SIMULATION

http://sim.sagepub.com

Simulation and Modeling Bandwidth Control in Wireless Healthcare Information Systems

Dimitrios D. Vergados

SIMULATION 2007; 83; 347

DOI: 10.1177/0037549707083114

Simulation and Modeling Bandwidth Control in Wireless Healthcare Information Systems

Dimitrios D. Vergados
University of the Aegean
Department of Information and Communication Systems Engineering
Samos, Karlovassi
Samos, GR 832 00, Greece
vergados@aegean.gr

Next generation wireless networks have been designed to provide support for multimedia services, with different traffic characteristics and different Quality of Service (QoS) guarantees. Medical broadband applications have attracted increased attention in recent years and furthermore, the tremendous growth of wireless technologies has introduced the potential of continuous healthcare monitoring for mobile patients. The bandwidth requirements and the emergency nature of medical applications introduce the need for QoS provisioning in wireless broadband medical networks. Wireless networks may support a number of e-health applications with different traffic requirements and characteristics, providing at the same time QoS guarantees. Resource allocation in e-health application is inherently different in many aspects including the offered services, traffic requirements, propagation characteristics, and network structure. In this paper, an adaptive resource allocation scheme for QoS provisioning in wireless healthcare information systems is proposed.

Keywords: Wireless healthcare information networks, modeling, performance evaluation, resource allocation, bandwidth control, simulation

1. Introduction

Communications and more specifically, wireless communications prevail in the modern world. Currently, the healthcare society depends heavily on the competence of communication services and this trend is expected to increase even more in the near future. Wireless healthcare information systems need to be able to access and use high-quality, high-complexity services at all times, and not just in the vicinity of a fixed network terminal. As mobile medical applications are expected to provide vital aid for moving patients, mobile network technologies have to be able to provide much better connectivity than the commercial networks, which often suffer from congestion, call dropping and increased errors. On the other hand, the diversity of network resources that are needed for different e-health applications, as well as the various levels of urgency in medical situations, make the channel assignment model an appropriate architecture for QoS provisioning in wireless medical information systems [1].

A limitation of wireless networks is that several e-health applications may be supported with different QoS constraints. Moreover, the mobile medical network must always be able to handle urgent medical alerts. The provision of this data delivery mechanism in a mobile medical environment requires the formation of networks comprised of wireless communication. Nevertheless, wireless communication networks are very different from the traditional cellular ones that are commonplace in present-day networks and these differences present significant challenges to designers [2].

Next generation wireless mobile networks have been designed to support different types of traffic (such as voice, video transmission and data traffic). In order to support such a wide range of e-health applications, the quality of service has to be taken into consideration during the design phase of the wireless mobile network infrastructure itself. Handoff is a crucial function in mobile networks and furthermore, poorly designed handoff schemes tend to generate very heavy signaling traffic and thereby, a dramatic decrease in QoS. In order to maintain QoS guarantees across the network topology, a modeling framework is needed. This model should allocate the necessary re-

SIMULATION, Vol. 83, Issue 4, April 2007 347–364

DOI: 10.1177/0037549707083114
Figure 1 appears in color online: http://sim.sagepub.com

sources and handle the different types of e-health applications taking into consideration their emergency nature. It should also attempt to reduce network overheads by binding resources for handoff calls in the networks for the QoS required [3,4].

Our research work has focused on providing resource allocation models to overcome these challenges. One of these is to find out how to efficiently allocate the available bandwidth to mobile terminals in a wireless healthcare environment [5]. Traditional wireless communication systems have been engineered to use fixed transmission settings. The properties of the wireless node/cell, however, should not be fixed but rather vary with time and service type. Fixed settings often result in an inefficient use of the resources when the base station's channel utilization is not high, and can preclude handoff blocking probability and cause user quality of service reduction when there is a lack of resources. This paper presents an adaptive resource allocation scheme for QoS provisioning in Wireless Healthcare Information Systems, in which the medical data transmission corresponds to different classes of service. We have designed a resource allocation model by introducing three e-health service classes in order to adapt service settings efficiently to the required capacity and provide the requested QoS to its service class. Therefore, the resource allocation scheme takes into consideration the QoS constraints of each class along with urgent or priority type of its application. In order to decrease the blocking call probabilities and increase the overall system performance, bandwidth degradation policies have also been taken into consideration.

Thus, the paper is organized as follows: in Section 2 an introduction to e-health applications takes place, in Section 3 the handoff control and channel assignment schemes for efficiently managing wireless resources are described and analyzed, Section 4 discusses the proposed model for QoS provisioning to e-health applications, and in Section 5 a performance evaluation is presented and discussed. Finally, Section 6 concludes the paper.

2. Technologies and e-Health

Wireless networks have increased in number dramatically during the recent years as they are used more and more in daily life. The medical, environmental and military sectors are some of the most important areas in which recent developments have been applied. Healthcare networks are expected to be able to operate at any time, allocating the available resources and ensuring the QoS provisioning for the specific healthcare applications. Information technology (IT) plays an important role in e-health [1]. The use of wireless networks is very important for the information delivery in out-of-hospital incidents, as they can be used for providing access to medical databases and electronic health records, routing text/audio/photo/video medical information, retrieving healthcare information, collecting or transmitting information gathered during a medical incident or from mobile patients. The areas of emergency healthcare, homecare, patient telemonitoring, telecardiology, teleradiology, telepathology, teledermatology, teleophthalmology, telepsychiatry and telesurgery [6,7] may all be covered and supported by the telemedicine applications. By the use of such applications, expert medical services may be supported in underserved locations, such as rural health centers, ambulances, ships, trains, aeroplanes as well as in home environments [2,8].

There are several factors that should be taken into account for data delivery in wireless health networks.

- Availability: in health networks the availability of resources is absolutely imperative, since the generated traffic may be crucial for the patients' health and life. However, these mechanisms are beyond the scope of this paper.
- Confidentiality and privacy: the delivery of the sensitive patients' data demands several degrees of security. Therefore, authentication mechanisms are needed in order to preserve the confidentiality and privacy of the patients' data. Nevertheless, these mechanisms are also beyond the scope of this paper.
- Data delivery latency: the quick delivery of a patient's measurements is an extremely important issue, especially in emergency situations.
- Reliability, QoS Provision and Mobility Support: in wireless health networks, network reliability, in terms of data delivery, is a very important issue. Especially in the emergency care, packet losses during the transmission of medical information may have disastrous impacts on a patient's diagnosis. Another important issue for wireless e-health applications is the mobility support, which is very crucial for service provisioning in telemedicine. Consider an ambulance or a vehicle, which is moving through different e-health domains, supporting different e-health applications. In the healthcare environment, the connectivity between the monitoring applications with the medical data source may be assured by the use of the different wireless technologies available, while the vehicle is moving. However, the decision of the proper channel assignment for the connection of the healthcare with the healthcare monitoring network may be based on factors such as the sensitivity of the application in jitter, delay, the type of the application and emergency nature of the information. In the emergency conditions or time critical situations (i.e. when the patient should be monitored by electrocardiogram (ECG) and this measure should be repeated every 10 min), the first issue that is examined is the network availability together with the QoS constraints of the application.

In such a case, the information should be delivered with the minimum loss and delay. Therefore, the use of priority schemes with service degradation will ensure the data delivery.

2.1 Wireless Telemedicine Systems

As far as the QoS provisioning in telemedicine is concerned, several research activities may be found in the literature. However, most of the research initiatives have been focused on solving issues at the application level, but little research work has been concentrated on the interaction of QoS and on the resource allocation in mobile telemedicine. In Salvador et al. [9] a system that enables the out-of-hospital follow-up of patients suffering of cardiac diseases by using the GSM (Global System for Mobile communications) technology for the transmission of the biometric information is described. Moreover, a telemonitoring system that enables follow-up of patients at inhome environment gathering the information from the inhome bio-signal sensors is presented in Rialle et al. [10]. In Lin et al. [11], a wireless monitoring device that can measure vital signs including ECG, SpO_2HR and blood pressure and that can communicate through a WLAN with a remote management unit is proposed. Lee et al. [12] designed a transmission system in order to achieve the high transmission rates required for certain types of biomedical applications. In Hu and Sunil Kumar [13] a mobile sensor network infrastructure which supports the third-generation telemedicine applications. In order to support the large-scale mobile sensor networks for critical medical data collections and to provide the guaranteed QoS for the arriving multimedia calls, a new multi-class call admission control mechanism is proposed which is based on dynamically forming a reservation pool for handoff requests. On the other hand, a prototype telemedicine system which provides human ECG signals transfer, via a mobile phone and also provides the management of electronic records of patients and access to databases on the hospital side is proposed by Engin et al. [14]. In Maglaveras et al. [15], a generic contact center architecture is introduced concentrating on the modules dealing with the communication between the patient and the center using mobile telecommunications solutions, like the Wireless Application Protocol (WAP) technology. A performance evaluation of the TeleBAT system for Ambulance Telemedicine is presented by LaMonte et al. [16].

2.2 QoS in Telemedicine Systems

An attempt of modeling and evaluating the traffic requirements of telemedicine networks has been made by Martínez et al. [17]. A methodology for the technical evaluation of QoS traffic requirements in healthcare services based on telemedicine was proposed, which includes the service description, considering both application requirements and network topologies, and the service evaluation, implemented by an automated tool. Hu and Sunil Kumar [18] have proposed a mobile sensor network infrastructure to support third-generation telemedicine applications, which uses an energy-efficient query resolution mechanism in large-scale mobile sensor networks and provides the guaranteed mobile QoS for arriving multimedia calls. The architecture of the European WAND (Wireless ATM Network Demonstrator) System is presented by Dudzik et al. [19], who evaluated it in a medical environment. The authors review QoS issues for transmitting videos over wireless ATM connections. Such mobile applications increase quality and efficiency of treatment, but require high bandwidth and low latency, which can be guaranteed by a wireless ATM network.

2.3 Telemedicine for Multiclass QoS Provisioning in E-Health

There are a variety of e-health applications that could be considered to produce traffic with diverse network requirements. Some applications only require limited connectivity in order to transmit an alert or a short text message, whereas others require massive amounts of bandwidth. On the other hand, while many medical applications are not characterized by urgency in the desired transmission latency, very few are based on real-time interaction between the patient and the doctor. One of the greatest challenges of today's medical wireless networks is to provide the appropriate QoS support for every application. Quality of service has a number of aspects that are described below: at first, one aspect of QoS is the packet loss probability, the probability of a packet sent from the transmitter never reaching the receiver. Voice transmission applications can tolerate a certain packet loss, which adds some noise to the transmission, but other applications, like data transmission, cannot accept any packet loss, because this would mean loss of data [3].

E-health applications are often characterized by special urgency that exceeds the urgency of the typical personal and commercial needs. While the consequences of increased call blocking and call dropping are typically limited to the delay of a few minutes in communicating, blocking and dropping in mobile medical applications can be fatal. Therefore, resource allocation has a vital impact on the operational survivability of a mobile medical network.

As QoS support can handle the variety in needs for medical applications, and resource allocation can ensure the availability of network resources, medical instances are characterized by diversity in urgency that unavoidably lead to prioritization. The mobile medical network must be able to handle different medical traffic flows in a rational manner.

Some representative types of medical activities may include the following items.

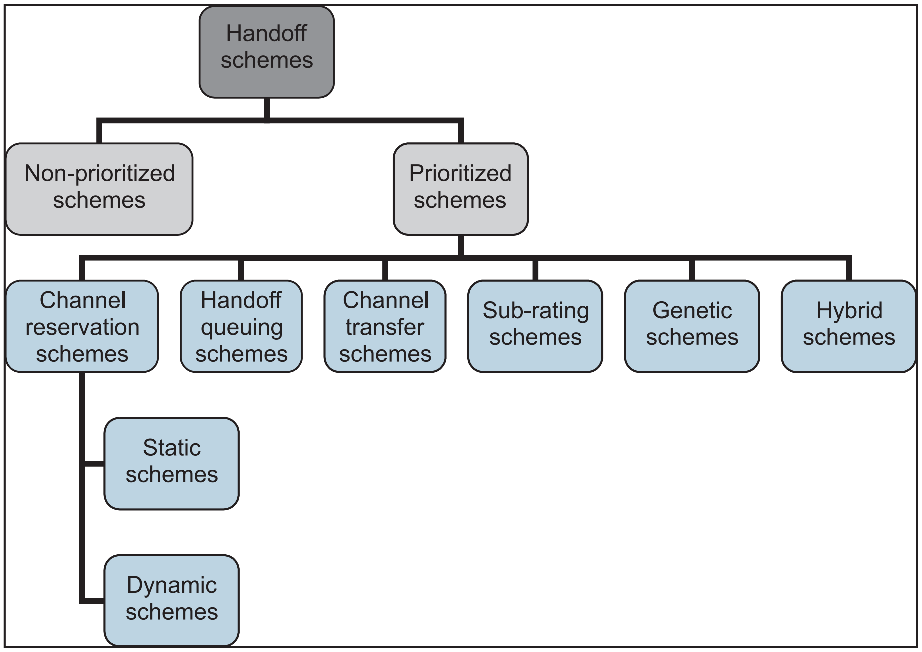

Figure 1. Handoff schemes classification

- Off-line applications: administrative files and electronic patient report (EPR) transfer (from medical data exchange between centers and moving vehicles or specialty sections), clinical routine consults through accesses to databases, queries to medical report warehouse, etc.
- On-line applications: multimedia connections including audio and video exchange, biomedical signals and vital parameters (such as ECG signal, blood pressure, oxygen saturation, etc.) transmission, etc.

3. Handoff Schemes for QoS Support in Wireless Networks

A crucial factor of the QoS provisioning is the mobility support. Due to the user mobility, the particular characteristics of the wireless networks and the limited radio frequency spectrum, the idea of handoff was introduced in order to achieve the uninterrupted communication of an ongoing call. Handoff is the process of changing the channel (frequency, time slot, spreading code, or a combination of them) associated with the current connection, while a call is in progress [20]. Handoff is often initiated either by crossing a cell boundary or due to a deterioration of the signal quality in the current channel. Several handoff strategies, that satisfy different QoS constraints and that use several mobility patterns, can be found in the literature. The handoff process is one of the most complex functions in a cellular network since it ensures the continuity of connection and has a direct impact on the QoS perceived by users. The handoff process is managed by the so-called handoff schemes. Therefore, the level of QoS of wireless mobile networks depends on the handoff strategy.

Several handoff schemes, that support different services and different traffic requirements, can be found in the literature. This section presents these schemes and classifies them into categories based on the concepts they adopt. Figure 1 depicts this classification.

3.1 Non-Prioritized Schemes

The non-prioritized scheme (NPS) [21] has been employed by the typical radio technologies proposed for PCS systems operating in a frequency fluctuating around 2 GHz. This scheme does not differentiate handoff and initial (originating) calls. Therefore, either an initial or a handoff call will be served, as long as there is a channel available in the cell. If there are no free channels, the request is blocked immediately. This scheme is able to minimize the call rejection and has the advantage of efficient utilization of the available frequency spectrum. However, due to the fact that no priority is given to handoff calls over originating calls, the forced termination probability is relatively higher than normally anticipated [21,22]. Hence, this scheme is not suitable for multi-service environments like healthcare information systems.

3.2 Prioritized Schemes

The basic concept of all handoff prioritization approaches is to give handoff requests precedence over the new session requests in some way [23]. Handoff prioritizing schemes (PS) provide improved performance at the expense of a reduction in the total admitted traffic and an increase in the blocking probability of new calls [24]. However, the improvement in performance is related to the way that each scheme gives priorities to handoff calls. Several handoff prioritization schemes, that support different services and different traffic requirements, may be found in the literature. These handoff prioritization schemes may be further classified into channel reservation schemes, handoff queuing schemes, channel transferred schemes, subrating schemes, genetic and hybrid schemes.

3.2.1 Channel Reservation Schemes

Channel reservation schemes (CRS) offer a method to increase the number of the accepted handoff requests by reserving a number of channels exclusively for handoff requests, in a predictive or non-predictive manner. The CRS can be further divided into static and dynamic.

3.2.1.1 Static Schemes The critical element of these static schemes (SS) is how to determine the optimal number of reservation channels [25]. The guard channel schemes (GCS) reserve a priori a number of channels exclusively for handoff requests. These schemes can be further divided into static and dynamic reservation schemes, depending on whether the set of reserved channels is fixed or varies according to the traffic conditions. These schemes [26,27] reserve a fixed number of channels in order to serve solely handoff requests. The main advantage of these schemes is their simplicity, because there is no need for exchange of control information between the base stations. However, such schemes are not flexible in handling the changing traffic situation, as they do not use the traffic information in the current cell and their neighboring cells, hence, they cannot adapt to the real-traffic conditions. The critical element of these schemes is how to determine the optimal number of reservation channels [25]. The fact that the number of reserved channels in these schemes is integer, made the determination of the optimal solution more difficult. To overcome this drawback, the fractional channel reservation (FCR) scheme [28] was proposed, in which the number of reservation channels is real and not integer. Ramjee et al. [28] also proved that the FCR scheme is optimal for the problem of minimizing the new call blocking probability, which is subject to a hard constraint on the handoff blocking probability for a given number of channels. Furthermore, in order to apply the FCR strategy to multiservice mobile wireless networks, the multiple fractional channel reservation (MFCR) scheme was proposed by Heredia-Ureta et al. [29], in which the fixed set of channels of the static priority schemes is extended to a multiple fixed set of channels in order to deal with multimedia traffic with different priorities. Furthermore, several schemes use different probabilistic measurements in order to determine the number of reservation channels. In Chen et al. [23] for example, the base station (BS) calculates the required bandwidth, which is going to be reserved for handoff calls based on a history record of the mobility of the user from neighboring cells. Using this information, the scheme predicts the handoff time and the amount of bandwidth that should be reserved. The BS adjusts the amount of reserved bandwidth by changing the size of the estimation window, depending on the handoff failures recorded.

3.2.1.2 Dynamic Schemes The dynamic schemes (DS) attempt to avoid the problem of finding the optimal number of channels by adjusting the number of reserved channels according to the variation in system parameters (e.g. traffic conditions and the position of users) [30,31]. For example, in Oliveira et al. [30] the number of channels to be reserved is calculated according to the requested bandwidth of all ongoing connections or the number of ongoing connections. Each base station monitors the handoff call blocking probability and the utilization of channels in its cell, and then uses this information to adjust the reservation accordingly, whereas in Chang and Chen [31] several groups (reservation time sections) are established according to the mobility information of mobile hosts in each base station. Thus, the amount of reserved bandwidth for each base station is dynamically adjusted for each reservation group. These schemes have the advantage of better utilization of the available frequency spectrum and due to their flexibility they are suitable for multi-traffic environments. However, in order to allow dynamic adjustments, this results in signaling and computational overhead. In Chiu et al. [32,33], the reservation is based on the current position, velocity and orientation of a mobile host. By using this information, the system can estimate the exact position where the mobile device will cross the cell boundary (on the condition that the call is not terminated by that time) and hence, it can determine the new potential base station. Once the mobile host is within range of the new cell, the currently serving BS sends a channel reservation request to pre-allocate a channel in the cell for the imminent handover. The road-map-based channel-reservation (RMCR) scheme [12] makes use of a mobile user's moving speed, direction, and the road information stored in the BSs in order to predict the handoff probabilities to neighboring cells. The amount of reserved bandwidth is dynamically adjusted according to the handoff probability and the traffic load in each cell.

3.2.2 Handoff Queuing Schemes

The handoff queuing schemes (HQS) give priority to handoff attempts by permitting them to queue instead of denying access, if the potential new BS is busy. This is possible due to the time a mobile device spends in the overlapping service region of cells, called the handoff area. If a mobile station (MS) is in the handoff area and the destination cell has no free channels, then the MS maintains the existing channel of the source cell. The handoff request is queued and sent to the base station of the destination cell. If a channel in the destination cell is available before the MS crosses the handoff area, then the channel is assigned to the MS. Otherwise, the call is forcibly terminated [34].

Queuing schemes can be further split up into static and dynamic schemes. The static schemes are served in a first-come-first-served manner. Several static schemes can be found in the literature. In Guerin [26] a queue for the originating calls is also introduced, whereas in Zeng and Agrawal [35] queues for both originating calls and handoff requests are proposed. A two-level priority reservation has been proposed in Rappaport [36], and Stojmenović [37]. In order to meet the demands for multiple types of services several combinations of reservation and queuing handoff have been proposed [20,35,37].

In the static handoff queuing scheme, the probability of forced termination is decreased. However, a handoff call may still be dropped because the handoff requests can only wait until the receiver's threshold is reached; in the case of high demand for handoffs, handoff calls will not be allowed to be queued due to the limited size of the handoff queue.

On the other hand, dynamic schemes (measured-based priority schemes; (MBPS)) [38] take into consideration the rate of degradation in the current radio channel, and dynamically reorder handoff requests in the queue to reduce the probability of forced termination. In order to enable the system to be adapted to the new traffic situation, information is required, which can be obtained either by the MS or the BS. However, both cases result in computational or signaling overhead.

3.2.3 Channel Transferred Schemes

In the channel transferred schemes (CTS), in the case that there are no available channels to accommodate a handoff call request, a channel from a neighboring cell may be transferred. The channel-carrying handoff scheme was proposed by Li et al. [39]. The key issue of this scheme is to allow the MS to carry its channel under certain mobility patterns from its current cell into the new cell, without blocking the handoff request and violating minimum reuse distance requirement. It ensures that an ongoing call will not forcibly be terminated due to an unavailability of channels. Since channels do not need to be reserved in advance, the efficiency of the system is increased. However, the major disadvantage of the scheme is that carrying a channel into a new cell results in an increased signaling overhead due to communication with the neighboring cell to negotiate the channel use. Another approach of the CTS is the channel borrowing scheme, which was proposed by Engel et al. [40]. The key issue of this approach is that when a cell has used all its nominal channels, it is allowed to borrow free channels from its neighboring cells (donors), in order to accommodate new calls. A channel can be borrowed, if the borrowed channel does not interfere with existing calls. When it is borrowed, several other cells are prohibited from using it. This is called channel locking.

3.2.4 Sub-Rating Schemes

The concept of a channel sub-rating scheme has been proposed by Lin et al. [41]. In this scheme, certain channels are allowed to be temporarily divided into two channels at half the original rate to accommodate handoff calls. By doing this, one half can be used to serve the existing connection and the other half to serve the handoff request so that the forced termination of calls can be virtually eliminated. It should be noticed that the channel sub-rating scheme is activated only if all the channels are occupied at the moment of a handoff request arrival. When a sub-rated channel is released, it is transferred into an original full-rated channel by being combined with another sub-rated channel. The channel sub-rating scheme can degrade the QoS, but minimizes the blocking probabilities, the forced termination probability for handoff calls, and the delay.

In addition, the adaptive handoff priority scheme [42] has been tailored for the requirements of multimedia services. This scheme provides two classes of services: the wideband class and the narrowband class. The narrowband class always requires the use of one channel, while the wideband class normally requires the use of two channels, but it can tolerate a lower QoS level with the use of only one channel to accommodate more calls in an overloaded system. Calls belonging to both classes are only accepted if the call can secure the full bandwidth requirements. If a new call cannot obtain full bandwidth, it is blocked. The adaptive handoff priority scheme proved more flexible and efficient in guaranteeing QoS than the guard channel scheme. However, this can be achieved by increased signaling overhead in order to indicate the bandwidth requirements of a connection.

3.2.5 Genetic Schemes

The genetic algorithms scheme (GAS) was introduced by Yener et al. [43]. This scheme uses genetic algorithms in order to assign the channels by local state-based call admission double-threshold policies. Yener et al. also proved that for large communication systems the GAS finds better admission policies compared with other well-known methods of handoff reservation. However, the time needed to assign channels for the GAS scheme is the main drawback of this scheme.

3.2.6 Hybrid Schemes

Hybrid handoff schemes (HHS) are combinations of channel reservation, handoff queuing, channel transferred, genetic and subrating schemes [44–51]. The key idea is to combine the different prioritization policies in order to further decrease the blocking probabilities or to improve the channel utilization. Several hybrid schemes may be found in the literature, i.e. the state-dependent rejection scheme (SRS) [44], a queuing priority channel reservation scheme for integrated real-time and non-real-time service wireless mobile networks, based on the complete sharing policy [45] and based on the complete partitioning policy [46], a queuing priority channel reservation scheme that combines the channel partitioning and the channel borrowing policy [47], a combination of a cut-off and a channel carrying policy [48], a more general handoff priority scheme, the general channel allocation scheme (GCAS) that combines the idea of a guard channel, static queuing and the sub-rating scheme [49], a non-preemptive priority handoff queuing scheme for a multi traffic wireless network that supports three types of traffic [50] and its extension of this scheme, where handoff request calls with higher priority may preempt other handoff request calls with lower priority [51].

4. The System Model

Future wireless networks will provide new and improved e-health services, which impose stringent QoS demands. Efficient resource management is a key feature in QoS provisioning in a wireless Telemedicine Environment. Scarce radio bandwidth, in conjunction with increased throughput requirement, lead to considerable limitations of the wireless interface. Resource allocation techniques are being developed to distribute the limited available bandwidth to different mobile e-health applications. Therefore, one of the challenges is how to efficiently allocate the limited radio resources among the multiple traffic type, while providing at the same time acceptable QoS and taking into account the emergency nature of each type of e-health application. In this paper, considering the emergency nature, we distinguish three classes of applications.

- *Emergency Response Applications* (Highest Priority): This category refers to emergency response situations, such a patient's transmission to a hospital, or delivery of immediate notifications on changes in patient status, such as respiratory failure or cardiac arrest. In the emergency response applications, the immediate delivery of data is a critical issue.

- *Non-Emergency–Real-time Applications* (Medium Priority): This category involves non-emergency–real-time applications, where the delay and the jitter of data transmission should be minimized.

- *Non-Emergency–Non-real-time Applications* (Lowest Priority): This category involves non-emergency–non-real-time applications, which include monitoring of patients with chronic conditions or children with intermediate intensity health care needs. It requires reliable delivery of monitoring messages. The size of the delivered information is small and the delivery of information is usually performed on a regular basis.

4.1 The System Model Description

The considered system model consists of a single cell and a number of wireless users that roam within the cell. The cell may serve the users by allocating a number of channels to them. The number of channels allocated to user i is denoted as c_i. The total number of channels in the cell is predetermined, and denoted as C. Since every channel may be allocated to only one user at a time, then, the sum of the channels allocated to every user must be less or equal to the total number of channels in the cell, or

$$\sum_i c_i \leq C. \tag{1}$$

The users may generate connections that are divided into three priority classes. Every priority class is characterized by the inter-arrival time, which is a random variable with a known distribution, and expresses the elapsed time from one connection generation, until another connection is generated, belonging to the same priority class. The generated connection may or may not be admitted to the system, as a result of the policy management strategy. If the connection is not admitted, then it is blocked. Depending on the priority class, each admitted connection requests a maximum number of channels that may or may not or partially be allocated to the user, depending on the policy management strategy used. As new connections are admitted, or existing connections are completed, the number of channels allocated to each user may change. However, the number of allocated channels by a user can never be lower than the minimum number of channels of the corresponding connection's priority class.

Every generated connection is characterized by its duration, expressed in bytes. This duration is also a random variable, with a known distribution. When c_i channels are allocated to a user, i, then the remaining bytes B_i for the user i are reduced at a rate of $\mathrm{d}B_i/\mathrm{d}t = c_i(t)R$, where R is the data rate of each channel. When the $B_i(t) = 0$, then the connection is completed, the allocated channels are released and the allocated channels of the existing connections are reallocated (re-assigned).

4.2 The Policy Management

The policy manager is the entity in the cell that decides if a connection is admitted or blocked, and how many chan-

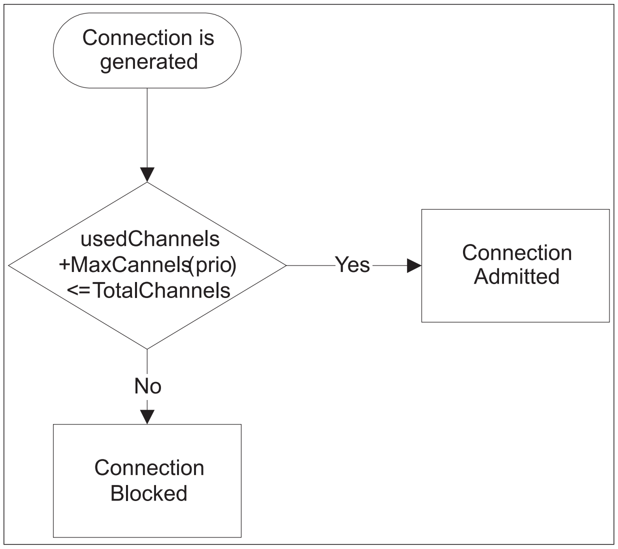

Figure 2. The “No degradation” policy management scheme

nels are allocated to every single user. In this research effort we consider and compare three different policy management schemes. The first scheme uses no prioritization and no degradation, the second scheme uses prioritization and no degradation, and the third scheme uses both degradation and prioritization.

4.2.1 No Degradation Policy Management

When a new connection is generated, the policy manager checks the number of the channels that are available (Figure 2). If the number of the available channels is larger than the one required by the priority class, then the connection is admitted, otherwise the connection is blocked. This policy management scheme does not differentiate among the flows.

4.2.2 The Prioritization Policy Management

The second policy management scheme, depicted in Figure 3, incorporates only prioritization, but no degradation. When a new call arrives, if there are not enough available channels for admitting the connection, then some extra channels are set free by pausing some lower priority connections. When a connection is paused, then no channels are allocated, and the remaining data for transmission do not decrease. When a connection is completed, and some channels are made available, then some of the paused connections are restored, allowing the completion of the connection. This strategy reduces the blocking probability of the higher priority class connections, but causes very large delay times in the transmission of the lower priority class connections.

4.2.3 The Degradation Policy Management

The third policy management scheme proposed is the “degradation” policy management scheme (Figure 4). In this scheme, instead of pausing the lower priority class connections, the allocated channels for these connections are reduced. These borrowed channels are used for admitting higher priority class connections. However, the delay times can be retained at a minimum, by setting a minimum number of channels for each priority class. Thus, this scheme can achieve a low blocking probability rate, especially for the highest priority class, while at the same time maintaining the delay of the lower priority classes at a reasonable level.

- The highest priority class could possibly incorporate life-threatening conditions, which would ideally have a very low blocking probability. Furthermore, this priority should have the desired bandwidth, if this is possible. The quality of service may be degraded only if this prevents other connections of the highest priority being dropped, and only up to a lowest acceptable level.
- The medium priority class could possibly represent real time e-health applications, which are not life-critical. These cases are treated at a lower priority than the highest priority. Thus, a higher blocking probability can be acceptable, and the quality of this class can be degraded in order to help the highest class connections to be admitted.
- The low priority class could represent non-real time e-health applications, which are served only when the resources are not required by the other classes.

5. The Simulation Scenario

The effectiveness of the proposed architecture was evaluated through simulations. The topology of the network consists of a base station and numerous wireless nodes that roam in the topology. The wireless nodes may generate telemedicine traffic of three classes and the simulation parameters are shown in Table 1. For these configuration parameters, the three policy management schemes, described in the previous section, were applied. The policy management schemes were tested in varying conditions, from not congested, to very congested, according to the *Normalized inter-arrival time* (λ). This value is proportional to the arrival rates of the three classes, where the inter-arrival time for classes 1, 2 and 3 are set to be $\lambda/3$, $\lambda/5$ and $\lambda/10$, respectively. All the connections are generated following a Poisson distribution for each class separately. All connections have an exponentially distributed duration, regardless of their class. The network chrematistics (number of mobile nodes, packet size (bytes), bandwidth per channel (kbps), and number of channels) are

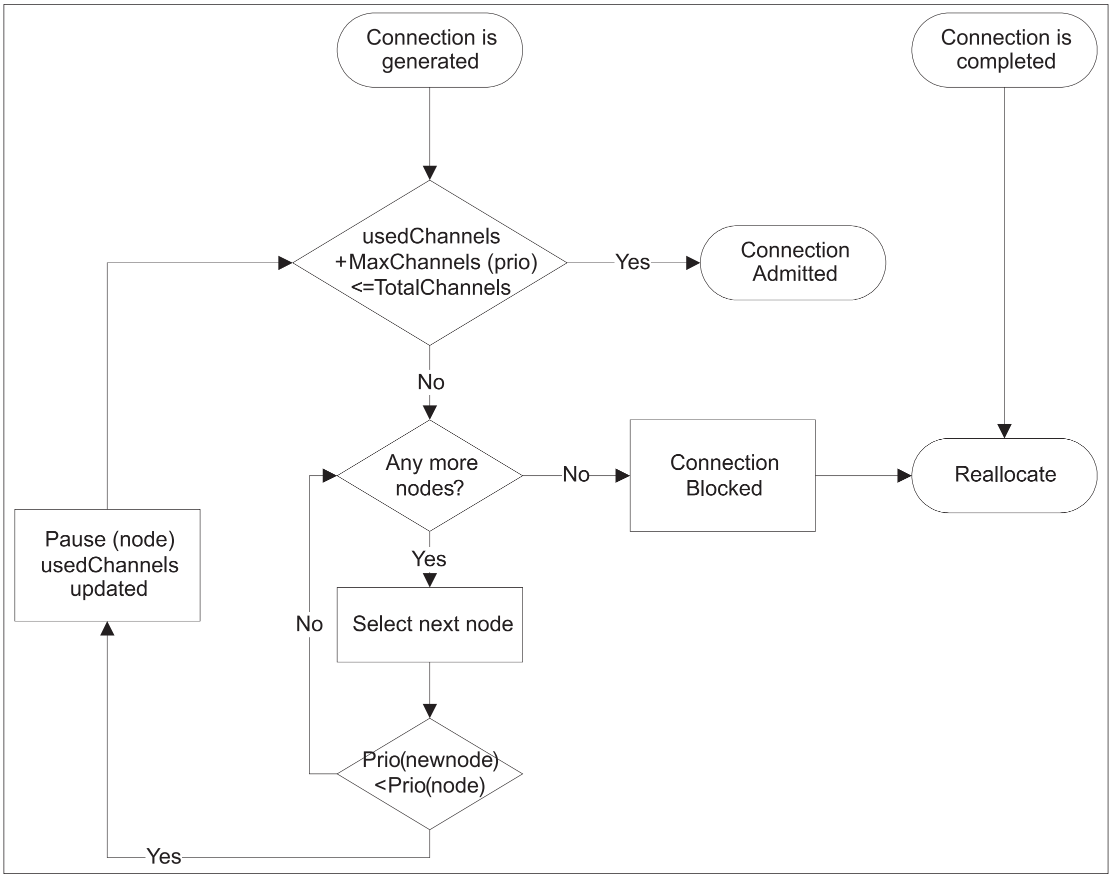

Figure 3. The prioritization policy management scheme. Prioritization is applied by pausing the lower priority classes, in order to admit the higher priority classes. No Degradation is applied.

summarized in Table I. The simulation duration was set at 20 000 s, for which the results seem to have converged. Finally, the maximum and minimum channels that can be allocated to each class, is also shown in Table 1.

The simulations were executed using "*Network Simulator 2*" [53]. A *policy manager* class was implanted in Tcl, which incorporated the channel allocation functions, described in the previous section. This channel allocation was realized directly at the application layer, where the number of allocated channels at each node reflected the cbr traffic generation rate. In addition, a specific traffic generator was created, that produced the desired three-class Poisson arrival distribution. The duration was set by specifying the number of bytes that should be generated.

5.1 Utilization Diagrams

For all three policy management schemes, the total utilization and the utilization of each class were calculated. Let $ch_i(t)$ denote the function describing the number of channels that node i allocates, at time t, and N denote the number of channels. The utilization of each class can be defined as the average percentage of channels used by connection of the specific class, or

$$U_c = \sum_{i \in c} ch_i\,(t)\,\mathrm{d}t/N. \tag{2}$$

On the other hand, the total utilization can be defined as

$$U = \sum ch_i\,(t)\,\mathrm{d}t/N = \sum U_c. \tag{3}$$

The total utilization is the average percentage of channels that are in use. If a policy management scheme features a utilization that is far from 1, and at the same time exhibits a blocking probability, then some network resources are wasted. Thus, the total utilization can be used as a metric to determine the network's efficiency. On the other hand, the utilization of each class shows which traffic class dominates the system. When one class's utilization is close to the total utilization, then this class is the dominant class in the network.

The utilization measured for the first policy management scheme (neither prioritization, nor degradation

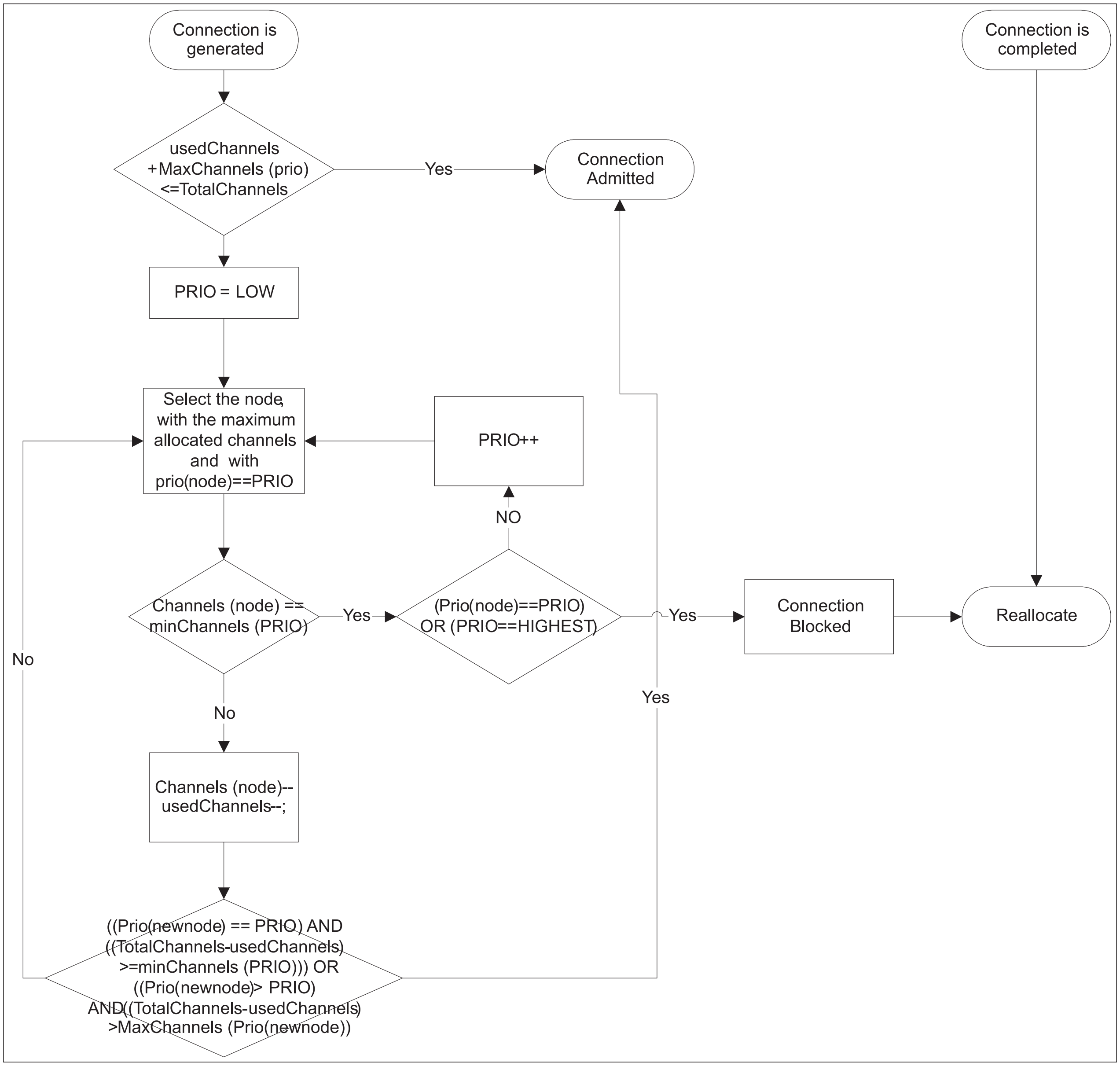

Figure 4. The degradation policy management scheme

schemes are applied) is depicted in Figure 5. Figure 6 depicts the utilization when only prioritization is applied, and Figure 7 depicts the utilization when both prioritization and degradation schemes are applied. The effect of the prioritization scheme is evident, as there is a clear distinction between the utilization of each class, with the higher priority classes attaining the majority of the bandwidth. Furthermore, the degradation scheme not only improves the total utilization, but also causes a clearer distinction among the bandwidth that is allocated at each class.

5.2 Call Blocking Probability Diagrams

The call blocking probability is an important network performance parameter, since it is an index of the network's availability. The call blocking probability of each class is defined as the percentage of the attempted connections in a class that actually pass the call admission control scheme, and manage to get served by the network. The call blocking probability is a critical factor of the medical network, since a blocked high priority call, may prevent the salvage of the lives of critical patients. In case of the

Table 1. The simulation parameters

Attribute	Value
Normalized interarrival time (λ)	0.1–2 s^{-1} (22 simulation rounds)
Class 1 interarrival time	$\lambda/3$
Class 2 interarrival time	$\lambda/5$
Class 3 interarrival time	$\lambda/10$
Interarrival time distribution	Exponential, for each class separately
Expected call duration ($1/\mu$) (s)	1000 (all classes)
Call duration distribution	Exponential
Number of mobile nodes	50
Simulation duration (s)	20000
Packet size (bytes)	1000
Bandwidth per channel (kbps)	100
Number of channels	30
Maximum channels per class 1 connection	4
Maximum channels per class 2 connection	3
Maximum channels per class 3 connection	2
Minimum channels per class 1 connection	1
Minimum channels per class 2 connection	0
Minimum channels per class 3 connection	0

degradation scheme, this metric counts all accepted calls, even if it does not allocate all the requested channels.

The total locking probability is the percentage of the attempted connections that are admitted. If a policy management scheme features a utilization that is far from 0, and at the same time exhibits utilization smaller than 1, then some network resources are wasted. Thus, the total blocking probability can be used as a metric to determine the network's efficiency. On the other hand, the blocking probability of each class shows which traffic class has the highest availability. When one class's blocking probability is close to 0, then this class is highly available, and can be used for serving urgent cases.

The blocking probability measured for the first policy management scheme is depicted in Figure 8. Figure 9 depicts the blocking probability when only prioritization is applied, and Figure 10 depicts the blocking probability when both prioritization and degradation schemes are applied. The affect of the prioritization scheme is evident, as there is a clear improvement in the blocking probability of the high priority class, whereas the other two classes exhibit worse service. However, the high priority class still exhibits significant blocking probability. The degradation scheme not only improves the total blocking probability, but also causes a clearer distinction among the availability of each class. The high priority class calls are blocked only after they have dominated all the bandwidth in the network.

5.3 Average delay

The average delay is an important network performance parameter, since it is an index of the network's service quality that users experience. If the duration of each connection is defined as the time difference from the moment that the call is admitted until it is completed, then the average delay of each class is defined as the average delay of every connection of the specific class. The average delay is a critical factor of the medical network, since there are many cases in which a communication should be timely in order to save the life of critical patients. In the case of the prioritization scheme, the average delay is high, because it incorporates the time during which the nodes remain paused, waiting for a free channel, in order to resume the transmission of their data. In case of the degradation scheme, this metric also increases, as channels are removed from some connections.

The average delay of each class can be used as a metric to determine each class quality. When one class average delay is very large, then this class is served poorly. Thus, the high priority class must have a low average delay, so that the service can be completed.

The average delay measured for the first policy management scheme is depicted in Figure 11. Figure 12 depicts the average delay when only prioritization is applied, and Figure 13 depicts the average delay when both prioritization and degradation schemes are applied. The effect of the prioritization scheme is evident, as average delay times are significantly larger than those in the first case, especially when regarding the lowest-traffic class.

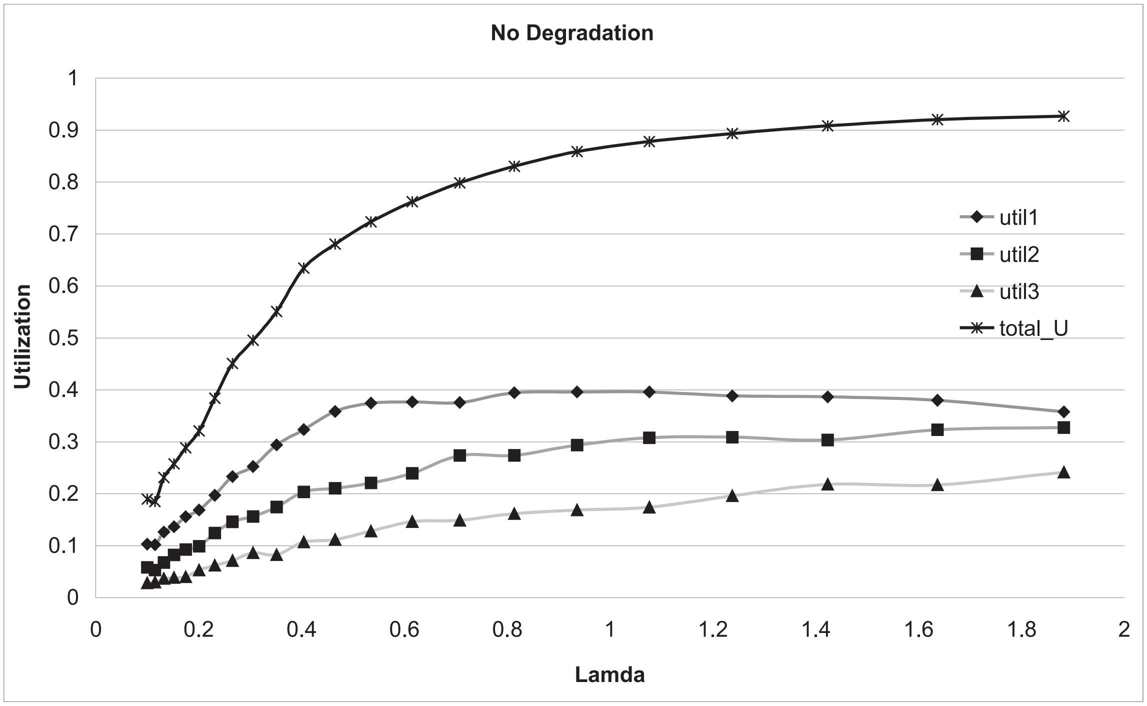

Figure 5. It depicts the utilization of each class (util1, util2, util3) as well as the total utilization (total_U) as a function of the normalized arrival rate, when neither prioritization nor degradation schemes are applied

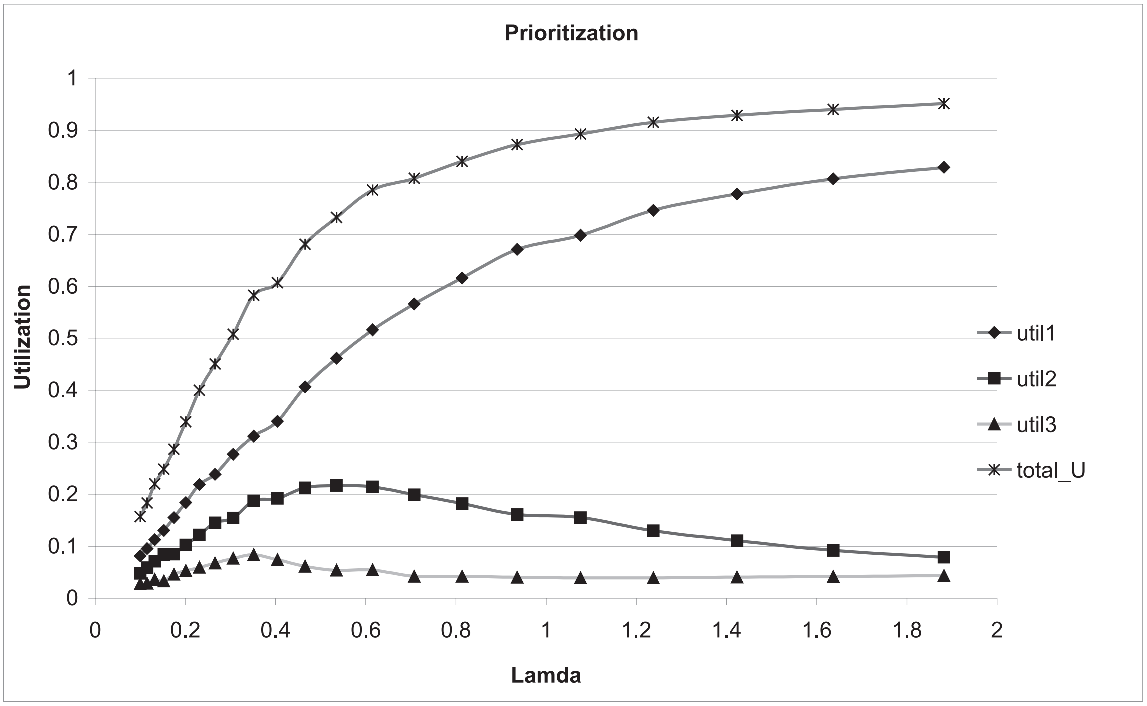

Figure 6. It depicts the utilization (util1, util2, util3) of each class, as well as the total utilization (total_U) as a function of the normalized arrival rate, when only prioritization and no degradation schemes are applied

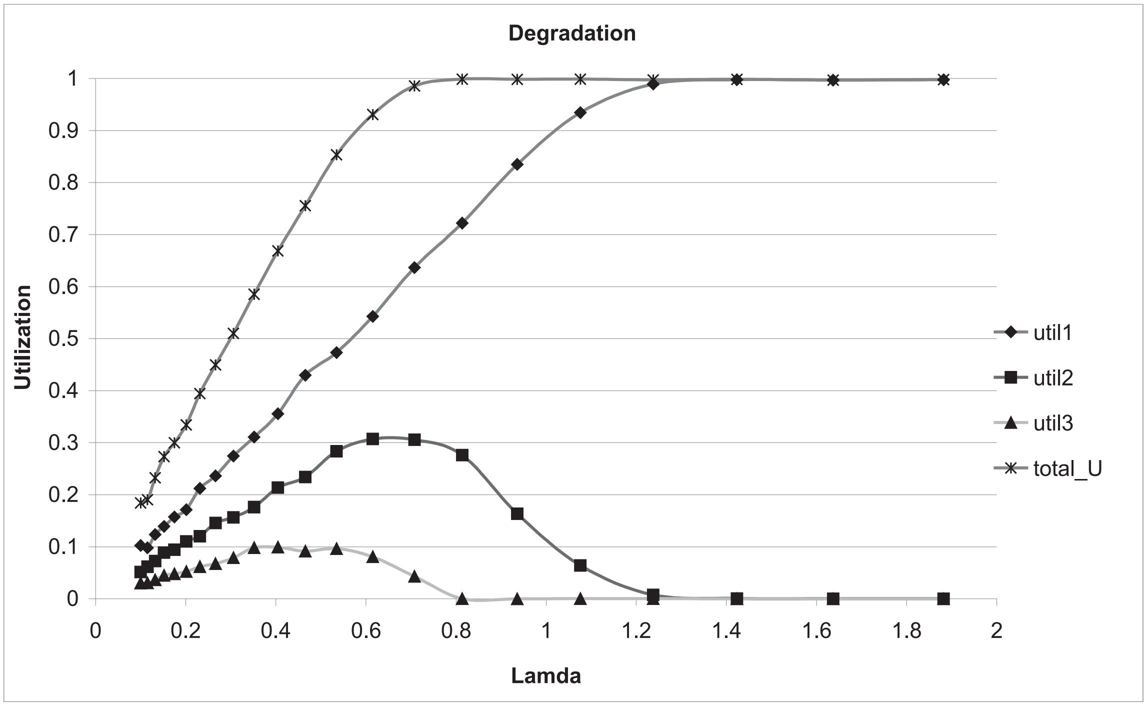

Figure 7. It depicts the utilization of each class (util1, util2, util3) as well as the average utilization (total_U) as a function of the normalized arrival rate, when both prioritization and degradation schemes are applied

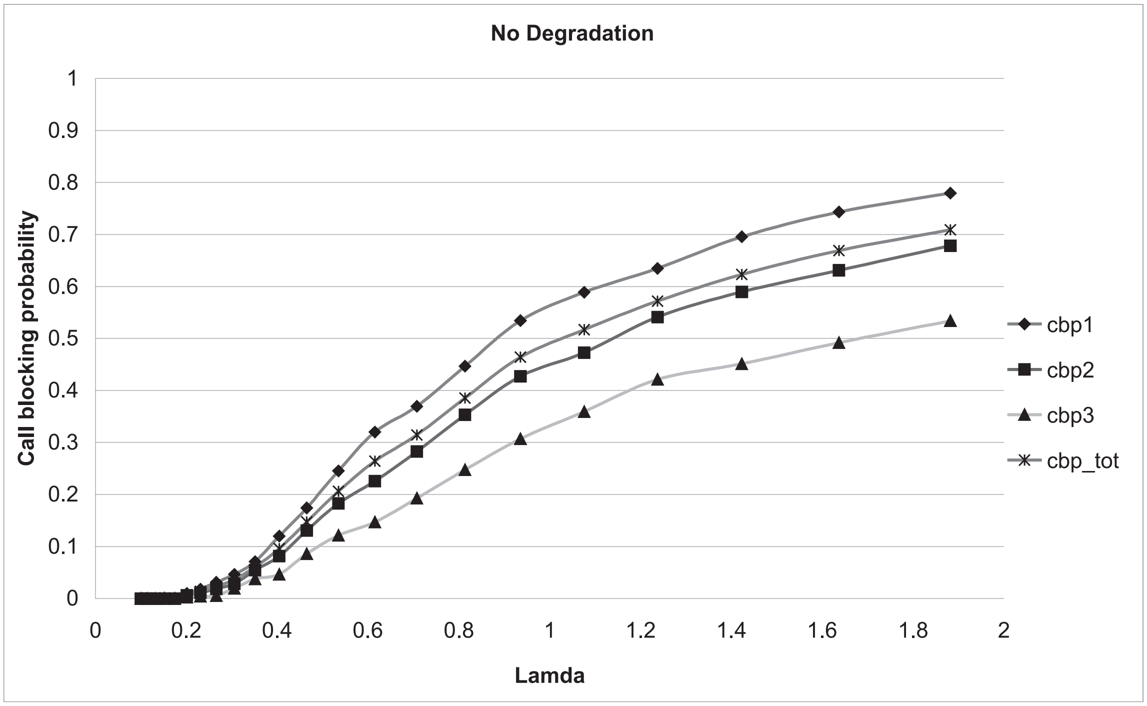

Figure 8. It depicts the call blocking probability of each class (cbp1, cbp2, cbp3) versus the call rate, as well as the average class blocking probability (cbp_tot) as a function of the normalized arrival rate, when neither prioritization nor degradation schemes are applied

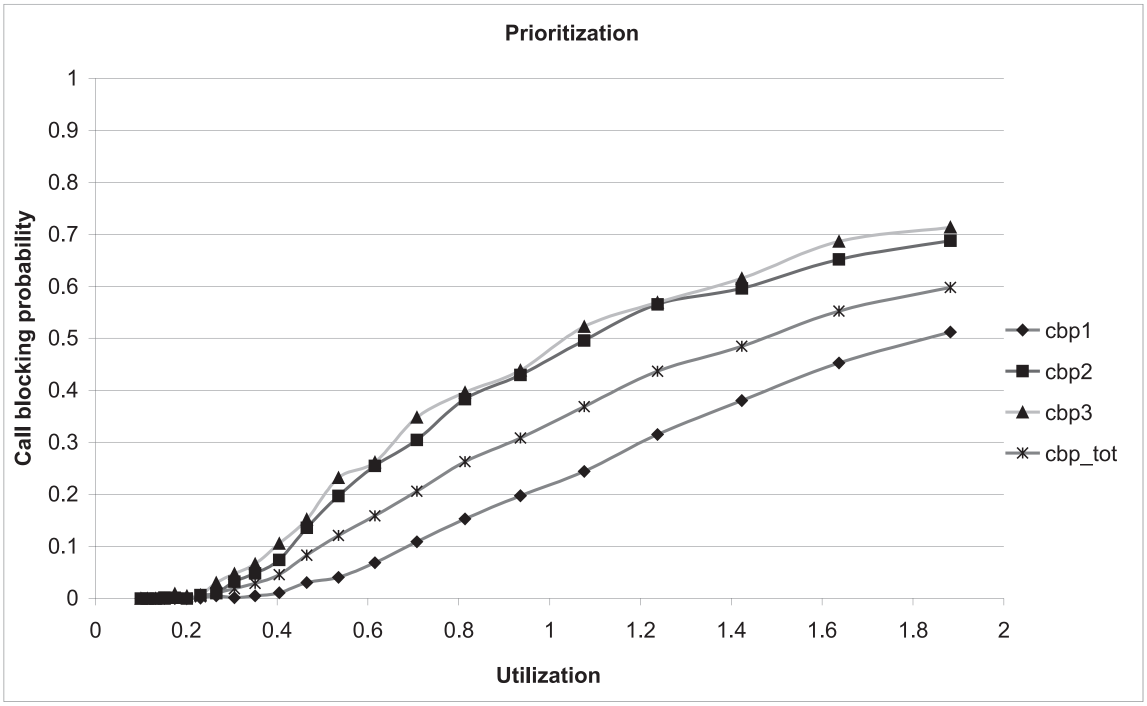

Figure 9. It depicts the call blocking probability of each class (cbp1, cbp2, cbp3) versus the call rate, as well as the average class blocking probability (cbp_tot) as a function of the normalized arrival rate, when only prioritization and no degradation schemes are applied

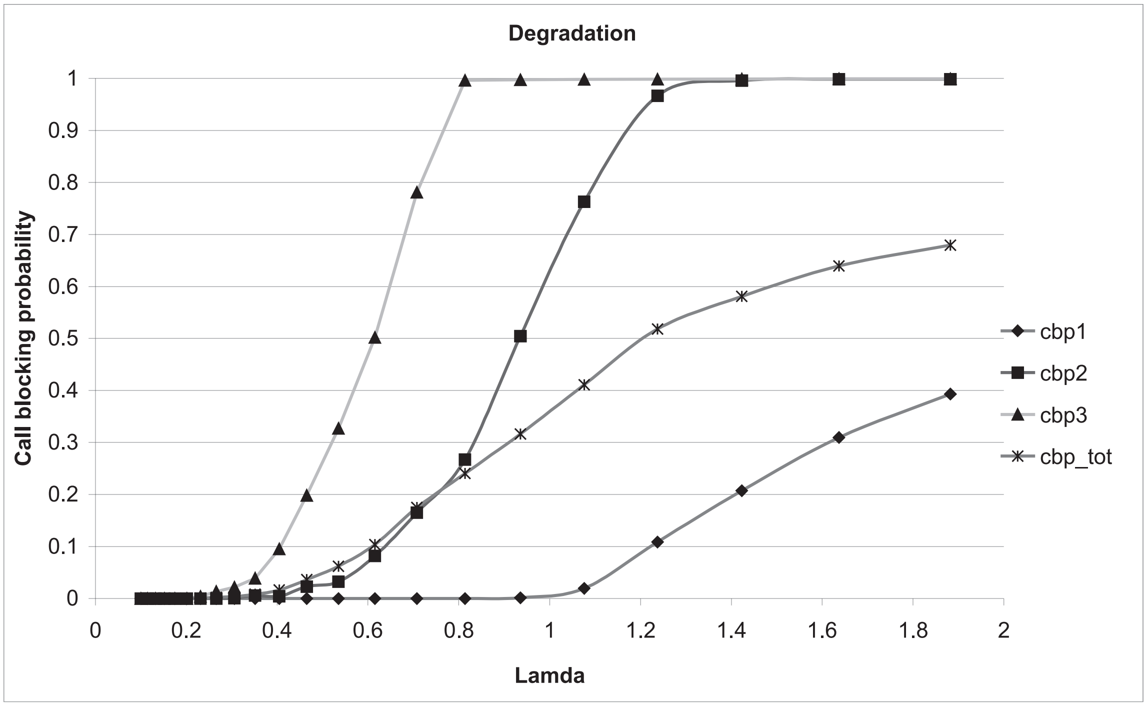

Figure 10. It depicts the call blocking probability of each class (cbp1, cbp2, cbp3) versus the call rate, as well as the average class blocking probability (cbp_tot) as a function of the normalized arrival rate, when both prioritization and degradation schemes are applied

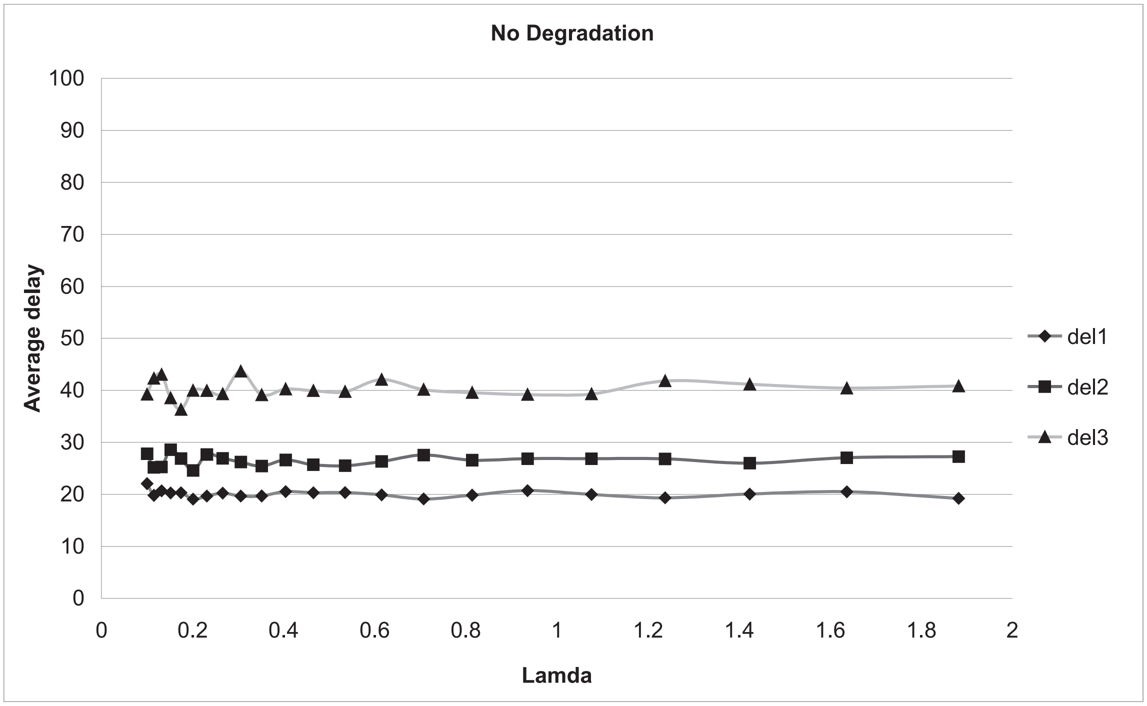

Figure 11. It depicts the average delay of each class (del1, del2, del3) as a function of the normalized arrival rate, when neither prioritization nor degradation schemes are applied

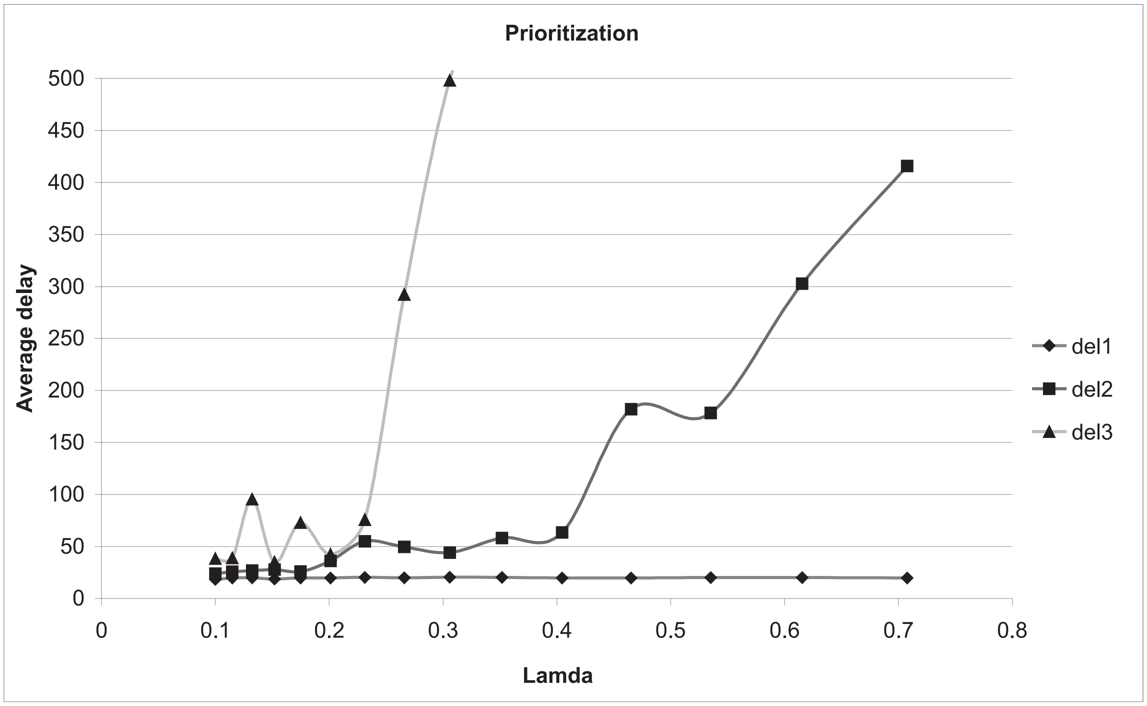

Figure 12. It depicts the average delay of each class (del1, del2, del3) as a function of the normalized arrival rate, when only prioritization and no degradation schemes are applied

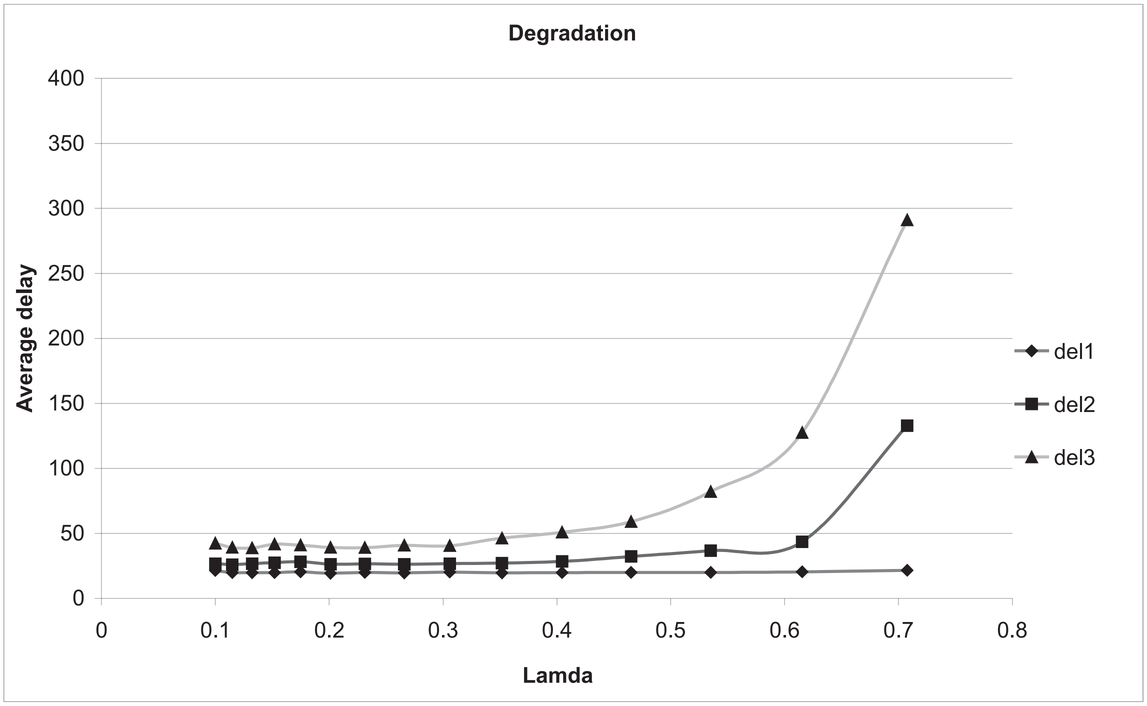

Figure 13. It depicts the average delay of each class (del1, del2, del3) as a function of the normalized arrival rate, when both prioritization and degradation schemes are applied

The high priority users experience very low average delay times. Even though the degradation scheme exhibits higher delays than the first scheme for the two lower priority classes, the delays are still much smaller than those in the second case. The first priority class delay is not affected by the policy management scheme used.

5.4 Discussion

As a result of the above performance evaluation, we have observed that the prioritization scheme shows a relative improvement of the differentiation among the utilizations and the blocking probabilities of the three schemes. However, the high priority class still exhibits a significant blocking probability, and the average delay is extremely large. On the other hand, the utilization of the third scheme is better than the other two. The blocking probability of the high class is as low as possible, and the average delay of the low classes remains low. As the arrival rate increases, the information rate is greater than the rate that can be served, and thus the incoming traffic causes congestion. As it was shown, after the policy management schemes have been applied, the high priority connections experienced lower delays and low packet loss, just as if there was no congestion in the network, and present much better performance than the lower ones. This improvement comes at a cost for the low priority connections that are either delayed or dropped. At medium incoming traffic rates, despite the low priority class's degradation in average delay and blocking probability, the medium priority class is still served at a good level. The medium priority class is only affected when the incoming traffic is so large, that the entire bandwidth is used by the highest priority class, causing degradation for both the lower classes. This will definitely cause the low priority medical applications that rely on specific network traffic characteristics either to operate at an unacceptable level, or to cut off the operation. However, the advantage in helping the urgent cases receive an acceptable quality of service, and the consequent salvage of human lives can be viewed as an important advantage of the proposed system. Therefore, the degradation scheme presents a very good behavior for serving emergency medical traffic.

6. Conclusions

Telecommunications and advanced information technologies have been increasingly used for clinical activities and research to improve healthcare delivery. Telemedicine services are usually based on multimedia technologies and they are expected to support multiple and diverse clinical applications over different network topologies. Such heterogeneous environments require that different applications should be provided with different QoS requirements to accommodate their distinct service types. This work presents a novel architecture for multi-class QoS provisioning in telemedicine using wireless technology. Resource allocation schemes for e-health services networks, aiming to provide compound QoS classes correspond to different e-health applications for high requirement services. Different classes, such as expedited forwarding, assured forwarding and best effort are supported, and resources are allocated to provide an optimal solution for each e-health application. In wireless health information systems, this process follows a logical order by determining firstly the available resources in the network, then analyzing the type, volume and QoS requirements of the information to be transferred, and finally by tuning the applications that the network will support.

Therefore, we propose an adaptive resource allocation for a wireless network with multiple service types and multiple priorities. Prioritization is essential in a multi traffic environment for the provision of an acceptable QoS level to the users. Moreover, in order to decrease the blocking call probabilities bandwidth and to increase the system's overall performance, degradation and upgrade policies have been considered. The simulation results validate the good performance of the proposed scheme. The proposed wireless network can handle both normal and life-critical medical applications that are characterized by their urgency nature. Assigning different priority levels according to the specific medical application requirements, and according to the urgency of the medical incident, it causes the network to intelligently drop and/or delay the packets, in order to achieve a high service level in a wireless healthcare environment.

7. References

[1] Arnold, J. L., et al. 2004. Information-sharing in out-of-hospital disaster response: the future role of information technology. *Journal of Prehospital and Disaster Medicine* 19(3):201–207.

[2] Shimizu, K. 1999. Telemedicine by mobile communication. *IEEE Engineering in Medicine and Biology Magazine* 18(4):32–44.

[3] Vergados, D. J., D. D. Vergados, and I. Maglogiannis. 2006. Applying wireless diffserv for QoS Provisioning in mobile emergency telemedicine. In *Proceedings of the IEEE Global Telecommunications Conference, (GLOBECOM '06)*, San Francisco, USA, pp. 1–5.

[4] Vergados, D. D., et al. 2006. Decision support algorithms and optimization techniques for personal homecare environment. In *Proceedings of the IEEE International Special Topic Conference on Information Technology in Biomedicine (ITAB 2006)*, Ioannina, Greece.

[5] Vergados, D. D., A, Sgora, I, Maglogiannis, and I, Anagnostopoulos. 2005. Channel allocation handoff schemes for cellular wireless networks: an overview. In *Proceedings of the 5th International Network Conference (INC 2005)*, Samos, Greece, pp. 425–432.

[6] Kyriacou, E., et al. 2003. Multi-purpose healthcare telemedicine systems with mobile communication link support. *Healthcare Engineering OnLine* 2(7).

[7] Maglogiannis, I. 2004. Design and implementation of a calibrated store and forward imaging system for teledermatology. *Journal of Medical Systems* 28(5):455–467.

[8] Pattichis, C. S., E. Kyriacou, S. Voskarides, M.S. Pattichis, R. Istepanian, and C.N. Schizas. 2002. Wireless telemedicine systems: an overview. *IEEE Antennas & Propagation Magazine* 44(2):143–153.

[9] Salvador, C. H., et al. 2005. Airmed-cardio: a GSM and Internet services-based system for out-of-hospital follow-up of cardiac patients. *IEEE Transactions on Information Technology in Biomedicine* 9(1):73–85.

[10] Rialle, V., J. B. Lamy, N. Noury, and L. Bajolle. 2003. Telemonitoring of patients at home: a software approach. *Computer Methods and Programs in Biomedicine* 72(3):257–268.

[11] Lin, Y., I. Jan, P. Ko, Y. Chen, J. Wong, and G. Jan. 2004. A wireless PDA-based physiological monitoring system for patient transport. *IEEE Transactions on Information Technology in Biomedicine* 8(4):439–447.

[12] Lee, D.-S., and Y.-H. Hsueh. 2004. Bandwidth-reservation scheme based on road information for next-generation cellular networks. *IEEE Transactions on Vehicular Technology* 53(1):243–252.

[13] Hu, F., and Kumar, S. 2006. The integration of ad hoc sensor and cellular networks for multi-class data transmission. *Ad Hoc Networks* 4(2):254–282.

[14] Engin, M. Y. Yamaner, and E. Z. Engin. 2005. A biotelemetric system for human ECG measurements. *Measurement* 38(2):148–153.

[15] Maglaveras, N., et al. 2002. Home care delivery through the mobile telecommunications platform: the Citizen Health System (CHS) perspective. *International Journal of Medical Informatics* 68(1–3):99–111.

[16] LaMonte, M. P., et al. 2004. Shortening time to stroke treatment using ambulance telemedicine: TeleBAT. *Journal of Stroke and Cerebrovascular Diseases* 13(4):148–154.

[17] Martínez, I., J. Salvador, J. Fernández, and J. García. 2003. Traffic requirements evaluation for a telemedicine network. In *Proceedings of the International Congress on Computational Bioengineering*, Spain.

[18] Hu, F., and Kumar, S. 2003. QoS considerations in wireless sensor networks for telemedicine. In *Proceedings of SPIE ITCOM Conference*, Orlando, FL.

[19] Dudzik P., M. Schöttner, A. Kassler, A. Lupper, and P. Schulthess. 1998. Wireless ATM as a base for medical multimedia applications and telemedicine. In *Proceedings of Computer Systems and Applications – CSA'98*, Irbid, Jordan.

[20] Tripathi, N. S., et al. 1998. Handoff in cellular systems. *IEEE Personal Communications* 5(6):26–37.

[21] Lin, Y. B., et al. 1994. Queueing priority channel assignment strategies for PCS handoff and initial access. *IEEE Transactions on Vehicular Technology* 43(2):704–712.

[22] Sidi, M., and D. Starobiniski. 1997. New call blocking versus handoff blocking in cellular networks. *ACM Journal of Wireless Networks* 3(1):15–27.

[23] Diederich, J., and M. Zitterbart. 2005. Handoff prioritization schemes using early blocking. *IEEE Communications Surveys* 7(2):26–45.

[24] Katzela, I., and M. Naghshineh. 1996. Channel assignment schemes for cellular mobile telecommunication systems: a comprehensive survey. *IEEE Personal Communications Magazine* 3(3):10–31.

[25] Chen, H., Q.-A. Zeng, and D. P. Agrawal. 2002. A novel analytical modeling for optimal channel partitioning in the next generation integrated wireless and mobile networks. In *Proceedings of the 5th ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems (MSWiM '02)*, Atlanta, Georgia, pp. 120–127.

[26] Guerin, R. 1988. Queueing- blocking system with two arrival streams and guard channels. *IEEE Transactions on Communications* 36(2):153–163.

[27] Kulavaratharasah, M. D., and A. H. Aghvami. 1999. Teletraffic performance evaluation of microcellular personal communication networks (PCNs) with prioritized handoff procedures. *IEEE Transactions on Vehicular Technology* 48(1):137–152.

[28] Ramjee, R., et al. 1997. On optimal call admission control in cellular networks. *Wireless Networks* 3(1):29–41.

[29] Heredia-Ureta, H., et al. 2003. Capacity optimization in multiservice mobile wireless networks with multiple fractional channel reservation. *IEEE Transactions on Vehicular Technology* 52(6):137–152.

[30] Oliveira, C., et al. 1998. An adaptive bandwidth reservation scheme for high-speed multimedia wireless networks. *IEEE Journal on Selected Areas in Communications* 16(6):858–874.

[31] Chang, J.-Y., and H.-L. Chen. 2003. Dynamic-grouping bandwidth reservation scheme for multimedia wireless networks. *IEEE on Selected Areas in Communications* 21(10):1566–1574.

[32] Chiu, M. H., et. al. 2000. Predictive schemes for handoff prioritization in cellular networks based on mobile positioning. *IEEE Journal on Selected Areas in Communications* 18(3):510–522.

[33] Chiu, M. H., et al. 1999. Predictive channel reservation for mobile cellular networks based on GPS measurements. In *Proceedings of the IEEE International Conference on Personal Wireless Communication*, pp. 441–445.

[34] Hong, D., and S. S. Rappaport. 1986. Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and non-prioritized handoff procedures. *IEEE Transactions on Vehicular Technology* 35(3):77–92.

[35] Zeng, Q.-A., and D. P. Agrawal. 2002. Modeling and efficient handling of handoffs in integrated wireless mobile networks. *IEEE Transactions on Vehicular Technology* 51(6):1469–1478.

[36] Rappaport, S. S. 1991. The multiple-cell handoff problem in high-capacity communication systems. *IEEE Transactions on Vehicular Technology* 40(4):546–557.

[37] Stojmenović, I. 2002. *Handbook of Wireless and Mobile Computing*. John Wiley & Sons.

[38] S. Tekinay and B. Jabbari. 1992. A measurement-based prioritization scheme for handover in mobile cellular networks. *IEEE Journal on Selected Areas in Communications* 10(8):1343–1350.

[39] Li, J., et al. 1999. Channel carrying: a novel handoff scheme for mobile cellular networks. *IEEE/ACM Transactions on Networking* 7(1):38–50.

[40] Engel, J. S., and M. Petrisky. 1973. Statistically optimum dynamic server assignment in systems with interfering servers. *IEEE Transactions on Vehicular Technology* 22(4):203–209.

[41] Lin, B., et al. 1996. The subrate channel assignment strategy for PCS hand-offs. *IEEE Transactions on Vehicular Technology* 45(1):122–130.

[42] Zhuang, W., et al. 2000. Adaptive quality of service handoff priority scheme for mobile multimedia networks. *IEEE Transactions on Vehicular Technology* 49(2):494–505.

[43] Yener, A., and C. Rose. 1997. Genetic algorithm applied to cellular call admission: local policies. *IEEE Transactions on Vehicular Technology* 46(1):72–79.

[44] Barceló, F. 2004. Performance analysis of handoff resource allocation strategies through the state-dependent rejection scheme. *IEEE Transactions on Wireless Communications* 3(3):900–909.

[45] Zeng, Q.-A., and D. P. Agrawal. 2002. Modeling and efficient handling of handoffs in integrated wireless mobile networks. *IEEE Transactions on Vehicular Technology* 51(6):1469–1478.

[46] Wang, J. Q.-A. Zeng, and D. P. Agrawal. 2003. Performance analysis of a preemptive and priority reservation handoff scheme for integrated service-based wireless mobile networks. *IEEE Transactions on Mobile Computing* 2(1):65–75.

[47] Li, W., H. Chen, and D. P. Agrawal. 2005. Performance analysis of handoff schemes with preemptive and nonpreemptive channel borrowing in integrated wireless cellular networks. *IEEE Transactions on Wireless Communications* 4(3):1222–1233.

[48] Jang, K.-W., and K.-J. Han. 2002. A channel assignment scheme for handoff in wireless mobile networks. *Lecture Notes in Computer Science*, Springer, Heidelberg, Vol. 2343, pp. 609-617.

[49] Li, W., Y. Fang, and R. R. Henry. 2002. Actual call connection time characterization for wireless mobile networks under a general channel allocation scheme. *iEEE Transactions on Wireless Communication*s 1(4):682–691.

[50] Vergados, D. D., and A. Sgora. 2005. Modeling and efficient handling of handoffs for multi service wireless networks. In *Proceedings of the 10th Panhellenic Conference on Informatics (PCI'05)*, Volos, Greece, pp. 363–372.

[51] Vergados, D. D., and A. Sgora. 2005. Performance analysis of a preemptive handoff scheme for multi-traffic wireless mobile network., In *Proceedings of the 10th IFIP International Conference on Personal Wireless Communications (PWC'05)*, Colmar, France, pp. 295–302.

[52] The Network Simulator (NS2). http://www.isi.edu/nsnam/ns/.

Dimitrios D. Vergados *was born in Athens, Greece in 1973. He is a Lecturer in the University of the Aegean, Department of Information and Communication Systems Engineering. He received his BSc in Physics from the University of Ioannina and his PhD in Integrated Communication Networks from the National Technical University of Athens, Department of Electrical and Computer Engineering. His research interests are in the area of Communication Networks (Wireless Broadband Networks, Sensor – Ad-hoc Networks, Military Networks, WLANs, IP, MIP, SONET), Neural Networks, GRID Technologies, and Computer Vision. He has participated in several projects funded by EU and National Agencies and has several publications in journals, books and conference proceedings. He is also Guest Editor and Reviewer in several Journals and he has served in technical program committees of several international conferences.*