A DISTRIBUTED SYSTEM FOR THE INTEGRATED MANAGEMENT OF HETEROGENEOUS WIRELESS NETWORKS

Nikolaos Koutsouris, George Koundourakis, Louisa Papadopoulou, Dimitris Kouis, Vera Stavroulaki, Nikolas Mitrou
School of Electrical and Computer Engineering, National Technical University of Athens, 9 Heroon Polytechneiou Street, Zographou 15773, Greece

Panagiotis Demestichas
Department of Technology Education & Digital Systems, University of Piraeus, Piraeus, Greece

Keywords: Composite Radio, GPRS, WLAN, DVB-T.

Abstract: In a composite radio environment, different wireless access technologies can be co-operating components of a combined heterogeneous infrastructure. The exploitation of a wireless system, operating in a composite radio context, requires upgraded service and network management capabilities. This paper presents an integrated management system and gives evidence of its capability of optimising service delivery and traffic distribution in a prototype composite radio environment comprised of three different wireless network technologies, i.e., GPRS, 802.11b WLAN, and DVB-T.

1 INTRODUCTION

Wireless/mobile communications continue to attract immense research and development effort (Varshney, 2000). Major technical evolutions include the migration towards 2.5G and 3G mobile communications, the introduction of Broadband Radio Access Networks (BRAN) (Varshney, Vetter, 2000), and the advent of Digital Video Broadcasting (DVB). Moreover, the composite radio (CR) or "wireless beyond 3G", concept has emerged, in an attempt to exploit further the potential of these individual wireless technologies. It assumes that mobile, BRAN and DVB networks can be co-operating systems in a CR infrastructure. Users, equipped with multi-mode or reconfigurable terminals, access their services through the most appropriate, in terms of cost and Quality of Service (QoS), radio network.

This paper presents an integrated management system that allows the provision of enhanced applications in composite radio environments (CREs) (work conducted within the IST Project CREDO). The paper gives measurement results of the system's operation that prove its efficiency and its ability to optimize the use of the composite radio infrastructure. The rest of this paper is organized as follows. Section 2 describes the network architecture of the CR infrastructure. Section 3 presents the management platform that is essential for the operation of different wireless segments as parts of the CRE, while section 4 introduces the terminal functionality for enabling the exploitation of the potential of a CRE architecture. Section 5 presents results from various test case scenarios. Finally, concluding remarks are given in section 6.

2 NETWORK ARCHITECTURE

The composite radio environment examined by the project consists of three different radio access technologies, GSM/GPRS, IEEE 802.11b WLAN and DVB-T. This section demonstrates the general network architecture for the exploitation of all these wireless systems operating in a CR context. As depicted in Figure 1, the private networks of all the

Koutsouris N., Papadopoulou L., Koundourakis G., Kouis D., Stavroulaki V., Demestichas P. and Mitrou N. (2004).
A DISTRIBUTED SYSTEM FOR THE INTEGRATED MANAGEMENT OF HETEROGENEOUS WIRELESS NETWORKS.
In *Proceedings of the First International Conference on E-Business and Telecommunication Networks*, pages 32-39
DOI: 10.5220/0001396400320039

involved radio access technologies are interconnected either through a specific router or by means of the public IP network (GSM/GPRS case).

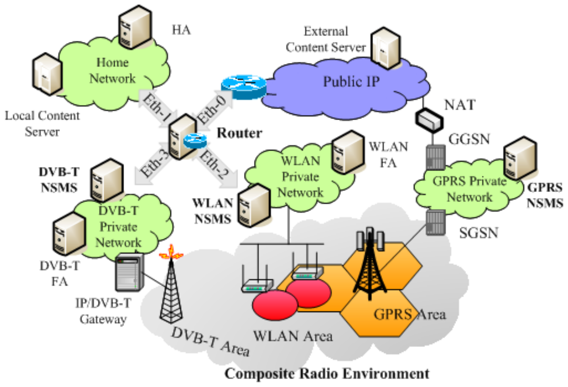

Figure 1: Composite Radio Environment Architecture

The functionality of the platform includes the following features:

- Management systems for each radio access technology. These systems, called Network and Service Management Systems (NSMSs) are located in the relative subnets, but they can inter-communicate and cooperate.
- Appropriate terminals, capable of communicating over different wireless technologies. These multimode terminals are equipped with the required intelligence for taking decisions, performing measurements and interacting with the local NSMS. The management system of the terminals used in the specific project, called Terminal Station Management System (TSMS), as well as the protocol implemented for the interaction with the NSMS are presented in section 4.
- Content servers for retrieving information relative to the applications and services provided.
- IPv4 backbone solution, selected for reasons explained below. Consequently, a Mobile IPv4 infrastructure is employed for the mobility management, especially during inter-system handovers. The home network (Figure 1), hosts the Home Agent (HA), while the Foreign Agents (FAs) are located in the corresponding subnets (WLAN and DVB-T). Moreover, the HA has been properly modified (with advanced tunneling functionality), thus enabling it to cooperate with the GPRS Network Address Translation (NAT) gateway. Also, proper modifications to the software of the DVB-T FA for enabling the establishment of the return channel were realized. The return channel is required due to the unidirectional nature of the DVB-T functionality. In the specific case, the wireless medium that acts as the missing uplink is the GPRS or the WLAN network.

It is obvious that IPv4 is selected everywhere, although IPv6 would be more convenient for the whole architecture because there is no need for including foreign agents and the NAT gateway is not necessary. The reasons for choosing IPv4 are the following (as studied at the time of the implementation of the project):

- IPv4 is much more widely deployed and multiple commercial products and networks are based on Mobile IPv4. On the other hand, IPv6 networks are still in development and Mobile IPv6 is not standard yet.
- The commercial GPRS segment and the commercial DVB-T products used do not support IPv6.
- The applications' clients and servers used are also IPv4 based.

3 MANAGEMENT SYSTEM FUNCTIONALITY

This section intends to provide useful information related to the Network and Service Management System (NSMS) introduced previously. As presented in Figure 2, NSMS consists of two main modules, namely Session Manager and Network Manager.

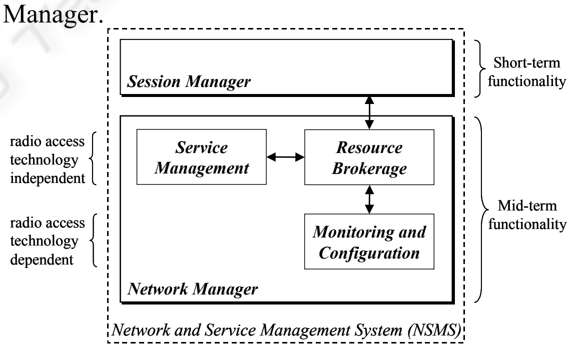

Figure 2: Management system architecture

Session Manager is the module responsible for the interface with the terminal, that is, the interface between NSMS and TSMS. Additionally, Session Manager issues recommendations to the terminal on the best network and the provided QoS level. These recommendations are based on lookup operations and/or "light" optimization problems.

On the other hand, Network Manager is responsible for the monitoring of the managed network infrastructure. It also assesses the relevant network and service-level performance, and dynamically finds and imposes the appropriate traffic distribution, through which the service management requests or new service area conditions are handled in the most cost-efficient manner. As depicted in Figure 2, Network Manager includes the following entities: Monitoring and Configuration, Resource Brokerage, and Service Management.

3.1 Session Manager

As already mentioned, Session Manager is the NSMS component responsible for performing all operations concerning the communication between the NSMS and the terminal. It also holds information about the active terminals that are served by each network, and also about the quality level assigned to them. Based on that information, and on consequent calculations, Session Manager issues recommendations to the terminals on choosing the best available network for the provision of a particular service. Thus, Session Manager addresses a short-term optimization problem, targeted to the assignment of the user terminal to a specific network. The solution of this optimization problem enables the sophisticated selection of the appropriate radio technology, for a specific user, through which services can be obtained efficiently in terms of cost and QoS, in near real time.

The optimization problem addressed by the Session Manager relies on the following input data: (a) the set of services the user is requesting and the corresponding set of quality levels at which these services are requested; (b) the profile of the user requesting the set of services (this includes parameters such as the maximum price that the user is willing to pay for the requested services); (c) the network policies, which mainly involves the cost deriving from the assignment of user demand to several quality levels and possible inabilities of a network to handle a specific service.

The optimization process carried out by the Session Manager should result in an allocation of the requested services to specific quality levels, and to specific networks. The calculation of these two allocations should optimize an objective function, which is associated with the quality levels at which each service will be provided, and the utility deriving from the assignment of the user demand to high quality levels. These allocations are bound to certain constraints, such as the capabilities of the user terminal, or the limit to the overall price that the user is willing to pay during usage of the composite radio system.

3.2 Network Manager

This section presents in more detail the three entities comprising the Network Manager. The Resource Brokerage entity has the general functionality of coordinating all the other entities of the NSMS so as to handle various conditions, such as congestion in a certain service area. Apart from this, Resource Brokerage has also an important role as regards to the efficient communication and co-operation of affiliated network providers in a composite radio environment, since it enables and assists the latter in exchanging, and negotiating on, sets of offers.

The Service Management entity provides optimization functionality for determining the appropriate service configuration (allocation of services to QoS levels) and aggregate traffic distribution (allocation of traffic to networks). In contrast with Session Manager short-term optimization, this is a mid-term optimization procedure, as it is explained in the sequence.

The functionality of the Service Management entity is similar to the functionality of the Session Manager, as related to the network selection of the TSMS. The difference between the algorithms of each entity is that Service Management provides a decision for a redistribution of the users of a service area, due to congestion, and not a recommendation to a single TSMS about the best network choice. As for the input and output data and the constraints, Service Management uses the same information described in the Session Manager’s section, but for all the involved TSMSs.

The operation of Resource Brokerage and Service Management entities is independent from the underlying radio access technology, while the Monitoring and Configuration entity operation depends on the radio access technology.

Monitoring and Configuration entity provides auxiliary functionality for handling new service area conditions or management requests. The aim of this entity is to provide insight on the status (offered load and performance) of the underlying network, ensure that the latter operates properly, and perform the necessary configuration actions to the managed network segments. These actions are achieved by using the Simple Network Management Protocol (SNMP). Apart from communicating monitoring related information to the Resource Brokerage entity, the Monitoring and Configuration entity also processes the rough network parameters and compares them with corresponding thresholds. In case some thresholds are exceeded for a number of sequential updates, the entity is responsible for triggering a redistribution request to Resource Brokerage.

3.3 Operation Sample

The sample operation of the network and service management system, provided in this sub-section (depicted in Figure 3), presents the interactions between the various components of NSMS and the terminals. It should be mentioned that the scenario is initiated from the WLAN network, but could be similar if it was initiated from the GPRS or the DVB-T network. The following steps are identified:

- The Monitoring and Configuration entity of the WLAN NSMS identifies a new environment condition (e.g., degradation of service quality or increased traffic load), which may require redistribution of the traffic load to the radio systems (step 1). It triggers (Alarm Request) the Resource Brokerage entity functionality (of the same NSMS). The latter forwards this request to the Session Manager, in order to obtain the current status of the users (per service and user class) in the affected service area.
- The Session Manager collects the aforementioned information (step 2) and triggers the WLAN Network Manager functionality (Distribution Request).
- WLAN network status acquisition phase takes place (step 3). The status of the network (e.g., traffic carried by cells) in the affected service area regions is obtained. It is noted that this information may already be available through monitoring.
- Offer exchange phase takes place (step 4). The WLAN Network Manager requests for offers from the co-operating (GPRS and DVB-T) networks. These offers should contain cost and capacity information.
- Based on the WLAN network status, and the offers provided by the GPRS and DVB-T networks, the Service Management entity of the WLAN NSMS decides on the assignment of services to quality levels, and of traffic to networks (step 5).
- Acceptance phase takes place (step 6). During this phase, the three co-operating Network Managers are accepting the solution proposed by the WLAN Service Management entity, in Step 5.
- The Session Manager and the terminals are notified about the decision of the WLAN Network Manager (step 7).
- Redistribution phase takes place (step 8).

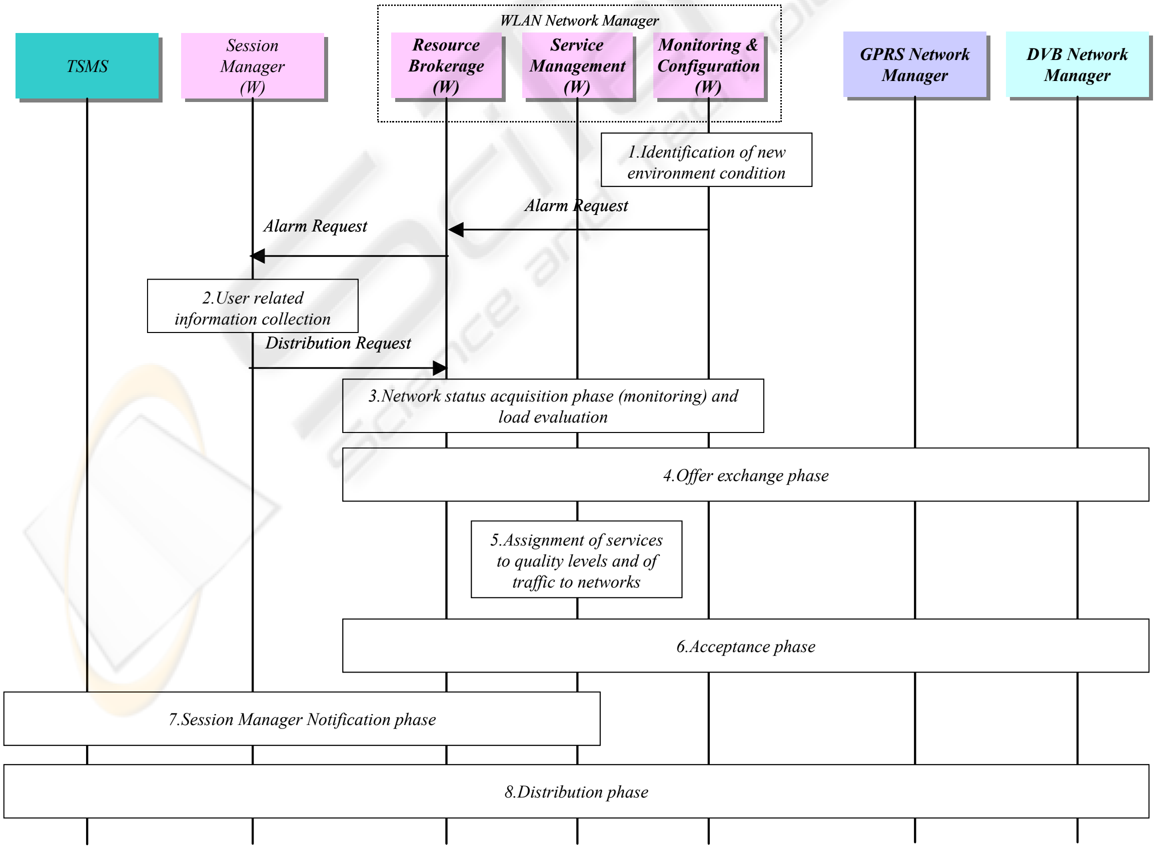

Figure 3: Management system sample operation

4 TERMINAL FUNCTIONALITY

The Terminal Station Management System (TSMS) resides in the user terminal and controls its operation within the CREDO system (Catalina, 2003). It is necessary for the exploitation of the benefits offered by the composite radio environment. TSMS is responsible for the following tasks:

- It receives service start and stop requests from the CREDO applications. In this way it can keep track of all the currently running applications. The communication with the applications is based on message exchange between the TSMS and the server through a specific interface.
- It monitors the terminal status: TCP/IP status, network interface status, application status, etc. Concerning the status of the network interface, the TSMS monitors IP and link layer parameters, related to each radio technology.
- It reports all the gathered information to the Session Manager on the NSMS.
- Together with NSMS it selects the best access network to use at each moment.
- It manages the terminal network configuration. It configures the network drivers and the TCP/IP stack according to the decisions it takes.

Additionally it has a user interface, which allows the configuration of the TSMS. The user can select his/her preferences and see the current status of the terminal and the network, as reported by the terminal monitoring system and the TSMS.

Finally, there is a module responsible for the communication between the terminal and the NSMS, through a specific protocol, implemented for this purpose. The TSMS – NSMS interactions, governed by this protocol, include the following messages:

- Service Contract Information Request and Reply. These messages are used once, at start-up, in order to specify the set of services to which a user is registered.
- Service Request and Reply. Through these messages, the terminal reports to the NSMS its current status (serving network, available networks, services used, request for a new service, etc) and the NSMS indicates by its response the list of the preferred networks, towards guiding the terminal in network selection. The messages are sent periodically (acting also as keep – alive probes), but also whenever a change in the current terminal status occurs (either in the network availability or in the services used).
- Quality Report Request and Reply. The terminal uses the request message in order to report to the NSMS quality degradation observed at the utilized services (e.g. a major traffic load alteration sensed). The NSMS after processing all the relative data, instructs the terminal which is the best action suggested in this case, by sending the reply message.
- Handover Required Notification. This message is sent by the NSMS and forces the terminal to switch to another network. A handover indication could also be included in the service reply message, but this is sent only after the service request from the terminal. The handover required notification does not require any trigger from the terminal and covers cases where the handover is necessary, without waiting for the next service request.

5 EXPERIMENTS AND RESULTS

In order to evaluate the benefits gained by the composite radio concept, several experiments and performance measurements took place under the framework of the project.

5.1 Test Environment Description

The overall platform used, consists of the relative infrastructure components, described in section 2.

More specifically, the access networks comprise one GPRS Base Transceiver Station (BTS) connected directly to a commercial GSM/GPRS provider, two IEEE 802.11b access points (APs) jointly forming a single ESS (Extended Service Set) and one IP/DVB-T multiplexer feeding a DVB-T modulator. Concerning the GPRS network, the CS-2 coding scheme is used and up to four non-dedicated time slots are used for packet switched traffic (the rest is only voice traffic). As for the IP traffic over DVB-T, a separate PID (Packet Identifier) has been allocated. The local NSMS entities are Windows PCs located at the corresponding subnets, while the application server (also a Windows PC) is at the home agent's subnet, in order to avoid additional delays. The multimode terminal used for the experiments is a desktop Linux PC, equipped with an IEEE 802.11b access card, a DVB-T receiver card and interconnected to a GSM/GPRS phone through the serial interface. The terminal possesses the full TSMS functionality described in section 4. Moreover, software applications have been developed for simulation of the terminal behaviour;

these applications have been used as virtual terminals in order to evaluate the NSMS functionality, because of the lack of equipment for more real terminals. Finally, a traffic generator tool has been used for simulating congestion situations. It is a software engine that runs over Linux systems and produces UDP packets creating background traffic in a specific radio segment (Loukatos, 2002).

During the experiments, three types of applications have been tested and provided in two different quality levels (high – low):

- Video Streaming Service, for retrieving streamed MPEG-4 encoded content from the application server. This service is accessible only through DVB-T and WLAN due to high bandwidth requirements (nominal bit rate 512 Kbps for the high quality level and 128 Kbps for the low one).
- Sports Event browsing, for acquiring information for the Olympic games from the application server. The bandwidth needed is 64 Kbps for the high quality level (not through GPRS) and 32 Kbps for the low one (served also by GPRS).
- Generic Internet Service Provision (GISP), for web browsing. This service is not decisive for the experiments due to its low demand in bandwidth (32 Kbps and 8 Kbps for each quality level). It is supported by all the examined radio access technologies.

Two typical scenarios are selected from the experiments and presented in the following subsections. Both scenarios are related to handling of congestion situations. Their difference lies on the results view aspect. Scenario 1 presents results of a more user-centric approach, while scenario 2 of a network-centric one.

5.2 Scenario 1

This scenario demonstrates the benefits deriving from the diverse radio networks interworking during high traffic situations (inside hot-spots regions). More specifically, when a stand-alone radio network cannot confront aggregate IP-based services requests from users inside a specific area, it is more preferable to divert the exceeding traffic to an affiliated segment rather than to reject it or downgrade the QoS levels provided. During the experiments and validation of the composite radio framework, many scenarios of this type where tested. The most representative scenario refers to the case where the terminal accessing the video streaming service through the WLAN network faces a congestion situation (simulated by a 4.4 Mbps UDP stream injected to the WLAN by the traffic generator tool). Consequently, the quality of the videos begins to downgrade as the aggregate traffic exceeds the alarm threshold (4.8 Mbps). At the same time, the NSMS located in the WLAN segment triggers the optimization process for solving the problem. After the completion of this process, the terminal is forced to handover to the DVB-T network with return path GPRS. During the handover procedure, the video continues without any interruption and after its completion it regains the best quality.

Figure 4 depicts, for the whole observation time, the traffic monitored in the WLAN and DVB-T segments as well as the traffic generator output and the alarm threshold. It must be noticed that the total response time of the platform against the congestion situation is app. 30 seconds from the point that traffic excesses the threshold value. The initiation of the optimization algorithm is deliberately delayed for 15 seconds, avoiding this way false alarm events triggered by short peak values of the aggregate traffic. The time interval and the alarm threshold are both configurable parameters.

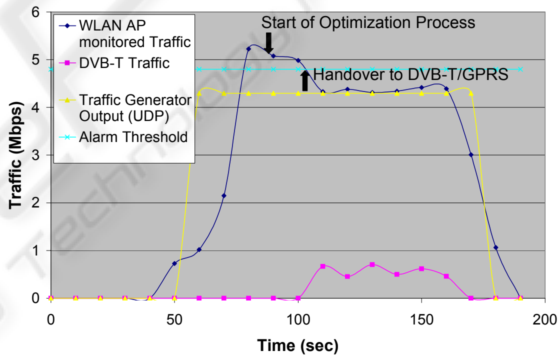

Figure 4: Traffic streams over time

Figure 5 displays the video's frame rate during the previous procedure.

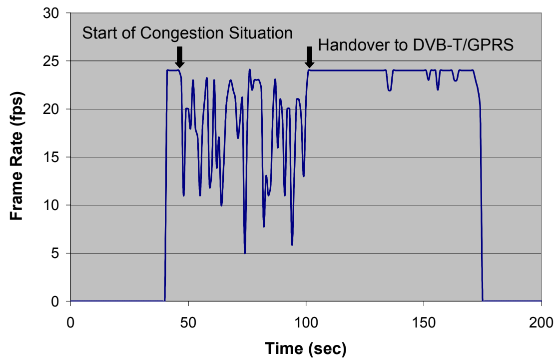

Figure 5: Frame Rate of the video stream during the congestion situation

Figure 6 demonstrates the interactions between the various components as the terminal switches from the WLAN to the DVB-T network. As depicted in the figure, the following steps are visible:

- After the completion of the mid term optimization algorithm, the NSMS sends the handover notification message to the terminal through the Home Agent (HA) and the WLAN Foreign Agent (FA), because WLAN is at this moment the serving network.
- The terminal sends a service request through the WLAN network. The WLAN FA delivers this message to the Home Agent (HA) that forwards it to the NSMS.
- The NSMS-response, suggesting of handover to the DVB-T network with return channel GPRS, follows the reverse way and reaches the terminal.
- The terminal sends a MIP registration request to the HA (for switching to the DVB-T network) through the GRPS NAT (return channel) and receives the reply through the same entity. After receiving the reply, the terminal has finished all the required actions in order to change the serving network from WLAN to DVB-T.
- The terminal sends a new service request through the GPRS network, which is delivered from the GRPS NAT to the HA and then to the NSMS. The NSMS response is sent through the HA and the DVB-T FA.

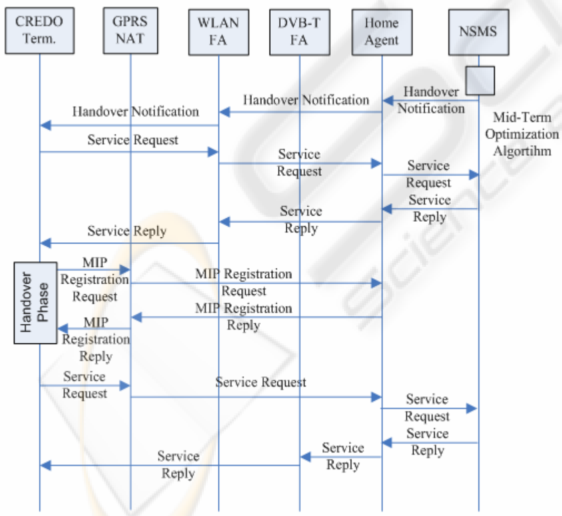

Figure 6: WLAN to DVB-T/GPRS handover procedure

5.3 Scenario 2

For the purposes of this scenario more than one terminal were essential, so a set of virtual terminals has been used. Furthermore, two user classes have been assumed: the Gold and the Economy user class. A user can choose to subscribe to different user classes for different services. Users of the Gold class are provided the service at the corresponding high quality level, whereas users of the Economy class can be provided the service at either of the two reference quality levels.

Table 1 depicts the distribution of concurrent users in the considered service area in the WLAN network. Background traffic was simulated in the WLAN network so as to create, over a period of time, a hot spot.

Table 1: Demand volume in the WLAN network

Service		**Generic Internet**		**Sports Event**		**Streaming Video**	
QoS Levels Description		High	Low	High	Low	High	Low
User Class	Gold	2	0	4	0	1	0
	Economy	0	0	10	0	2	0

The normal condition of the service area is configured to allow a cell load of 45% to 55% for the cell (cells) covering the particular service area. A snap shot of the WLAN cell under normal conditions, serving the demand volume presented in the previous, is depicted (Figure 7). The cell load has reached 52% of its overall capacity. The simulated traffic gradually increases.

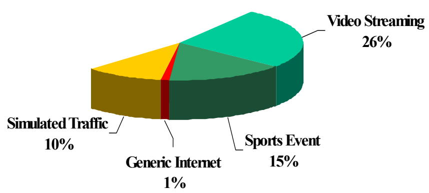

Figure 7: Traffic distribution: normal condition

Under loaded service area conditions the simulated traffic has reached 30% of the cells capacity. In other words, the cell is now approximately 72% loaded (Figure 8).

There are two typical solutions that can be proposed. (i) To maintain all the users at the WLAN network. Actually, this will result to the degradation of the quality offered (Figure 9). In fact this is the solution that would be imposed without the composite radio concept and the exploitation of the NSMS functionality. (ii) To maintain all users, of both user classes, at the high quality level by exploiting the GPRS and DVB-T networks. In this respect, a subset of the users (specified by the mid-term optimisation algorithm) will obtain the corresponding service through the WLAN network, and the remaining users will be instructed to obtain the service either through GPRS or DVB-T.

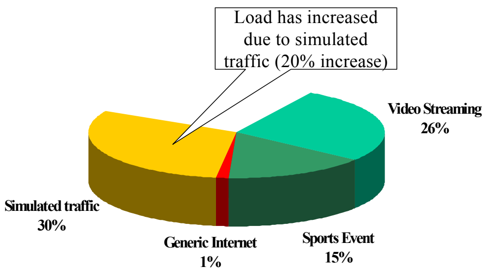

Figure 8: Traffic distribution: loaded condition

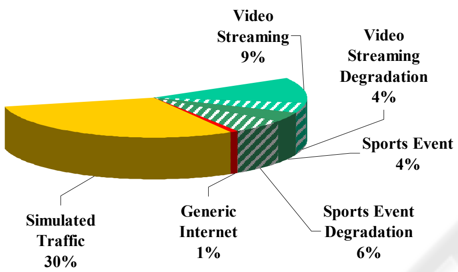

Figure 9: Degradation of Economy user class

As depicted in Figure 10, exploitation of the networks of GPRS and DVB-T results in part of the terminals being instructed to switch to these networks. The Session Manager functionality and the overall NSMS operation assist in avoiding congestion while continuing to provide all users with the highest possible quality level.

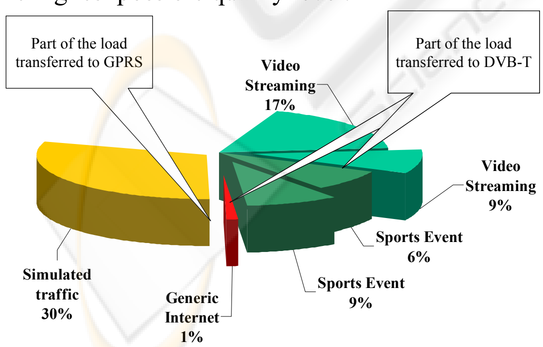

Figure 10: Exploitation of GPRS and DVB-T networks

6 CONCLUSIONS

This paper tries to validate the benefits of the composite radio concept by demonstrating results from the prototype architecture of the IST project CREDO. It addresses the profits gained for the network operator (resolution of congestion situations) and also for the user (usage of demanding services with the best quality level). Simulations could estimate the efficiency of this architecture in a more realistic environment (larger areas to cover, many real terminals to serve) (Kontovasilis, 2003). The structure of the architecture is flexible enough to be adapted for handling of larger scale situations and encompass other radio network types with minimum effort, because of its distributed form and technology independent optimization algorithm. The study of such extensions and the feasibility of producing more practical terminals are issues for future research.

REFERENCES

Varshney, U., "Recent advances in wireless networking", *IEEE Computer*, Vol. 33, No. 6, June 2000.

3rd Generation Partnership Project (3GPP) Web Site, www.3gpp.org, Jan. 2002.

Varshney, U., Vetter, R., "Emerging mobile and broadband wireless networks", *Commun. of the ACM*, Vol. 43, No. 6, June 2000.

Digital Video Broadcasting (DVB) Web site, www.dvb.org, Jan. 2002.

IST project CREDO (Composite radio for enhanced service delivery during the Olympics) Web site, www.ist-credo.org, Feb. 2001.

Catalina, M., Stathopoulos, P., 2003. Terminal Management System for Optimized Service Delivery in Composite Radio Environments. In *IST Mobile &Wireless Telecommunications* Summit.

Loukatos, D., 2002. *Traffic Generation and Analysis, Emphasizing on ATM and IP Network Technologies*. Ph.D. Thesis. National Technical University of Athens, Athens.

Kontovasilis, K., Skianis, C., Kormentzas, G., 2003. Estimating Signalling Efficiency in a Composite Radio Environment. In *1st International Working Conference on Performance Modelling and Evaluation of Heterogeneous Networks (HET-NETs'03).*