

Admission Control for QoS Provisioning in Wireless IP Networks

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ABSTRACT

We propose a hybrid admission control mechanism in wireless IP access network, which integrates different demands from different traffic types: on a call level basis (for A1 and A2 traffic, applied to CBR and VBR real time applications) and on a packet level basis (for A3 traffic, given as best effort with minimum QoS guarantees). Packets from B class (best effort) are always admitted in the wireless network, but with lowest priority. Hybrid Admission Control algorithm (HAC) minimizes new call blocking probability under given initial conditions for call dropping probability (for A1/A2 traffic) and average packet delay of A3 traffic. For the evaluation of the experiments we create an analytical framework and perform simulation experiments. The results show the advantages of the proposed algorithm in a multi-class environment. However, bounded average packet delay is accomplished by increasing call blocking probability of A1 and A2 traffic.

1 INTRODUCTION

Wireless IP networks should provide different multimedia services via transparent communication between the mobile terminal and wired network. Our main task is QoS provisioning for different applications: voice, video, audio, interactive multimedia and data. For that purpose one needs appropriate classification of the traffic into classes. In our previous work [8], we have proposed classification of IP traffic in two main traffic classes: class A (for applications with specified QoS guarantees) and class B (without any QoS guarantees). Due to diversity of the applications and their different QoS demands, we further divide the class A into three subclasses: A1, for Constant Bit Rate (CBR) applications; A2, for Variable Bit Rate (VBR) applications; and A3, for Best Effort applications with minimum service guarantees (we will denote it as BEmin).

Call admission control in the first and second generation of commercial mobile networks is considered on a call level base [1] [5]. In [5] the authors analyze algorithms for minimization of new call blocking probability under given constraint on the call dropping probability as well as algorithm for minimization of both probabilities and network resources planning. Also, call-level QoS parameters are usually found in admission

control in the case of a network with multiple traffic classes [4] [6]. Authors of [6] consider admission control in a network with multiple traffic classes, where traffic is classified into narrow-band calls and calls with higher bandwidth demands. There, the authors propose adaptive distributed QoS admission control over all neighboring cells. In all these approaches are used channel reservations in the wireless link for handover calls (*guard channels*), because blocking of a handover call is more sensitive to the users compared to the new call blocking. On the other hand, [2] and [3] propose strategy for admission control in multimedia mobile networks with variable resource reservation for handover calls. But, in all strategies for admission control in wireless networks the problems are considered only on one level, either a call level or a packet level, for both cases, with one or multiple traffic classes.

2 SYSTEM MODEL

Let first consider QoS support on a call level. As usual, we assume that more sensitive to the users is dropping of an already established call. Using this assumption one can conclude that call dropping probability should be lower than new call blocking probability.

Different A class connections may demand different bandwidth shares. We group the traffic into mini-classes, based on the amount of bandwidth that is demanded by applications. So, a mini-class is consisted of all flows that belong to the same traffic class or subclass and have equal bandwidth demands per call. Traffic class B is compatible with today's best-effort traffic in Internet. We propose unconditional acceptance of B-calls either new or handover, independently of the bandwidth occupied by A flows. Packets of B class flows should be sent to the wireless link only when there will be no A packets in the queue. Both, A3 packets and B packets are served in FCFS manner. But, A3 packets have priority compared to all B packets. Actually, A3 traffic is targeted to non-real time applications. However, most of these applications are interactive and they do have demands considering the packet delay. Therefore, one should consider A3 packet's delay as a QoS parameter. The question is how to combine different QoS demands in the admission control algorithm.

Resource reservation depends on wireless access technology in the network (FDMA, TDMA, CDMA etc). But, here we refer to the admission problem in general and we are not going to enforce some specific access technology. We only consider the conditions that should be met by the wireless medium.

3 HYBRID ADMISSION CONTROL

Wireless IP networks are assumed to provide heterogeneous multimedia services with different QoS demands. The traffic is hybrid. The admission control should be hybrid, too. Therefore, here we define an admission control algorithm named HAC (*Hybrid Admission Control*).

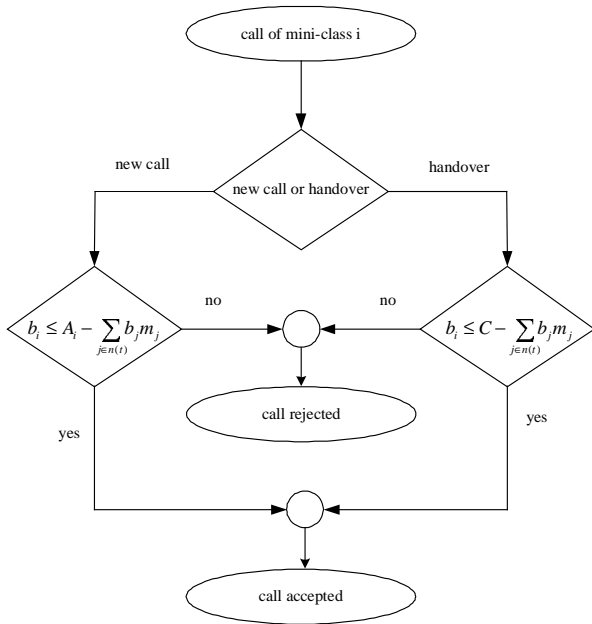


Figure 1: Hybrid Admission Control scheme in wireless IP networks with multiple traffic classes

Let assume that the number of available logical channels in a given cell is N . One logical channel corresponds to the minimum bandwidth that one can allocate to an A1 or A2 call (e.g. one logical channel can be a single TDMA time slot, but also it can be 1/3 time slots or 2 time slots etc.). We denote with b_i the number of logical channels which are demanded by a flow from mini-class i ($i=1,2,\dots,N$). Throughout the text A_i is used to denote the A-threshold of a mini-class i . The basic scheme of the algorithm is shown in Figure 1.

In the HAC algorithm we give traditional priority to handovers over the new calls. At this point we will assume that handover calls are always accepted if there are enough free non-reserved resources in the cell (it will deteriorate a little when we will include into HAC the average packet delay of A3 packets). A new call from mini-class i is accepted only if the sum of reserved resources in the cell and demanded bandwidth by that call is lower than A_i . In Figure 1, m_i denotes the number of

admitted flows from mini-class i . A handover request of mini-class i is accepted in the target cell if the sum of occupied or reserved bandwidth by the other active traffic flows in the cell and requested bandwidth for that call is lower or equal to $\min(C, L_i)$, where C and L_i are wireless link capacity and A1/A2 allowed bandwidth, respectively.

The input QoS parameters in the HAC are call dropping probability of A1/A2 traffic and average packet delay of A3 traffic. With given initial input, the algorithm minimizes new call blocking probability for A1 and A2 flows. So far, we assumed different thresholds for every mini-class. However, there is possibility to declare a single threshold for all of them. The last one requires less computation processing in network nodes, but decreases bandwidth utilization of the wireless link.

4 ANALYTICAL ANALYSIS

We assume that A1 and A2 calls are arriving according to the Poisson process with given average arrival rate λ_i for mini-class i , and average call duration distributed by exponential law with mean $1/\mu_{t,i}$. Average channel holding time is assumed to be exponentially distributed with mean $1/\mu_{h,i}$. Then, one can calculate the probability that an established call in a cell will make a handover by using the following equation:

$$P_{h,i} = \frac{\mu_{h,i}}{\mu_{t,i} + \mu_{h,i}} \quad (1)$$

The probability that a call will end in the current cell is calculated as $1-P_{h,i}$. Average time that is spent by a call of mini-class i in a single cell can be calculated according to:

$$T_{ch,i} = \frac{1}{\mu_{t,i} + \mu_{h,i}} \quad (2)$$

Further, in this analysis we will also use the assumption for equilibrium between incoming and outgoing handovers in a given cell.

Using the given traffic model for a single call one can derive the probability for call dropping probability of mini-class i by using the following relation:

$$P_{F,i} = \sum_{j=0}^{\infty} P_i^{j+1} (1 - P_{Fh,i})^j P_{Fh,i} \quad (3)$$

From (3), with some algebra, we get:

$$P_{F,i} = \frac{P_i P_{Fh,i}}{1 - P_i (1 - P_{Fh,i})} \quad (4)$$

For the purpose of traffic modeling on a cell level we use the Markov model, where each state in the model is defined by number of active calls in each mini-class. We denote new call intensity with λ_i , serving intensity with μ_i ,

handover intensity with h_i , number of requested channels per call per traffic mini-class with c_i , and number of occupied logical channels by mini-class i with n_i .

To define an optimal threshold per mini-class, which will not be necessarily an integer number (as it is the case in [5] and their IGP- *Integral Guard Channel* policy), we use a principle of a partial fractional guard policy. Our target is to provide general optimal thresholds (e.g. the threshold may be 86.77 logical channels, it should not be necessarily rounded to an integer value 86 or 87). The probability for admission of new calls from mini-class i is denoted as λ_i , where $\lambda_i \in [0,1)$. When number of occupied logical channels in the cell is $j > \lfloor A_i / c_i \rfloor$, then all new calls are rejected from the network. In such case we have network congestion. One can queue all incoming calls, but that approach is rarely used in wireless networks.

Fractional guard policy, which is also defined and analyzed for the traditional case with one traffic class in [5], is more general than IGP. One can extend such approach to multimedia environment. Then, the new call intensity is given by:

$$\lambda_i(j) = \begin{cases} \lambda_{n,i} + \lambda_{h,i}, & \dots, 0 \leq j < \lfloor A_i / c_i \rfloor \\ \beta_i \lambda_{n,i} + \lambda_{h,i}, & \dots, j = \lfloor A_i / c_i \rfloor \\ \lambda_{h,i}, & \dots, \lfloor A_i / c_i \rfloor < j \leq \lfloor C / c_i \rfloor \end{cases} \quad (5)$$

where $\lambda_{n,i}$ and $\lambda_{h,i}$ are new and handover call intensities of mini-class i , respectively, and $\beta_i = A_i / c_i - \lfloor A_i / c_i \rfloor = \text{fract}(A_i / c_i)$ is fractional part of the threshold A_i . Call termination rate is given by:

$$\mu_i(j) = j(\mu_{t,i} + \mu_{h,i}) \quad (6)$$

where $1/\mu_{t,i}$ and $1/\mu_{h,i}$ are average time interval between two consecutive call terminations and average time between two consecutive handovers of mini-class i , respectively; and $1/(\mu_{t,i} + \mu_{h,i})$ is average cell residence time.

Further, one can extend the analytical framework to more than two classes. In the case with multiple traffic classes in wireless network one can define the probability that n logical channels in the cell are occupied by using the relation:

$$P_A(n) = \sum_{\forall (\sum_{j=1}^K n_j b_j = n)} P(n_1, n_2, \dots, n_K) \quad (7)$$

where $P(n_1, n_2, \dots, n_K)$ is probability that there are n_1 flows from mini-class 1, n_2 flows from mini-class 2, ..., n_k flows from mini-class k . Then, one can calculate the new call blocking probability of i -th mini class:

$$P_{B,i} = \sum_{n=A_i-b_i+1}^C P_A(n) \quad (8)$$

where C is bandwidth of the wireless link; b_i is demanded bandwidth per connection from i -th mini-class (if number of allocated time slots per a call is c_i , then $b_i = c_i$).

Handover blocking probability of A calls can be calculated by:

$$P_{Fh,i} = \sum_{n=C-b_i+1}^C P_A(n) \quad (9)$$

If we apply Markov diagrams in wireless network with multiple traffic classes and higher capacity per cell (as it is expected), then one will get a huge system of equations to solve (there may be several hundreds up to thousands of equations). This is time consuming and processing demanding. To avoid solving the multidimensional Markov diagram model, it is usually practiced to split K -dimensional Markov diagram into K one-dimensional Markov chains [6]. Common Markov chain model is shown in Figure 2, $i=1, \dots, K$, where K is the number of mini-classes.

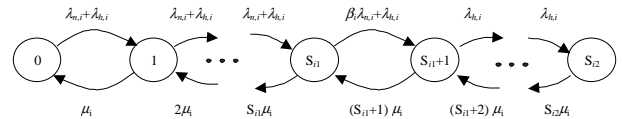


Figure 2: One-dimensional Markov chain for a wireless link with multiple traffic classes

From Figure 2 one can calculate the optimal threshold of mini-class i as $S_{i1} + \beta_i$, where the integer part S_{i2} is calculated by:

$$S_{i2} = \left\lfloor \frac{C - \sum_{j=1, j \neq i}^K c_j m_j}{c_i} \right\rfloor \quad (10)$$

where $c_j m_j$, $j=1, \dots, K$, is average number of allocated resources per mini-class. Then, new call blocking and call dropping probabilities can be calculated as follows:

$$\begin{aligned} P_{B,i} &= (1 - \beta_i) P(S_{i1}) + \sum_{k=S_{i1}+1}^{S_{i2}} P(k) = \\ &= \frac{(1 - \beta_i) \left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{S_{i1}} + \sum_{k=S_{i1}+1}^{S_{i2}} \frac{\left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{S_{i1}} \left(\frac{\beta_i \lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right) \left(\frac{\lambda_{h,i}}{\mu_i} \right)^{k - (S_{i1}+1)}}{k!}}{\sum_{k=0}^{S_{i1}} \frac{\left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^k}{k!} + \sum_{k=S_{i1}+1}^{S_{i2}} \frac{\left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right)^{S_{i1}} \left(\frac{\beta_i \lambda_{n,i} + \lambda_{h,i}}{\mu_i} \right) \left(\frac{\lambda_{h,i}}{\mu_i} \right)^{k - (S_{i1}+1)}}{k!}} \end{aligned} \quad (11)$$

$$P_{Fh,i} = P(S_{i2}) = \frac{\left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i}\right)^{S_{i1}} \left(\frac{\beta_i \lambda_{n,i} + \lambda_{h,i}}{\mu_i}\right) \left(\frac{\lambda_{h,i}}{\mu_i}\right)^{S_{i2} - (S_{i1} + 1)}}{S_{i2}!} \\ P_{Fh,i} = P(S_{i2}) = \frac{\sum_{k=0}^{S_{i1}} \frac{\left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i}\right)^k}{k!} + \sum_{k=S_{i1}+1}^{S_{i2}} \frac{\left(\frac{\lambda_{n,i} + \lambda_{h,i}}{\mu_i}\right)^{S_{i1}} \left(\frac{\beta_i \lambda_{n,i} + \lambda_{h,i}}{\mu_i}\right) \left(\frac{\lambda_{h,i}}{\mu_i}\right)^{k - (S_{i1} + 1)}}{k!}}{(12)}$$

One can calculate the total incoming call intensity in the cell, denoted as Λ_i , by using the following relation:

$$\Lambda_i = \lambda_i (1 - P_{B,i}) + \lambda_{h,i} (1 - P_{Fh,i}) \quad (13)$$

where Λ_i is intensity of the calls accepted in a cell. Handover intensity from a cell to its adjacent cells is given by:

$$\lambda_{h,i} = P_i \Lambda_i = P_i [\lambda_i (1 - P_{B,i}) + \lambda_{h,i} (1 - P_{Fh,i})] \quad (14)$$

where P_i is the probability that a given call will perform a handover before it will terminate. From (14) one cannot directly determine new call blocking probability and handover blocking probability. For that purpose, we should use iterative calculations, where initial values for $P_{B,i}$ and $P_{Fh,i}$ are set to zero. Then, one does iterations until both probabilities converge.



Figure 3: A3 packets servicing

So far, we have analyzed QoS parameters of A1 and A2 subclasses, while not referring to the A3 traffic at all. But, although A3 flows have lower priority compared to A1 and A2 traffic, A3 average packet delay cannot be analyzed separately. Simply, it is a consequence of the fact that A3 flows use the remaining resources after servicing A1 and A2 flows. For the simplicity of the analysis one may assume that A3 packets are arriving at wireless link buffers by a Poisson law, although it is not exactly the case. One can use buffering of A3 packets in base stations according to the FCFS scheme, so packets that first enter into the wireless link buffer first are transmitted. Total A3 packet delay is a sum of waiting time in the buffer and transmitting time over the wireless link. According to the discussion above, one can model A3 traffic in the base station as a queue with varying service rate. The service rate can be anything between 0 and cell capacity C . Admission control algorithm is used

to allocate specific number of logical channels (bandwidth) for each call.

To avoid infinite delays during high network loads, one reserves a part of the bandwidth only for A3 traffic. Basically, it should be smaller part of the wireless link resources, which is dependent upon prediction of traffic load per class in the network. For that purpose, we introduce another threshold L_{A12} , which defines maximum capacity allowed to A1 and A2 connections. Then, $C - L_{A12}$ is bandwidth reserved only for A3 traffic.

Let $E[D_i]$ denote average packet delay of A3 packets at the base station when there are i logical channels occupied by A1 and A2 flows. Then, one can calculate average packet delay by using the following:

$$E[D] = \sum_{i=0}^{L_{A12}} E[D_i] P_A(i) \quad (15)$$

To satisfy grade of service, given at the network dimensioning process, we need to determine optimal A-thresholds in the HAC algorithm for the admission control in the wireless network.

The thresholds are initially set at the network design phase and later they are evaluated by using real traffic measurements. However, in both cases stated above, we need an algorithm to determine the optimal A-thresholds under given constraints on call dropping probabilities of A1 and A2 classes, and average packet delay of A3. Such algorithm should lead to minimization of new call blocking probability while satisfying previous two constraints.

5 OPTIMAL THRESHOLDS

Now, we determine the optimal A-thresholds by minimizing the new call blocking probability. The main problem arises from various bandwidth demands of different traffic subclasses and mini-classes within them.

Let briefly discuss the dependence of thresholds upon given QoS parameters of A-traffic. We first consider single class network scenario. If there is only one mini-class in the network, then moving the threshold up causes increase of call dropping probability and decrease of new call blocking probability, and the opposite way. The behavior of average packet delay of A3 traffic is expected to be similar to the one of the call dropping probability. But, it is not always the case, because it also depends on new call and handover intensities in the network. In multiclass wireless network one can determine one threshold or multiple thresholds. With only one A-threshold, one can solve the problem of finding an optimal one by a binary search. However, the problem becomes more complex when there is more than single A-threshold.

Here we propose a procedure for finding multiple optimal thresholds under given traffic classification. The steps of the procedure are outlined as follows:

1. Set call dropping probability $P_{F,i}$ and new call blocking probability $P_{B,i}$ for each mini-class i to their given maximum; Also, set average packet delay of A3 traffic to the given maximum $E[D]_{max}$
2. Calculate the optimal threshold of mini-class i when all other thresholds are set to their maximum by using binary search algorithm: $A_j=C \lfloor C/c_j \rfloor$ calls) for $j \neq i$; Use the obtained threshold in the rest of this algorithm as initial values for the optimal thresholds search; Repeat this step for each mini-class i ; Here, let denote with $P_{B,opt,i}$ the new call blocking probability of mini-class i at optimal A_i -threshold
3. Repeat steps 4, 5 and 6 for all combinations of resource allocation per mini-class
4. Calculate $P_{B,i}$, $P_{F,i}$ (using finite number of iterations) for A1 and A2 traffic, and $E[D]$ for A3 traffic
5. If given conditions for the QoS parameters are satisfied i.e. $P_{F,i} < P_{F,max,i}$ and $E[D] < E[D]_{max}$, then if $P_{B,i} < P_{B,opt,i}$ then $P_{B,i} = P_{B,opt,i}$
6. If $\{P_{B,i} > P_{B,i,threshold} \text{ and } (P_{F,i} > P_{F,i,threshold} \text{ or } E[D] > E[D]_{max})\}$ then go to step 7.
7. It is not possible to determine an optimal A-threshold, then it means that there are not enough resources in the wireless network for the given traffic demands or initial constraints are too strict for at least one QoS parameter.

Exact determination of optimal thresholds needs solving of K -dimensional Markov chain model, a process that requires huge calculations. One will not want to perform this processing in real time at the base station, due to limited processing power of the base station and its multi-functionality in a wireless IP network. However, traffic intensity is not uniformly distributed during the day. Operators should determine the update rate by using traffic measurements. Each base station is supposed to have information of the status of each subscriber, which resides within its coverage area. Such information is necessary for the admission control of A1 and A2 calls, e.g. for paging purposes at the call initiation. On the other hand, wired nodes in the network do not need to have information on a per flow base. For them, it is enough to have information per class/subclass. Wired nodes perform differentiation of the packets according to their classification (routing and location management in wireless IP networks are discussed in [9]).

6 SIMULATION ANALYSIS

Here, we present performances analysis of the hybrid admission control in a multiclass environment in wireless IP networks. In these experiments we observe the following QoS parameters: new call blocking probability and call dropping probability of A1 and A2 subclasses, and average packet delay of A3. First, we perform analysis of A3 packet delay for different values of A-threshold. In this experiment we use single threshold for new calls of A1 and A2 subclasses. It is assumed that the base station allocates a single logical channel per call, and

it is not changed during the connection duration. The following input settings are used in the experiment: cell size is set to 1 km; average velocity of the users is 50 km/h; bit rate of the wireless link is 2 Mbit/s (this value is arbitrarily chosen); A3 packets are arriving with the rate 30 packets/sec with average packet length 1000 bytes, exponentially distributed. We set new call rate to 3 calls/sec. The average number of users per cell is 1000, while average call duration is set to 100 seconds. In the following experiments we reserve one logical channel for A3 traffic only. The capacity of a cell is set to $C=100$ logical channels.

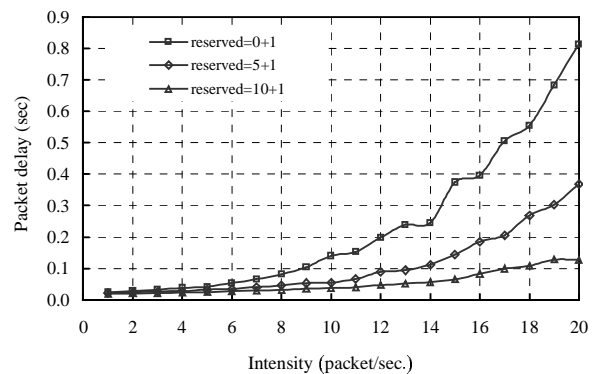


Figure 4: Average packet delay for A3

We analyze A3 packet delay versus A3 packet intensity for different number of reserved logical channels for handover calls of A1 and A2. The results are shown in Figure 4. We conclude that average delay of A3 packets is higher at higher intensity of new calls, because higher traffic load occupies more of the bandwidth resources and leaves less bandwidth for servicing the A3 traffic. By increasing the number of reserved channels for A1 and A2 handovers we notice decreasing of average A3 packet delay. Main reason for this is the smaller number of admitted connections in the access network when we have more reserved bandwidth for handovers. It is a consequence of higher number of rejected new calls at lower A-thresholds. But, at the same time it means more channels for serving A3 traffic.

Next, we show the QoS parameters behavior in wireless network with multiple classes. For the presentation purposes we consider network analysis for two scenarios: first with two mini classes and then with three mini classes. In the scenario with two mini-classes, average number of arrival calls is set to 0,1 calls/sec, average call duration is 250 seconds, while average cell residence time for an ongoing call is 100 seconds. One can calculate that there should be 2.5 handovers per call of each mini-class. The only difference between the two scenarios is the number of allocated logical channels per call: $c_1=1$ channel/call, $c_2=2$ channel/call. For the first mini-class we allocate one logical channel per call, while two logical channels are allocated per call for the second mini-class.

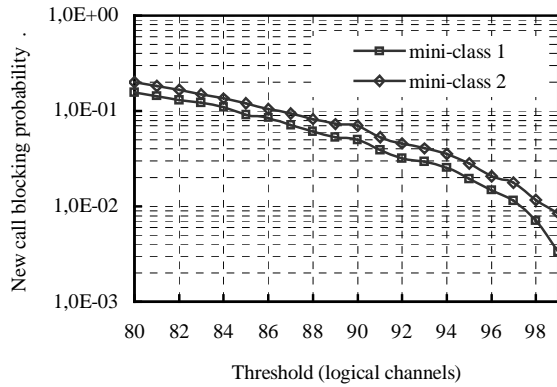


Figure 5: New call blocking probability as a function of the A-threshold (a scenario with two mini classes)

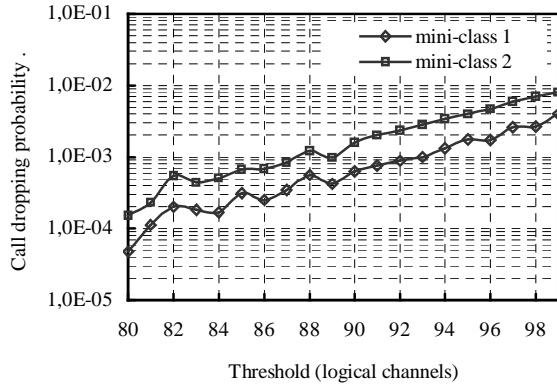


Figure 6: Call dropping probability for a scenario with two mini-classes

Here, we change A-threshold simultaneously for both mini classes. The results from simulation runs are shown in Figures 5 and 6. One can notice that both mini classes have similar behavior considering new call blocking and call dropping probabilities. However, the blocking probabilities are higher for the second one. This is a result of the fact that calls from the second mini class, when compared to calls from the first mini-class, require more logical channels per call. So, calls of the second mini-class cause larger segmentation of the wireless link bandwidth and lead to lower bandwidth utilization and higher call losses, either new or handover calls.

For the scenario with three mini-classes we use the following input data: new call intensities are $\lambda_1=0,15$ calls/sec, $\lambda_2=0,05$ calls/sec, $\lambda_3=0,01$ calls/sec; average call durations are $1/\mu_1=100$ sec; $1/\mu_2=250$ sec, $1/\mu_3=500$ sec; average cell residence intervals are $1/h_1=50$ se, $1/h_2=50$ sec, $1/h_3=200$ sec; while allocated bandwidth shares are $c_1=1$ channel/call, $c_2=2$ channel/call, $c_3=5$ channel/call. With aim to analyze different admission control conditions in wireless IP networks, we choose to restrict bandwidth reservation for handovers of the third mini class, i.e. its threshold is fixed at the cell capacity C .

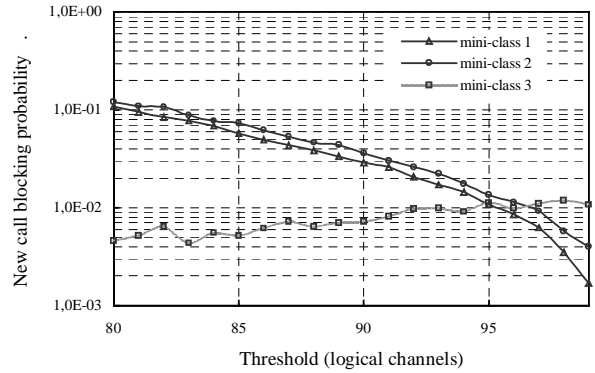


Figure 7: New call blocking probability for a scenario with three mini classes

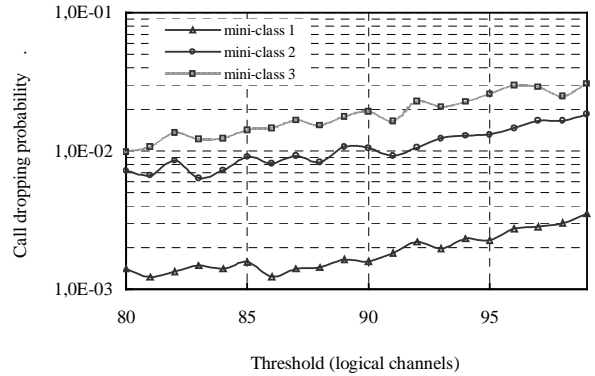


Figure 8: Call dropping probability for a scenario with three mini-classes

The other two mini classes have a same varying threshold. The obtained results are given in Figures 7 and 8. Using these results, one can notice that increase of the threshold of the first two mini classes results in decrease of new call blocking probability of A1 and A2 subclasses and increase of forced call termination probability. Unlike the first two mini classes, one notices increase of all QoS parameters for the third mini class. One can explain this behavior by the fact that network accepts more new connections by increase of the threshold of the first two. However, this results in less available bandwidth for new calls as well as handovers of the third mini class.

Further, we can continue with analysis by adding more and more traffic classes. But, it is not necessary because we have already observed possible situations through the above examples and the results are clearly showing the advantages of a hybrid admission control in wireless IP networks with heterogeneous traffic.

7 CONCLUSIONS

We analyzed admission control with QoS support in wireless IP networks with multiple traffic classes. In such heterogeneous environment, network needs suitable

admission control. Different traffic types have different QoS constraints. For instance, real time services have higher QoS demands and they need particular guarantees on the allocated bandwidth during the connection. On the other hand, non-real time services and applications are more flexible to the QoS support.

For the adaptation of various QoS requirements in the network, here we proposed a new type of admission control called Hybrid Admission Control (HAC). Unlike the usual practice in the creation of admission control algorithms for wireless networks, which are mainly associated with only one level, either a call level or a packet level, we integrated all QoS parameters, either call-based or packet-based.

New call blocking probability and call dropping probability are considered as QoS parameters of A1 and A2 subclasses, while average packet delay is a parameter of A3. As usual, HAC implements guard policy for handover calls of A1 and A2, because dropping of an already established call is more sensitive to the user than rejecting a new call.

We proposed an algorithm for determination of optimal thresholds under given constraints on QoS parameters. The algorithm bounds call dropping probability of A1 and A2 subclasses and the average packet delay of A3, while at the same time minimizing new call blocking probability of A1 and A2. With aim to avoid extreme delay peaks during heavy network load, we proposed reservation of a small part of the bandwidth only for A3 traffic. However, B class is not considered in admission control algorithm. B packets are serviced only when all A packets from queues are transmitted over the wireless link.

We created an analytical envelope for the analysis of the hybrid admission control. The exact calculation of optimal thresholds requires solving of a system with hundreds up to thousands of equations. Therefore, we proposed approximate transformation of N-dimensional Markov model to N one-dimensional Markov chains. Also, the network operator can schedule the optimal threshold search, which is based on periodical traffic measurements, during time interval of the day with lower network load, i.e. late night.

The analytical and simulation analyses showed two main compromises that have to be made in HAC algorithm: 1) between new call blocking probability and call dropping probability of A1 and A2; and 2) between new call blocking probability and average delay of A3. Constraints on QoS parameters are given at the phase of network design, but they can change later due to the network policy or traffic behavior. If it is not possible to determine optimal thresholds, then network has too low resources for the given QoS demands or initial constraints are too strict for one or more parameters.

REFERENCES

- [1] D. Hong, S.S. Rappaport, "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Nonprioritized Handoff Procedures", IEEE Trans. Veh. Technology, Vol. VT-35, No. 3, August 1986, pp.77-92.
- [2] M. Oliver, "Admission Control Strategy based on Variable Reservation for a Wireless Multi-Media Networks", The First International Symposium on Wireless Personal Multimedia Communications WPMC'98, Yokosuka (Japan), November 1998, pp. 338-343.
- [3] M. Oliver and J. Paradelis, "Variable Channel Reservation Mechanism for Wireless Networks with mixed types of mobility platforms", 48th Annual Vehicular Technology Conference VTC'98, Ottawa (Ontario), Canada, May 1998, pp. 1259-1263.
- [4] M. Naghshineh, M. Schwartz, "Distributed call admission control in mobile/wireless networks", IEEE Journal on Sel. Areas in Comm., Vol. 14, no. 4, pp.711-717, May 1999
- [5] R. Ramjee, R. Nagarajan, D. Towsley, "On Optimal Call Admission Control in Cellular Networks", Wireless Networks Journal, vol.3, no.1, pp.29-41, 1997.
- [6] J. Mistic, S.T. Chanson and F.S. Lai, "Quality of Service Management for Wireless Networks with Heterogeneous Traffic", pp. 1406-1412, GLOBECOM'98, Sydney, Australia, November 1998.
- [7] Vern Paxson and Sally Floyd, "Why We Don't Know How To Simulate The Internet", Winter Simulation Conference, Atlanta, December 1997.
- [8] Toni Janevski, Boris Spasenovski, "QoS Provisioning for Wireless IP Networks with Multiple Classes Through Flexible Fair Queuing", GLOBECOM 2000, San Francisco, USA, 27 November-1 December 2000.
- [9] Toni Janevski, Boris Spasenovski, "A Novel QoS Scheme for Handoffs in Wireless IP Networks", IEEE Wireless and Communications Networking Conference- WCNC 2000, Chicago, USA, 23-28 September 2000.