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Adjusting DICOM Specifications When Using Wireless LANs: The MedLAN example

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Abstract—**Wireless networks will become increasingly useful in point-of-care areas such as hospitals, because of their ease of use and their flexibility. A system called MedLAN has been developed by the Central Middlesex Hospital and Brunel University to take advantage of the above desirable properties of WLANs for use in Accident & Emergency departments to broadcast live, high quality video images and sound over a LAN or the Internet.**

However, in many cases, the limited available throughput of such a WLAN system makes the use of high demanding specifications, such as DICOM, problematic especially when using no compression during transmission.

In this paper we will present some practical results when combining low compression with wireless LANs. We will conclude with the assessment of images and sounds by several doctors showing that the system we have devised is very useful in this setting.

Keywords—**802.11b, DICOM, wireless, WLAN**

I. The MedLAN System

Mobile telemedicine is a new and evolving area of telemedicine that exploits the recent developments in mobile networks for telemedical applications in general. Presently, a project named "MedLAN" is developed to accommodate these medical needs [1].

MedLAN consists of two main parts: A mobile trolley that exists in the Accident & Emergencies area (A&E) and a consultation point, within or outside the hospital.

The mobile trolley consists of a high-end laptop computer that is equipped with a WLAN PCMCIA card using the IEEE 802.11b protocol that permits total mobility within the A&E department and beyond. An access point (AP) within the A&E department acts as a wireless bridge for the network data to be transmitted to and received from the rest of the network. A high quality digital camcorder is connected to the laptop and high quality video, audio and still pictures can be transmitted. Additional medical instruments like otoscopes, dermascopes can also be connected to the system. Overall, the system is capable of sending still images (x-rays, CT, US, MR, etc), sound and video.

In the consultation point (either within the same hospital or in another NHS hospital) the consulting physician can have a choice of teleconferencing either from a fixed computer within the existing hospital network, or from a mobile computer, sharing the same mobility advantages of the former laptop. It can even transmit video to a PDA. Fig. 1 displays the basics of such a system.

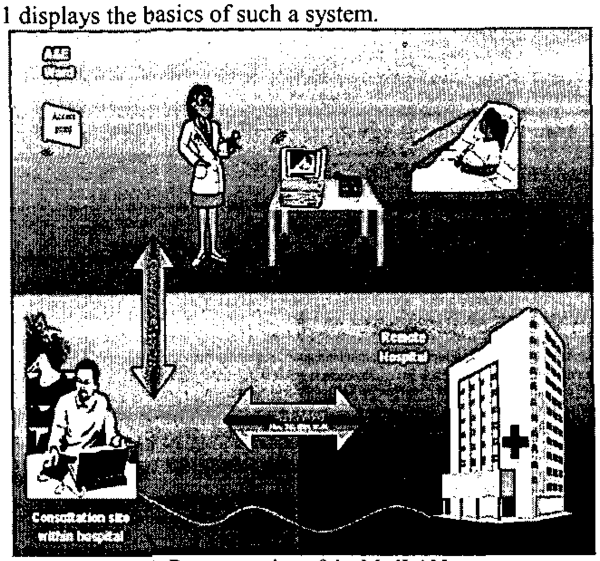

Fig. 1. Representation of the MedLAN system

II. Dicom

Digital Imaging and Communications in Medicine (DICOM) standard has been developed to meet the needs of manufacturers and users of medical imaging equipment for interconnection of devices on standard networks [2]. Its multiple parts provide a means of expansion and updating. The design of the standard aimed at allowing simplified development of all types of medical imaging. It also describes a hierarchical structure of communication between medical and storage / retrieval devices, as well as specifications on patient records. Overall, DICOM provides a set of specifications for interconnection of medical devices.

It is beyond the scope of this paper to describe the specifics of the DICOM standard as they extent to great length [2]. However, we will discuss the DICOM specifications and the consequences that this poses to a transport layer of a network, if a WLAN is to be used. More specifically, we will deal with still images (x rays, CT, MR, etc), video (patient live video, ultra sound scan, etc) and sound (heart, lung murmurs) and will contrast between the DICOM specifications and the abilities of a WLAN. Specific attention will be given to still images.

III. THE PROBLEM

A. Bandwidth requirements

As the number of medical application that requires the use of computer imaging increases, so does the required storage space (and thus the bandwidth demand for transferring the file within a network) for this application. Increased complexity high-efficiency algorithms have been developed to compress the data before they are stored or transferred. When applied in still imaging, these algorithms are divided into lossless (a procedure that after decompression, regenerates the exact same image as the original) and lossy (a procedure that loses some part of the original quality but achieves a much better compression). The first scheme uses techniques that try to find similarities within the image and pack them together in order to save space (thus transfer time). The second one works in the same way but it extents its operation on *creating* similarities when the image components are so close, that the difference would not be very visible to the end-viewer. The user is able to adjust this "forcing" of similarities [3].

Doctors tend to agree that a lossless compression is more suitable for medical image interchange as it retains all its original quality and makes diagnosis more accurate. This is generally true if an infinite storage space is offered coupled with a very large bandwidth (although some may argue that grouping very similar image components may result in reducing the "grain-of-rice" noise effect) [4]. However when trying to make use of the image, especially while using wireless networks, the problem becomes apparent. Table 1 below, summarizes the space required to store an image of various sizes:

TABLE I
STORING A 10-bit COLOUR IMAGE

Size	Storage space required (KB)		
	Uncompressed	Lossless	Loossy
2048x2048	5120	2048-2512	1400-1700
1024x1024	1280	500-740	100-500
512x512	327	150-170	30-70

B. Wireless networks

The wireless network that has been used with the MedLAN system is the IEEE 802.11b, the most standard WLAN in use within Europe. 802.11b is capable of transferring data with a top speed of 11Mbps. As the mobile terminal moves away from the Access Point (AP) and the noise increases, the system falls back in speed to maintain data integrity [5]. The intermediate speeds are 5.5, 2 and 1 Mbps.

Unfortunately, and for the best-case scenario of 11Mbps, a relatively small portion of it is available to the user. Specifically only 2.3 to 2.8 Mbps are available while the rest of the bandwidth is occupied by signaling data, protocols, encapsulation, etc.

It is apparent that with an average of 2.5Mpbs, transferring the images listed in Table 1 would require a considerable amount of time. That, combined with the fact that the MedLAN system is specifically designed to operate in an Accidents and Emergency Department, would render the system unusable. Table 2 summarizes the time required to send an image of various sizes:

TABLE II
SENDING A 10-bit COLOUR IMAGE

Size	Time required (sec)		
	Uncompressed	Lossless	Loossy
2048x2048	16	6-8	4-5
1024x1024	4	1-2	0.5-1.5
512x512	1	0.5-0.6	0.1-0.2

Due to several factors like protocol collision and network congestion, all the above times increase dramatically when the image file is transferred simultaneously with a live video stream.

There are newer WLAN trends, like IEEE 802.11a that operates in a maximum speed of 54Mbps. However, in contrast with the IEEE 802.11b that uses the 2.4GHz band, 802.11a uses the 5GHz band thus considerably limiting the range that each AP has [6]. That means that a much greater number of APs have to be installed in order to cover the same space. In a mobile system this leads to an increase of the hand-over time (time to disconnect from one AP and connect to another) that vary from 5 to 15 seconds.

C. Searching for the "golden rule"

The MedLAN system is trying to combine a diagnostic acceptable quality with the present limitations of the WLAN systems. Therefore, a new set of specifications were developed, tested and finally validated by the doctors.

The basic idea behind these new sets of rules is that *a well-compressed image, even while being slightly loosely compressed, can maintain its diagnostic value while saving a considerable amount of bandwidth and time.*

As a result, the MedLAN system can output images in three different compression ratios, to accommodate for different available network speeds: 5.5:1, 10.3:1 and 14.3:1.

TABLE III
COMPARING DICOM and MedLAN IMAGE OUTPUTS

	DICOM	MedLAN
Image resolution	512x512 to 2048x2048	1152x864
Colour depth	10 bits	16 bits
Image format	DICOM	JPEG
Average size	2048KB	512KB

Keeping the best (5.5:1) as a default, Table 3 summarizes some of the properties of the system, compared with the DICOM specifications

The same rules were used when transferring video and sound:

- Video stream resolution is 320x240 pixels and the frame rate is dynamically adjusted depending on the available bandwidth. That means that if a high quality image is being transferred, the frame rate (fps) will be reduced. Typically frame rate is 13-18 fps
- Sound is being compressed using CCITT A-Law or u-Law with 8 KHz sampling rate, 8 bits per sample and monophonic audio transmission. Since heart and lung murmurs use the lower band of the acoustic spectrum, 8KHz sampling rate should be proven adequate.

III. Methodology

To evaluate the system's performance, the following steps were made:

- A large number of x-rays, CT and MR have been captured and stored from four different hospitals.
- Several videos were recorded, including connecting the MedLAN system to an external device, such as an ultra sound monitor.
- Numerous heart and lung murmurs were captured and transmitted. Both electronic stethoscopes and pre-recorder sounds were used for that matter.

In total 5 consultants within the NHS were asked to evaluate: more than 110 still pictures, 28 videos and 45 different sounds. In each of the above, three different compression rates were used to find the percentage of medical acceptable quality. The questionnaire included the following subject: image clarity, colour fidelity, depth versatility, sound quality, image/sound delay, total delay and x-ray gray-scale clarity

Table IV summarizes the results of the doctors' evaluation. For convenience, the average of all the above factors are recorded in the appropriate cells.

TABLE IV
EVALUATION OF RESULTS

Compressed sample	Quality	Poor %	Acceptable %	Good %
Still images	low compression 5.5:1	0	15	85
	medium compression 10.3:1	0	30	70
	high compression 14.3:1	5	80	15
Video	20 fps	0	50	50
	15 fps	10	55	35
	10 fps	20	50	20
Sound	low compression	0	8	92
	high compression	5	80	15

A detailed representation of the results will be published in a later time.

IV. Discussion

Clearly Table IV indicates that even when the medical data are compressed in a non-reversible way (some information is sacrificed in order to limit the size of the files) the files maintain their diagnostic ability. Especially when low compression rates are used, none of the files fall below the "acceptable" threshold.

The most difficult part was proven to be the acquisition of x-rays. This was due to the fact that the camera was "fooled" by both the low contrast of the film and the room lighting. Setting a non-auto brightness level resulted in the best outputs.

As a last part, after the files / videos / sounds have been received, the consultant can convert them into a DICOM format thus adding additional information to the file, such as patient data, dates, diagnosis, etc. This way files can be stored in a larger format that will follow DICOM specifications, but having already saved critical time while being transferred.

V. Conclusion

The use of wireless LANs in hospitals will become more and more apparent. However, along with their ease of use there come some limitations that are directly related with their operation: lower bandwidth, security, administration, etc [7]

On the other hand, standards like ACR-NEMA's DICOM, try to impose specific rules that are necessary for the interoperability between different medical architectures.
There has to be a balance between the standardisation (that often means additional overhead) and the flexibility of the system. This is especially true in time-critical environments like the Accidents and Emergency Departments.

The MedLAN system is dedicated to be used within A&E departments. It tries to balance the standardization of medical procedures and the flexibility of the system that has to respond very fast in such a demanding environment. For that reason a new set of specifications were tested and finally suggested, that reduce considerably the amount of information sent and thus the time before the consulting doctor has the data available, while maintaining the information necessary to make a valid diagnosis. Using a low compression rate 100% of the samples fall within the category of either "acceptable" or "good".

The DICOM standards are not carved in stone. According to ACR they are "*not rules, but guidelines that attempt to define principles of practice that should generally produce high-quality care. The physician and medical physicist may modify an existing standard as determined by the individual patient and available resources*" [8]

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