Admission Control for QoS Support in Heterogeneous 4G Wireless Networks

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Abstract

Admission control plays a very important role in wireless systems, as it is one of the basic mechanisms for ensuring the quality of service offered to users. Based on the available network resources, it estimates the impact of adding or dropping a new session request. In both 2G and 3G systems, admission control refers to a single network. As we are moving towards heterogeneous wireless networks referred to as systems beyond 3G or 4G, admission control will need to deal with many heterogeneous networks and admit new sessions to a network that is most appropriate to supply the requested QoS. In this article we present the fundamentals of access-network-based admission control, an overview of the existing admission control algorithms for 2G and 3G networks, and finally give the design of a new admission control algorithm suitable for future 4G networks and specifically influenced by the objectives of the European WINNER project.

One of the most important radio resource management (RRM) mechanisms used in wireless networks is admission control (AC). AC algorithms are utilized to ensure that admission of a new flow into a resource constrained network does not violate the service level agreements guaranteed by the network to already admitted flows. The goal of an efficient admission control algorithm is to ensure the quality of service of the ongoing connections, while at the same time, to care for the optimal utilization of the available radio spectrum [1]. Admission control schemes are the decision making part of the networks aiming at providing users with services of guaranteed quality, something that leads also to reduced network congestion and call dropping probabilities and thus to more efficient resource utilization [2, 3].

There are several criteria AC algorithms use for accepting or rejecting a flow. Many algorithms are power-based, which means that they rely upon periodic measurements of the transmitted power, then they compute the interference at the user’s receiver and based on that they make the decision of admitting or rejecting the user [4, 6]. Other algorithms [1] monitor the load of the system against predefined thresholds, above which the network will be considered overloaded. In throughput-based algorithms [7] the throughput that can be delivered by the system is determined according to some dimensioning calculations, assuming the existence of certain conditions in the system. There are also algorithms [5] that use the equivalent capacity of aggregated traffic, which is an estimation of the arrival rate of a class of traffic. Finally there exist algorithms that focus on the bandwidth and delay constraints of each flow.

In mobile communications, admission control ought to consider not only the current cell where a call/session resides, but also the available resources in adjacent cells, because of the possibility that a session will need to perform a handover. In addition, in next-generation wireless networks, call admissions should be designed so that it can be performed across many co-located networks. Such a future network is the aim of the WINNER project, a European research initiative toward defining a new radio interface for covering the increasing requirements of mobile users [8]. Furthermore, WINNER will be able to interwork with all other networks in the same area. Then admission control should be executed not only in one network, but across multiple networks in a combined networking architecture. Thus, the admission control algorithm does not have to check only one network, but should find the best suitable uncongested one for the user by checking all the available networks operating in the user’s area.

Handovers in legacy networks usually receive lower priority than new sessions, and many priority-based schemes have been proposed [2] to address this issue. However, in future networks, the need for cooperation among various wireless networks of different nature (GSM, UMTS, WLANs, etc.) poses new challenges for admission control algorithms. In such an environment there is the need not only to monitor and control numerous parameters in parallel, but also to deal with the peculiarities of each access technology separately. Certain networks may not be able to support the quality of service (QoS) classes other networks do. Hence, we consider the possibility that QoS degradation/renegotiation might become one intrinsic element of the techniques used by call admission.

The remainder of this work is structured as follows. We give a short overview of the most important admission control algorithms for second-generation (2G) and 3G cellular radio access networks (RANs), as well as a review of some recent initiatives targeting heterogeneous networks. We present the design of a novel admission control algorithm for heterogeneous wireless access networks. Then we give a set of simula-
tion results as well as guidelines on how the proposed algorithm should be applied and fine-tuned. Finally, we present the conclusions of our work.

**Existing Admission Control Algorithms**

In this section we highlight some admission control algorithms that are related to and have inspired our approach. The Simple Sum algorithm presented in [1] is a very simple algorithm that ensures that the admittance of a new flow does not exceed the link’s bandwidth. The algorithm accepts a new flow if \( v + r_a < \mu \), where \( v \) is the sum of the already reserved rates, \( \mu \) is the link bandwidth and \( r_a \) is the rate of the flow \( \alpha \). The Measured Sum is an alternative approach to the Simple Sum algorithm [1]. It uses measurements to estimate the load of the network we want and is the rate requested by the flow \( \alpha \). The algorithm checks if the sum of the measured load of the existing traffic plus the rate of the new flow exceeds the target utilization of the link’s bandwidth; if not, it admits the new flow. If the flow exceeds the link’s bandwidth, the new flow is rejected.

A Load Based algorithm presented in [3] performs the following check in order to make its decisions \( \eta + \Delta L < \eta_{\text{threshold}} \) where \( \eta \) is the current load of the network, \( \Delta L \) is the load increase of the new flow, and \( \eta_{\text{threshold}} \) is the threshold of the load. The load increase is calculated by the following expression:

\[
\Delta L = \frac{1}{W} \left( 1 - \frac{1}{\varepsilon} \right) \left( \frac{E_o}{N_o} R \right)
\]

where \( W \) is the chip rate, \( R \) is the data rate of the new flow, and \( \varepsilon \) is the activity factor [9]. This call admission is applicable in cases where we attempt to determine the uplink load factor in a wideband code-division multiple access (WCDMA) system. In these cases, the load factor of a single user is calculated first, and then the other-to-own cell interference is taken into account by a factor \( i \) such that the “true” load is approximated by \( 1 + i \) over the sum of individual (single cell) user loads.

In [10] an admission control algorithm for heterogeneous networks is described. This algorithm focuses on the cooperation between existing networks, especially the cooperation between Universal Mobile Telecommunications System (UMTS) and wireless LAN (WLAN). The algorithm described in this article is a throughput-based algorithm. The decisions are taken at the RNC entity of UMTS, where the common admission control algorithm sends the users in either the UMTS or the WLAN taking into account only the available throughput of the networks. The RNC calculates the load values \( \eta_{\text{new}} \) of the new service, and after that it evaluates the load \( \eta_{\text{new}} \) on Node B. If \( \eta_{\text{new}} + \eta_{\text{UMTS}} \leq \eta_{\text{threshold}} \), the service is admitted to UMTS. Otherwise, the RNC evaluates load \( \eta_{\text{WLAN}} \) on the access point. If \( \eta_{\text{new}} + \eta_{\text{WLAN}} \leq \eta_{\text{threshold}} \), the service is admitted to WLAN. If this procedure fails, the service is blocked, and the user should try to request that service again.

In [11] another admission control scheme for heterogeneous wireless networks is provided. This algorithm is similar to the previous one but works with different priority criteria. Here we have a central entity that supervises the networks and makes the decisions on admission. This algorithm distinguishes the calls and sends data calls to WLAN, voice calls (and data calls when WLAN is congested) to UMTS, and when all these networks are congested, it sends all calls to General Packet Radio Service (GPRS).

From the above it is obvious that admission control in heterogeneous wireless networks is becoming increasingly important. In the next section we present and analyze an efficient AC algorithm for the cooperation of the WINNER network with legacy ones that could be adopted in other heterogeneous wireless networking environments as well.

**Admission Control in the Context of Future Heterogeneous Wireless Systems**

Next-generation wireless networks will be built on ubiquitous and converged network and service infrastructures. WINNER [8] is developing a new air interface that provides a seamless level of service across a coverage area similar to that achieved by UTRAN and GERAN systems deployed today. This covers rural areas and provides a contiguous coverage layer in towns and cities (wide area, WA), where it will overlap with metropolitan and local area (MA and LA) deployments. Another important target is to support the full range of mobility scenarios up to high-speed trains.

In order to ensure a high degree of satisfaction of user QoS requirements, a form of cooperation between WINNER and other RATs is required. A universal admission WINNER mechanism across all networks that operate in the same area is a key element in achieving their efficient cooperation. The main goal of the AC algorithm is to control the admission of new or handover sessions while maintaining the load of the network within some boundaries that do not disturb the QoS of any other sessions. The main function of an efficient AC algorithm for heterogeneous networks is to decide at a specific point in time if there is a network that has the available resources to serve (to satisfy the QoS requirements of) a new session [9]. The design of the AC algorithm must be made very carefully to minimize the following:

- **False rejections**, which occur when the algorithm rejects a session, although there is a network that can meet the session’s requirements. In this case capacity is wasted, and the operators’ revenues are not optimized.
- **False admissions**, which occur whenever the algorithm accepts a session although it turns out that the network did not have the available capacity for the session. In this case QoS guarantees are not provided, and user satisfaction is degraded.

The basic assumptions for admission control in heterogeneous wireless networking environments are the following:

- Coexisting RATs are to cooperate with each other.
- Mobile users can alternatively access different RATs during a call (intersystem handovers).
- Traffic will be routed through the cooperating systems according to the restrictions and advantages of each system.
- Different levels of service classes can be identified for users in terms of QoS and priority.
- Mobile users can alternatively access different RATs during a call (intersystem handovers).
- Radio access technology (RAT) may have to be handed off to another RAT.
- New calls and handover calls normally have to be treated differently in terms of resource allocation.
- Handover calls are normally assigned higher priority than new calls.
- Handover sessions should normally be treated differently than new sessions in terms of resource allocation, decision time (the session will be rejected if the admission decision time is getting long), queuing, and so on.

The terms **new session** and **handover session** in
future heterogeneous wireless networks are slightly different than in legacy networks and could be described as follows:

• A new session is a session request in a specific network that cannot be admitted in that network and is checked for whether another network (and which one) can meet the session requirements.

• A handover session is an ongoing session (it already has a vital connection with a network), and for some reason it needs to hand over to another network.

Future wireless networks will have to consider many service classes with different delay, throughput, and bit error rate (BER) characteristics in order to meet diverse user QoS requirements. The different service classes of the RANs are considered by the AC algorithm in terms of resource allocation and prioritization. Different service classes have different priorities in the algorithm. The criteria for each class's priority should be based on the characteristics and requirements of each class (delay sensitivity, bandwidth requirements, etc.). A class with high priority should be checked (admitted or rejected) before a low-priority class, although the low-priority class may arrive first, or a high-priority class could be admitted while a low-priority class is rejected [12]. Due to the nature of future service classes, there could be services that should have higher priority. For example, if a service class is defined in a network for "emergency calls" (i.e., calls directed to ambulances or the police after a car accident), these calls (which are new calls) should have higher priority than even handover calls.

We present a new AC algorithm design for future heterogeneous wireless systems that aims at ensuring good cooperation between heterogeneous network systems. We focus on cooperation between the WINNER system and legacy systems, such as GPRS, UMTS, and WLAN 802.11b. WINNER is a new wireless system developed by the IST project IST-2003-507581 WINNER [8]. As mentioned, the main objective of WINNER is to develop a single new ubiquitous radio access system concept whose parameters can be scaled or adapted to a comprehensive range of mobile communication environments from local area to wide area. WINNER is intent on filling the "gap" between legacy wireless systems, providing a uniform means of access while still cooperating with legacy networks. The presented AC algorithm ensures this cooperation by shifting traffic between WINNER and legacy RANs, always selecting the most suitable network for the user according to its requirements [13].

The admission control algorithm for future RANs aims to maximize the number of admitted or in-session traffic sessions supported over the RANs, while guaranteeing their QoS requirements and ensuring that a new session does not violate the QoS of ongoing sessions. The presented AC approach enables cooperation between WINNER and legacy RANs in order to provide users with the best possible QoS taking into account the possibility of admitting a user in another network if the current one is congested or unavailable or even unsuitable (in terms of service provision) for the user. The movement of users between networks is another key characteristic of our admission control, as it enables traffic balancing between networks in order to maximize their performance and the QoS provided to users.

Legacy networks usually use a single criterion in deciding whether to admit or reject a session. In the case of systems with multiple heterogeneous (including legacy) wireless networks, where different types of service classes are provided to users (in WINNER there are 18 different service classes defined for the users), the admission decision cannot be made based on a single criterion, since there are many important factors that have to be taken into account. Specifically, we consider the following criteria:

• Network load: The predicted load of the network after the admission of the new session is computed; if it remains under a certain threshold, the new session can be accepted; otherwise, it will be rejected. The load is not computed in the same way in all networks, and the algorithm takes into account the distinct characteristics of each network before performing the measurements.

• User's QoS requirements: QoS parameters such as mean throughput, bandwidth demands, service class, and priority of each session are taken into account to decide whether or not to admit the session.

• User's context: The algorithm normally gives priority to handover sessions, which require lower blocking probability than new sessions. There is an exception for emergency calls. Also, there is an option or grouping the users according to their subscription. For example, we may have classes of gold, silver, and bronze users who are assigned priorities in descending order (i.e., gold users get the highest and bronze the lowest). The overall priority of the session will be the service class priority and the user's priority.

• Link quality: If the admission of the new session results in a decrement of the link's quality under a desired value, the session is rejected. Link quality refers to the quality of the radio link between the base station and the mobile terminal. Link quality is measured based on the received signal strength at the mobile terminal and the interference caused to this link by other mobile terminals in the same area.

The admission control algorithm takes into account all the above criteria in order to make a decision on admitting or rejecting a session into the network that has been preselected for this purpose based on its characteristics and the advantages it presents for that particular session.

In Fig. 1 the flowchart of the proposed AC algorithm is given, illustrating the actions that have to be performed before making a decision to admit a new session or not. In particular, when a new request arrives at the AC entity, the algorithm is triggered in order to find out if there is a RAT that can meet the session's requirements and if the session can be served by that RAT.

The first action of the algorithm is to determine the characteristics of the session. In general, a session declares its type, bandwidth requirements, delay sensitivity, the RAT from which the session request came (if it is a handover session), and possibly a RAT preference. Based on these requirements, the session is corresponded to a service class and assigned a priority, at the same time taking into account constraints depending on the user's context.

The next step of the algorithm is to select the RATs that meet the session's requirements and will provide the best QoS to it. The selection of the RAT follows the following procedure:

• The algorithm makes a list of the candidate serving networks and candidate cells of each network. The lists contain the candidate networks and cells capable of providing the requested session service, ordered in a way that better fulfills the requirements in each network.

• If there is only one RAT that operates in the session's location area and the session can be served by that RAT, this RAT is selected; otherwise, the session is rejected.

• If there are more than one RATs operating in the session's location area:

  - If the session's priority list contains only one RAT, if the RAT's candidate cell list is not empty, this RAT is selected; otherwise (if the cell list is empty), the session is rejected.
  - If the priority list contains several networks:
    • If there are no candidate cells in any of these RATs, the session is rejected.
    • If there are candidate cells in just one network included in the list, this RAT is selected.
Figure 1. Admission control algorithm.

1. New session request arrives
2. Determine the characteristics of the session
3. Select the target RAT
4. If there are available RATs
   - New session
5. Determine number of queued sessions in that RAT
   - If there are sufficient resources
     - Accept the session
     - Handover session
   - Else
     - Check if it can be served by another RAT
       - If it can be served
         - Force high loaded sessions to handover to another RAT and check if after the session can be admitted
         - Admit the session
         - Handover session
       - Else
         - Check if low priority sessions can degrade their QoS as much as it needs to admit the session
           - If it can degrade
             - Admit the session
             - Handover session
           - Else
             - Enter the session in the queue
6. If there are no available RATs
   - Reject the session
7. Check if it can be served by another RAT
   - If it can be served
     - Select another suitable RAT
     - New session
   - Else
     - Handover session
8. Check the session's priority
   - If low priority
     - Can't accept the session in the RAT
   - Else
     - High priority
     - If low priority sessions can degrade their QoS as much as it needs to admit the session
       - Admit the session
       - Handover session
     - Else
       - Enter the session in the queue
8. If it can't be served by another RAT
   - Reject the session
• The session leaves the cell (i.e., the user moves to another cell) or the session is completed.

• The session is terminated due to timeout — a user should not wait forever to receive service, so the calls are assigned an admission timeout variable.

The degradation of the QoS of low-priority sessions is the last action (also called QoS renegotiation action) that the algorithm performs before rejecting a session [14]. The sessions whose QoS should be degraded should be selected according to the service class they belong to and how flexible this class is in terms of data rate. For example, a Web browsing session is generally flexible in respect to the available data rate and can tolerate lower values than requested, although voice over IP (VoIP) calls must have a certain datarate for efficient performance and user satisfaction. Although the downgrading of the connection quality is a step that helps very much in gaining the needed resources for admitting a new session, it is a step that should be treated very carefully. There are many applications whose received quality cannot be downgraded without significant loss of useful information (i.e., voice calls or video streaming) or being noticed by the user.

Moreover, it is not a wise approach to degrade the QoS of ongoing sessions, which is why it is the last step of the algorithm (before rejecting new sessions or putting handover sessions in queues) and is performed (or at least attempted) only for handover sessions or new sessions with high priority [14].

After degrading the QoS of low-priority classes, there is another action the network should perform. When a session is terminated in the specific cell and the load goes under a restoration threshold, the session whose QoS was degraded (or as many of them as possible, again according to their priority) must be restored to their required QoS. The restoration procedure takes place only when no handover sessions are waiting in the queue. The steps that should be followed are presented in Fig. 2.

**Performance Results**

The performance and functionality of the algorithm have been tested through system-level simulation for a simple scenario, using an emulation of the WINNER system together with a high-throughput WLAN.

Users were generated at random positions using a uniform distribution inside the boundaries of the cells of each network in the networking topology, and make calls by selecting one of eight service classes. For each service class they use different weights according to the frequency of the usage of each class for an amount of time that is between the two values described in Table 1. The probability of selecting a service class is not the same for all classes but varies significantly. In particular, services that are used more often (e.g., Web browsing or voice calls) have much higher probability of being selected than services such as high-quality video streaming or interactive ultra-high definition media. Although in our scenarios mobility is not explicitly modeled, we nevertheless generate handover users that have higher priority than new users. These handover users are not the result of mobility but are ongoing users that for some reason need to change a service or request a handover to a new network because of their needs and preferences.

**Simulation Topology**

In order to perform the simulations a topology of 24 cells has been created: eight cells correspond to GSM/GPRS, four to UMTS, six to WLAN hotspots, five to WINNER metropolitan area cells, and one WINNER wide area cell. At this stage the WINNER network is emulated by a WLAN network through...
deploying a macrocell for the wide area and standard cells for the metropolitan area [15].

Service Classes

We decided to consider eight representative classes from the total of 18 service classes defined by WINNER [16]. The selected classes are the most indicative, and their requirements were also adapted to the simulations' needs. Another criterion for the selection of these specific service classes is the fact that most of them could be provided effectively by legacy RANs.

The list of the service classes chosen for the simulations together with their characteristics is given in Table 1.

In this table we also define priorities for the service classes, taking into account the delay requirements of each class and also how the user perceives the characteristics of the offered service. By this we mean that, for example, a problem in a voice call is noticed easily by a user and is unacceptable, but a problem in a Web browsing session can be tolerated much easier. The priorities indicated in Table 1 correspond to new users. Handover users have different priorities (higher in most cases). We should note here that the mentioned priorities have been assigned just for the case of the particular simulations, in order to have an input for the algorithm. Also in the column “Delay — max,” where no value is indicated, no maximum delay value for the corresponding service class is defined, and the delay could be very high (delay-tolerant service classes).

Due to the nature of our simulations, where we have many wireless networks operating in the same area with partially (or in some cases fully) overlapping cells, it is quite difficult to compute the total capacity of our network. In particular, the cells are assumed squared and are next to each other in the same square area for all networks. The different sizes of the cells in each network result in the cells of the networks not fully overlapping, but only partially. Only if the cells were all fully overlapping could we state that the network's capacity would be the sum of the maximum capacities of all cells.

It is important to analyze here the QoS restoration step of the algorithm presented earlier. In order to demonstrate the functionality of the algorithm and the importance of the QoS renegotiation step, the algorithm has also been tested without the QoS renegotiation step. Because the decrease in QoS is not very well accepted from the users’ perspective, the algorithm tries to restore the data rate of users when the load of the network comes under a certain restoration threshold. Restoring the QoS of users is a very important and critical procedure, since the operator also does not want to have users with less QoS than their service needs. This decrease has happened in order to admit high-priority users, so when the load is low enough the algorithm should restore the data rate. The restoration threshold should be lower than the threshold for admitting a user. For example, if the admission

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Priority</th>
<th>Duration (s) (min-max)</th>
<th>Data rate (kb/s) (min-max)</th>
<th>BER (min-max)</th>
<th>Delay (ms) (min-max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>Large files exchange</td>
<td>8</td>
<td>50MB - 500MB</td>
<td>1000 - 50000</td>
<td>1.0E-06 - 1.0E-06</td>
<td>200</td>
</tr>
<tr>
<td>SC2</td>
<td>HQ video streaming</td>
<td>6</td>
<td>300 - 600</td>
<td>2000 - 40000</td>
<td>1.0E-09 - 1.0E-09</td>
<td>200</td>
</tr>
<tr>
<td>SC3</td>
<td>LAN access and file service</td>
<td>4</td>
<td>120 - 300</td>
<td>500 - 50000</td>
<td>1.0E-06 - 1.0E-06</td>
<td>100 - 200</td>
</tr>
<tr>
<td>SC4</td>
<td>Interactive ultra high media</td>
<td>1</td>
<td>120 - 500</td>
<td>1000 - 50000</td>
<td>1.0E-03 - 1.0E-06</td>
<td>20 - 100</td>
</tr>
<tr>
<td>SC5</td>
<td>Lightweight browsing</td>
<td>5</td>
<td>300 - 900</td>
<td>64 - 512</td>
<td>1.0E-06 - 1.0E-06</td>
<td>200</td>
</tr>
<tr>
<td>SC6</td>
<td>Data and media telephony</td>
<td>2</td>
<td>60 - 120</td>
<td>64 - 512</td>
<td>1.0E-03 - 1.0E-06</td>
<td>100 - 200</td>
</tr>
<tr>
<td>SC7</td>
<td>Simple telephony and messaging</td>
<td>3</td>
<td>10 - 120</td>
<td>8 - 64</td>
<td>1.0E-03 - 1.0E-06</td>
<td>100 - 200</td>
</tr>
<tr>
<td>SC8</td>
<td>Multimedia messaging</td>
<td>7</td>
<td>5 - 15</td>
<td>8 - 64</td>
<td>1.0E-06 - 1.0E-09</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 1. Service class characteristics.

<table>
<thead>
<tr>
<th>Class ID</th>
<th>Class name</th>
<th>Traffic mix percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>large files exchange</td>
<td>9%</td>
</tr>
<tr>
<td>SC2</td>
<td>HQ video streaming</td>
<td>6%</td>
</tr>
<tr>
<td>SC3</td>
<td>LAN access and file service</td>
<td>9%</td>
</tr>
<tr>
<td>SC4</td>
<td>Interactive ultra high media</td>
<td>6%</td>
</tr>
<tr>
<td>SC5</td>
<td>Lightweight browsing</td>
<td>13%</td>
</tr>
<tr>
<td>SC6</td>
<td>Data and media telephony</td>
<td>19%</td>
</tr>
<tr>
<td>SC7</td>
<td>Simple telephony and messaging</td>
<td>19%</td>
</tr>
<tr>
<td>SC8</td>
<td>Multimedia messaging</td>
<td>19%</td>
</tr>
</tbody>
</table>

Table 2. Service classes traffic mix.
high-priority users by decreasing the QoS of lower-priority users, when QoS renegotiation is initiated, the algorithm tries to admit directly rejected due to insufficient resources in the networks. To get a full view of the results, because as stated earlier, it is not good to have users with QoS lower than expected, which is why, after decreasing their QoS, the algorithm tries to restore it as soon as allowed.

As we can observe, higher restoration thresholds lead to higher restoration percentages and higher blocking probabilities. From the two figures it can easily be derived that the best threshold is around 0.77, because it combines low blocking probability with excellent restoration percentage. The restoration percentage is about 85 percent, which is quite high, and the blocking probability is also quite acceptable.

In Fig. 5 we present the evolution of the number of users forced to perform intersystem handover, the number of users that have decreased and restored their QoS, and the number of blocked users in relation to the average equivalent throughput per cell in kilobits per second. These values are given as a percentage per 1000 users and only for one simulation run with the QoS renegotiation threshold at 0.75.

In Fig. 6 we show a trace of the load at the WINNER cells through time for a QoS restoration threshold of 0.8 and incoming traffic around 5 Mb/s. As load is a ratio of the current throughput of a network divided with the maximum throughput, a load value of 1 is the maximum load the network can offer users. As we see from the figure the load of the WINNER cells remains below the admission threshold (0.9) for the whole simulation period. The blue line (cell 1) is the wide area cell, and the others are metropolitan area cells. This figure shows that the algorithm does its job perfectly, since the network does not become congested: all the cells have load significantly below the threshold. This is achieved because the algorithm tries to split the traffic evenly between the cells of all the networks, so there are no very highly loaded cells in the same area as cells with very low load.

From all the simulation results above, the value of the presented admission control algorithm for future heterogeneous networks is obvious. The algorithm finds the network that will serve the session with the best QoS, taking into account the advantages of each network and considering the requirements of the session. Also, the algorithm tries to minimize the number of the sessions that are blocked due to insufficient resources in the target network. Another advantage of the algorithm is the efficient use of each network’s resources by sending to each network traffic that can be best served by that network according to its technical capabilities. For example, we can send all voice sessions to GSM and fast Internet connections to WINNER or WLAN, another advantage of this algorithm is that it uses different criteria for each network in order to make its decisions. These criteria are tightly joined with the technical characteristics of each network in order to gain the advantages of each network and of course in order to measure correctly the conditions in each network (if it is overloaded or not). Finally, the results also show the most important impact of admission control algorithms on maintaining the overall network load within reasonable range.

Conclusions
In this article we have presented the design of a generic admission control algorithm for future heterogeneous wireless networks. This algorithm has been developed from the per-

![Figure 3. Call blocking probability vs. restoration thresholds.](image)

![Figure 4. Percentage of users restoring their QoS.](image)
spective and needs of a new wireless networking technology (WINNER) that will coexist and interoperate with legacy networks. An efficient admission control algorithm is very important for future networks, since it allows maximum utilization of the network, preventing overloading situations and ensuring that users are served with the best QoS. This algorithm takes into account many criteria and performs many steps for the final decision, in order to explore the many available possibilities for admitting a session request.

We demonstrate how an algorithm that is intent on satisfying multiple criteria can perform well in both light and heavy traffic. QoS renegotiation opens the possibilities that requests will be accepted that would not otherwise have been accepted. Of course, a very important parameter then becomes the threshold for the restoration of the data rate of the users. If the threshold is very low, the blocking probability would be very low too, but only a few users will restore their QoS, which would be undesirable to many users. On the other hand, if the threshold is very high, almost any user will restore his/her data rate to normal values, but the blocking probability would be higher, and that is not desired from an operator’s point of view. Thus, the operator should be very careful when choosing the threshold for data rate restoration.

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References


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