has been described, developed and proved by simulation that end-to-end delay is reduced 37% and the throughput is increased by 70% comparing to the normal standard of BWSN as presented in Chapter 5.

6. **Mobility in IAPAM enabled BWSN.**

   An IEEE 802.15.4 based IAPAM enabled BWSN is composed at variable speeds (5m/s, 10 m/s and 20 m/s) which describes a mobile patient at hospital or home. In proposed scenarios, the mobile node uses different mobility patterns such as random, directed and controlled mobility models and their impact on the performance of the BWSN.

7.2 Future Work

There are several research directions could be followed in order to enhance the performance and functionalities of wired wireless converged network. These directions are considered as a further step ahead for this research:

1. **Convergence of 60 GHz IEEE802.15.3c and Satellite Communications:**

The 60 GHz is a new WPAN technology that is required to be enhanced with the approaches that are presented in this thesis. Power saving issue is very critical for this technology and it should be enhanced for more network efficient and longer battery lifetime. Routing issue should be studied in this technology and the application and power control could be applied to accomplish further enhancement for the 60 GHz mesh WPAN performance for applications management. Satellite communication infrastructure could be enhanced in this work to enable the time sensitive application for emergency and urgent communications.

2. **Radio over Fiber Based Fast Handover Solutions for Vehicular Communication System**

The demand for intelligent transportation systems (ITSs) using the latest mobile communication technologies continuously increase to exchange traffic information and achieve safe, smooth, and comfortable driving. In particular, the system supports not only voice, data but also multimedia services such as realtime video under high mobility conditions. Since current and upcoming mobile cellular systems (e.g., GSM, UMTS) at microwave bands cannot supply a high-speed user with such high data rate traffic, mm-wave bands such as 36 or 60 GHz can be consideredAlthough these bands have higher bandwidth. It leads to very small cell size (up to tens of meters) due to its higher free space propagation loss. One promising alternative to the issue can be the design of smart handover technique of different interfaces.

3. **Security Enhancement for Optical Wireless Convergence:**

More efficient security technique could be developed in order to enhance the data encryption for more data protection. At the same time, network overload due to heavier overhead control packets should be avoided. Network analysis with several security technologies should lead to adapt one of the currently used security techniques or to develop a specialised security algorithm in order to satisfy the network security requirements according to the requirements of user applications. Comparison study of several techniques is required using simulation model in order to prove the proposed approach.

4. **IAPAM Route Discovery and Provisioning:**

A potential avenue that can extend the work in this thesis is to devise a more functioning cross layer design that uses parameters of IAPAM at the routing layer so that if there is some urgent data arriving from different flows then it could be assigned those routes that are reliable and congestion free. Dynamically assignments of routes will result in the increase of the throughput. It also assigns the prioritized data packets those routes that are congestion free.

The scheme can also be enhanced to deal with the multimedia traffic. Sending and receiving voice and video traffic over the network and maintaining the desired throughput and delay levels for urgent data flows is a challenging task.

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