User Behaviour Modelling for Resource Management in a Hybrid UMTS/DVB-T Network

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Abstract

Third generation mobile networks such as UMTS are designed to enhance the deployment of multimedia services providing high data rates and new flexible communication capabilities. However, these systems are interference limited and as such their performance is lowered in the case of a large number of users generating heavy traffic. A solution to this problem is to interconnect the UMTS network to a Digital Video Broadcasting-Terrestrial (DVB-T) network, so that the lack of capacity of UMTS during busy periods can be offset by the high bit rate available on the broadcast network. In order to justify this choice a prediction of the number of subscribers requesting the new multimedia applications designed for this scenario is needed. This paper focuses on the user behaviour modelling for multimedia services in a hybrid UMTS/DVB-T platform. The aim of the paper is to provide operators with a forecast of the demand for new multimedia services showing how they can be subject to a very high number of subscriptions, which UMTS would hardly be able to handle.

1. Introduction

This paper is based on research developed within the "Converged IP based Services for Mobile Users and Networks in DVB-T and UMTS Systems" (CISMUNDUS) project [1]. CISMUNDUS is an EU-funded research project investigating the convergence of digital broadcast and mobile telecommunications.

Digital Video Broadcasting-Terrestrial (DVB-T) is already supplying broadcasters with a new target audience by virtue of the fact that it can be received on portable and mobile terminal devices. DVB-T does not provide a built-in return channel, which is essential for interactive TV and data services. However, a return channel could be made available by mobile telecommunications. Telecommunication companies are also looking for value added services to offer to their subscribers, while at the same time trying to minimize additional infrastructure investment. Digital broadcast offers a cost efficient solution for distributing the same multimedia content to a large audience. Thus, the mobile operators can potentially benefit from the possibility of delivering their services through cooperating cellular and broadcast networks. CISMUNDUS has investigated and developed services that are enabled when a mobile terminal device has access to a hybrid network consisting of a DVB-T network cooperating with a Universal Mobile Telecommunication Systems (UMTS) network. A schematic representation of the CISMUNDUS architecture is given in Figure 1.

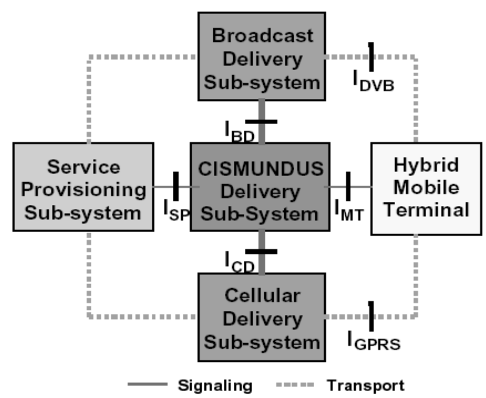


Figure 1. Block Diagram of CISMUNDUS architecture.

Different services have been designed within the CISMUNDUS project, all of them provided by the Service Provisioning Sub-system and managed by the CISMUNDUS Delivery Sub-system (CDS). Most of these services are highly resource demanding and as such they would easily cause congestion if deployed via a UMTS network. A partial solution to this problem is the design of new methods for radio resource allocation as described in [2] and [3]. In such methods new mechanisms for optimising the usage of the capacity available in third generation mobile networks are proposed. However, these methods are not designed to satisfy massive numbers of requests for new multimedia services. Such services could easily consume all the available capacity and therefore result in a breach of the service level agreements as contracted with the users.

The CISMUNDUS project takes a different approach to the problem of optimising service deployment. Here, the delivery of the service is controlled by the CDS, which decides on whether to deliver a service via the broadcast network or via the telecommunication network. This decision is made on the basis of resource monitoring and the number of service subscriptions. Such a service deployment mechanism needs to be configured by setting thresholds for the number of users per service. When the number of subscribers for a particular service is lower than the threshold the deployment will be done via UMTS, otherwise the service will be delivered via DVB-T. However, some services may be so resource demanding that a "one way" deployment via "DVB-T only" is the best solution for the current infrastructure.

The design of such a resource management system requires estimation of the traffic that will be generated by the new services that are planned for deployment on the hybrid network. The approach taken is to design stochastic models from which a forecast of the traffic generated by these new services can be gained. This solution could provide network operators with important information as to whether or not the newly proposed services could be successfully deployed on the cellular network alone or whether rerouting via a broadcast network is required. Similar types of traffic and user behaviour models can be found in the literature and have been applied to the most commonly used wireless applications. In [4] and [5] for example, models for temporal and spatial distributions of traffic in urban areas and for traffic forecasting have been developed for GSM networks. However, the main service considered in these models is the circuit-switched voice service, which makes the modelling of the traffic load relatively simple due to the one-to-one relationship between users and channels. A similar research path has been followed in [6], where the authors again propose models describing the traffic on both a temporal and spatial basis but also consider services such as wireless Internet. Therefore, the models are closer to an actual third generation services scenario but do not provide a forecast of the tremendous increase of traffic that could be generated by the deployment of multimedia applications such as video on demand. In addition, statistical models at both the packet and session level can be found in [7], [8] and [9]. In such cases source traffic can be represented by stochastic models that can give a prediction of what the traffic load would be for a specific application under certain conditions. Again, the mathematical models do not consider the consequences that the deployment of new interactive multimedia services could have on the traffic generated and therefore on the overall network performance.

In this paper the problem of what the traffic load could be due to the deployment of new multimedia applications is addressed. User behaviour models are presented based on data collected from Internet servers that provided similar services to those being analysed. Although the models derived are based on analysis performed within a particular service scenario, the concepts behind their design could be applied to any service scenario using any network technology. This makes the proposed technique flexible and applicable to different cases. This paper does not address the problem of how different tariffs could influence traffic trends and we reserve this issue for future work.

The remainder of this paper is organized as follows: in section 2 the scenario analysed is presented together with the services; in sections 3 and 4 the user behaviour models designed are illustrated; the paper is concluded in section 5.

2. The Football Match Scenario

The scenario analysed is that of a football stadium where 60,000 people are watching a football match. The total number of UEs in the stadium is 6000, i.e., the penetration is 10%.

The area of the football stadium is supposed to be covered by 4 UMTS cells made of 3 sectors of 120 degrees each and by one DVB-T cell.

The services provided through the UMTS/DVB-T network have been designed in the CISMUNDUS project together with their announcement and subscription schemes [10]. The most important of them are listed below:

1) Match Program – Provides web pages with pictures and information about the match users are watching, the teams playing, the latest events concerning the match and links to pages containing information on other matches in the

English premier league. This service is continuously announced during the match.
2) Goal Alert – Provides video clips of the most important events (goals scored, free kicks, bookings, etc.) occurring in other matches playing at the same time in different locations. The service is announced as soon as the event occurs.
3) Multiview Football – Provides streaming videos from different angles of view of the match users are watching. This service is announced once, before the start of the match and is accessible by the users at any time during the match. As it demands heavy resources, it is designed to be delivered via DVB-T only.

In order to plan for the utilization of these services and consequently to estimate whether they can be deployed through UMTS or not, user behaviour models need to be developed. These models have to be based on historical data, which are not available at the moment due to the existence of such a network and services only as a research test bed. Therefore, a similar scenario must be found where users will behave similarly using similar services on a similar network. Such a scenario is that of Internet users accessing the Web site of the France '98 Football World Cup. This Web site provided Internet users around the world with a wide range of information. Besides being able to access the current scores of the football matches in real time, fans could also access previous match results, player statistics, player biographies, team histories, information on the stadiums and a wide range of photos and sound clips. In the next section an analysis of the Internet log access traces collected from the France98 Web servers will be performed.

3. User Behaviour Modelling

The 1998 World Cup data set used is composed of the access logs collected from each of the servers used in the World Cup Web site. Data traces from this site are available on [11] and further analysis of the workload can be found in [12]. Some general statistics regarding the overall set of data analysed are listed in Table 1. It can be seen from this data how GET requests account for almost all the requests for the World Cup site. This is not surprising since the primary purpose of this site was to provide information to people. It can also be seen that quite a high percentage of the total requests resulted in a 304 response code being returned. The 200 response code will be returned from the server if the file requested by the client is available for transfer, whereas the 304 code will be returned if the request header includes an "if modified since" parameter, and the file has not changed since that date. Therefore, 304 responses correspond to users trying to refresh their Web pages and their analysis turns up to be very useful for the modelling of user behaviour especially when the number of subscribers for real time services, such as real time football match scoring, is to be analysed. The most passionate and interested users will in fact keep on refreshing their page very frequently, in order not to miss any occurring event. These users will consequently correspond to the population of IP addresses to which 304 codes have been sent. Moreover, the total number of such users can be used to estimate the percentage of UEs that will subscribe to the Goal Alert and Multiview Football service, since in the UMTS/DVB-T network the action corresponding to refreshing an Internet page is to subscribe and consume the Goal Alert and Multiview Football service.

Table 1. Statistics collected over the entire set of data.

Duration	May 1st – July 23rd, 1998
Total Unique IP Addresses Connected	2,770,108
Method	%of Requests
GET	99.88
Response Code	% of Requests
200-Successful	80.52
304-Not Modified	18.75

4. Service Models in the Football Match Scenario

User behaviour modelling in the Football Match scenario involves a low time scale analysis of the Internet data adopted. For this reason a web site access trace corresponding to one of the most popular matches of the tournament (Argentina *vs.* England) has been chosen for a deeper analysis. Statistics regarding the data trace during this match are listed in Table 2. It can be observed from this table how the percentage of 304 response codes is notably increased with respect to the average statistics collected over the entire set of data in Table 1. This result validates the assumption that the users receiving 304 response codes are those following the real time scoring service on the site.

Table 2. Statistics collected during the match Argentina vs. England

Duration	June 30th 18:30 (GTM)– June 30th 22:30 (GTM), 1998
Total Unique IP Addresses Connected	60,000
Total IP Addresses Receiving 304Codes	43,300
Method	%of Requests
GET	99.94
Response Code	%of Requests
200-Successful	64.68
304-Not Modified	35.11

It is possible at this stage to forecast what the user behaviour will be for the Multiview Football service. In fact, if this service is deployed through DVB-T its announcement will occur only once at the beginning of the match [10]. Hence, we can say that the total number of subscriptions will be proportional to the total number of hosts receiving 304 response codes, i.e.,

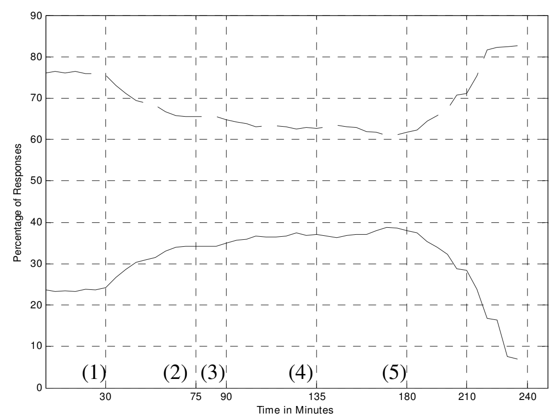
$$\begin{matrix}\text{Multiview Football}\\ \text{Subscribers}\end{matrix} = K * \begin{matrix}\text{Number of Hosts}\\ \text{receiving 304 codes}\end{matrix}$$

where the constant K depends on the penetration of the type of technology used and on the tariff fixed for the service. The constant K can be calculated as

$$K = \frac{\text{Total Number of UEs}}{\text{Total Number of Hosts}} * t$$

where t is the factor that takes into account the tariff adopted. If at this stage the type of tariff is not taken into consideration, t could be set to 1 and K would have the value 0.1. The total number of subscribers for the Multiview Football service would be 4,330. Such a number of users (requesting a live streaming video) would be hardly handled by the UMTS network either because of the high number of users or the type of resource demanding service to be deployed.

For the user behaviour modelling of the Match Program and Goal Alert services, the model cannot be based only on the total number of hosts connecting to the web site during the whole match. This is straightforward for the Goal Alert service: this service is in fact announced only when an event occurs. Hence, only those users interested in the service at that particular instant of time will access it. On the other hand, the Match Program service is continuously announced and the number of subscriptions changes continuously with time. In both cases an analysis of the data on a smaller time scale is required in order to forecast the number of subscriptions per service in a particular instant of time. The Argentina *vs*. England data trace has therefore been decomposed into intervals of five minutes and for each interval statistics have been collected. Figure 2 shows part of the results obtained. In this figure a very interesting phenomenon can be observed: as we get closer to the most popular event of the match (the penalty kicks) the percentage of 304 response increases while the percentage of 200 response decreases. This gives further support to the assumptions that 304 responses reach the more interested and watchful users.



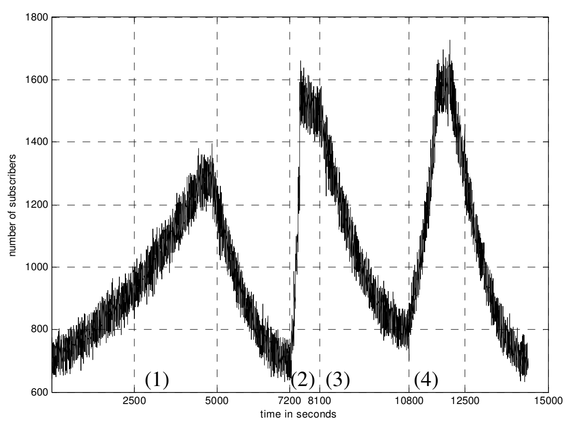
- - -Percentage of 200 Response codes
— Percentage of 304 Response codes
(1) Beginning of the match
(2) End of first half
(3) Beginning of second half
(4) End of second half
(5) Penalty kicks

Figure 2. Percentage of 200 and 304 response codes. Each value represents the average over a five minutes interval.

From these results a forecast of the number of subscribers for the Match Program service can be obtained. This number is determined using a non-homogeneous Poisson process [9], where the value of λ is assumed to be proportional to the total number of hosts connected to the site (the influence of the tariff structure is not considered). This assumption comes from the fact that the Match Program is a service providing general information about the match users are watching with links to web pages in which other matches of the premier league are described. Therefore, the type of user interested in consuming this service will be any of the users in the stadium carrying a UE, and not only the users calculated from the number of hosts receiving 304 codes. The choice of Poisson models comes from the fact that, as widely reported in literature and as mentioned in [12], the frequency with which a human decides to use the network for a specific task is well described using Poisson processes. The parameter λ for the non-homogeneous Poisson process is determined for each five minutes interval of time and its value is calculated as follows

$$\text{Average Number of Subscribers } (\lambda) = \frac{\text{Total Number of UEs}}{\text{Total Number of Hosts}} * f * \begin{matrix}\text{Total Number of Hosts}\\ \text{Connected During the}\\ \text{actual 5 minutes interval}\end{matrix} \quad (1)$$

For the user behaviour modelling of this service it has been taken into consideration that during the match users will be busy following its events and it will be less probable that they will consume the service. Therefore, the number of subscriptions is forecast to be burstier than in the World Cup traces, with very high fluctuations between playtime and non-playtime. Consequently, in equation (1) this phenomenon is taken into account with the parameter *f*. Figure 3 shows the result of the simulated number of subscribers for the Match Program service.



(1) Beginning of the match
(2) End of first half
(3) Beginning of second half
(4) End of the match

Figure 3. Simulation results representing the number of subscribers for the Match Program Service.

This figure shows how the peaks are reached when the match is not playing, while during the match the number of users requesting the service goes down to values resembling the number of subscribers before the start of the match. If the service is announced only once before the start of the match (as it will be in case of delivery via DVB-T), this result could be useful in forecasting the number of subscribers during the interval and at the end of the match as it could give an idea of when it is more opportune to announce the service in order to receive a significant number of subscriptions. The peak values are always above 1000. This means that during the peak time it would be recommended to deploy the service via DVB-T due to the limited resources of the UMTS network, as explained in [13].

For the Goal Alert service a different approach is needed because it is announced only when an event occurs. Therefore, the announcement is not a deterministic event, but it is a random event for which a distribution has to be fitted. For this purpose a Poisson based stochastic model describing the occurring of events in seven football matches played at the same time has been designed. Events are classified depending on their popularity. Three levels of popularity have been created: high, medium and low. For example, a goal scored in a very important match of the premier league will fall into the "highly popular events" class. The output of this stochastic model is used to determine when subscriptions for the Goal Alert service will occur. In order to determine the number of users subscribing at each announcement, three average values of subscriptions have been assigned, one for each class of events. These values have been calculated as the maximum number of hosts receiving 304 response codes in a five-minute interval taken from three matches of the France '98 Football World Cup, each match corresponding to a popularity class. The average number of subscribers for each class is listed in Table 3. A Poisson model with average values equal to the values listed in Table 3 determines the exact number of subscriptions occurring for each event. The predicted number of subscribers is shown in Figure 4. From the results shown in this figure it can be deduced that the traffic forecast for this service is very bursty and intense. This behaviour is likely to generate problems in the UMTS network due to a severe increase in interference and lack of resources [13].

Table 3. Average value of subscriptions per popularity class for the Goal Alert service.

Popularity	High	Medium	Low
Average Subscriptions N°	1320	869	445

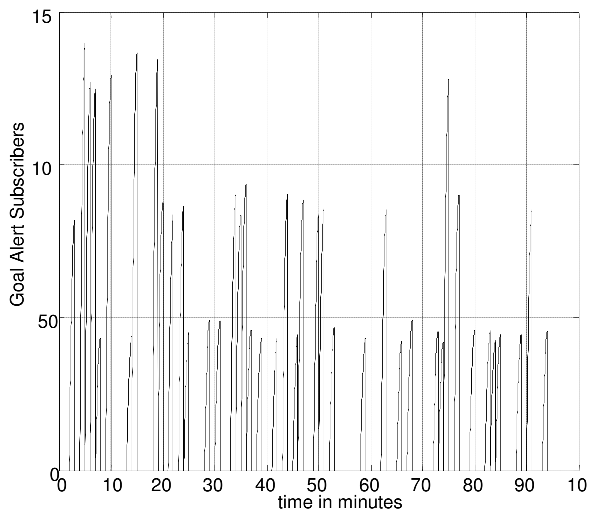


Figure 4. Predicted Goal Alert subscriptions.

5. Conclusions

In this paper traffic modelling of multimedia services planned to be deployed on a hybrid UMTS/DVB-T network has been analysed. User behaviour models for estimation of the services demand have been designed, focusing on the forecast of the peak number of subscribers for each service. The novel idea presented consists of designing stochastic models for user behaviour on the basis of the number of hosts receiving 200 and 304 response codes in an Internet scenario providing services similar to those planned to be deployed on the hybrid platform. This method could be applied to all sorts of service cases, on condition that a parallel Internet scenario is found. The results show that the forecast number of subscriptions can be very bursty and subject to very high peaks. Therefore, if the deployment of these services is to be performed via UMTS, problems could occur due to high interference levels and a lack of resources. Hence, the results obtained can provide support for the idea of broadcasting high demand traffic, for example via DVB-T, in order to relieve congestion in the UMTS network. Although the models obtained are based on real data collected from a very similar Internet scenario, the results obtained cannot be validated due to the absence in the real world of the hybrid platform. The results are therefore only indicative and can be interpreted as a forecast of what such traffic per service would be, with higher accuracy for the peak demand.

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