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Performance analysis of multi-service wireless network: An approach integrating CAC, scheduling, and buffer management

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Abstract

Traffic management (TM) mechanisms such as Call Admission Control (CAC), Scheduling, and Buffer Management (BM) play a key role in the design of multi-service wireless network by providing service differentiation from diverse applications and assigning the network resources (radio channels or buffer) according to the quality of service (QoS) requirements of each service class. We propose in this work two new models that integrate CAC, Scheduling, and BM in the design of multi-service wireless network. By presenting their Markovian models and their performance metrics, we investigate their respective design tradeoffs and compare their performance.

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Keywords: Wireless networks; Performance models; Call admission control; Scheduling; Buffer management

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1. Introduction

Work developed in these last years has revealed the explosive growth of wireless communications raised by technological advances in the telecommunication industry. The low price of the wireless terminals has also strongly contributed to the growth of the number of users. However, one of the main agents that has helped to increase the number of users is the ubiquitous wireless access to voice and data services. With the integration of these services, the quality of service (QoS) provisioning became more challenging and the design of the network has deserved special attention because the support of integrated services demands service differentiation in order to satisfy the diverse range of service requests and QoS requirements. In such context, Traffic

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Management (TM) mechanisms as Call Admission Control (CAC), Scheduling, Buffer Management (BM), and Flow Control play a key role in the design of multi-service wireless networks by providing service differentiation from diverse applications and assigning the network resources (radio channels or buffer) according to the QoS requirements of each service class.

1.1. Bibliographic review

Several works in the literature have been proposed to deal with the problem of designing multi-service wireless system using TM. Traditionally, CAC is employed on the first stage. Its task is to accept or to deny access to network resources based on the QoS requirements of the incoming requests thereby controlling the number of ongoing calls. A lot of CAC schemes have been proposed on literature. Generally, they are grouped in the following way: Complete Partition scheme (CP) and Complete Sharing scheme (CS). In CP, as the name implies, the radio bandwidth is partitioned among service classes. CP is simplest and may be rapidly deployed in real systems, but will result in poor performance when the traffic patterns do not conform to the partition [1]. In CS, the whole radio resources are shared among service classes. Mechanisms as preemptive priority may be assigned to voice service over data service. In order to mitigate the effect of this priority, data packets may be buffered while waiting for a free radio channel to be transmitted [2]. In CS, there is no distinction between handoff voice calls and new voice calls for channel allocation. Nevertheless, a handoff voice call is an user from an adjacent cell or even from another network, so that from his/her perspective, dropping an ongoing call is less desirable than blocking a new voice call. Thus, a lot of schemes have been proposed favoring handoff voice calls [2–6]. A well-established scheme is the guard channel, which reserves some radio channels for handoff voice calls. In that scheme, a new voice call is only admitted by CAC if the radio resource occupancy is below a threshold (the number of radio channels minus the amount of reserved radio channels); otherwise, it will be blocked. On the other hand, a handoff voice call will only be blocked if there is no radio channel available. This way, a guard channel scheme acts in favor of handoff voice calls at cost of a degradation of the QoS of new voice calls. Thus, there is a performance tradeoff between the QoS provisioning of new voice calls and handoff voice calls. Guard channel may result on low utilization of the radio channels, which is undesirable because they are scarce and expensive resources. A simple way to overcome this drawback is to share the guard channel between handoff voice calls and data packets with priority to the former [2]. Another approach to mitigate the forced termination of ongoing calls is to queue handoff voice calls when there are no available radio resources. This approach is quite feasible due to the handoff area (the region between adjacent cells). In this respect, there are important aspects to be taken into account on the performance of the system: the handoff area and the queue sizes [3,5]. A good overview about handoff prioritization schemes is found in [4]. Recent trends on the design of multi-service wireless network are the multi-threshold-based schemes in which the radio channels are divided into blocks that are shared among calls based on the priority of each one [1,7,8].

Another TM mechanism explored in literature is the scheduling, which is employed to give access to network resources to data packets already accepted. A traditional approach is the Weighted Fair Queueing (WFQ) that, as its name implies, provides fairness among flows by using weights to prevent monopolization of the bandwidth by some flows. Other scheduling approaches for wireless communication are the Idealized Wireless Fair Queuing (IWFQ) and Channel Condition Independent Packet Fair Queuing (CIF-Q) that have been proposed for wireless packet fair queuing [9–12]. In [13], it is proposed a Distributed Fair Scheduling (DFS) that achieves proportional fairness in wireless shared channels. A simple method that supports service differentiation is the Priority Queueing (PQ) [9]. In PQ each buffer queues its priority data packet traffic and the scheduler schedules the traffic classes based on the occupancy of the higher priority buffers.

BM has also been explored in literature. A simple strategy is the Drop Tail that discards a data packet when the buffer is full. A BM for fast handoff is proposed in [14], which aims at, among other things, supporting QoS during handoff process, while maximizing the buffer utilization. Another BM mechanism is the Random Early Detection (RED) that uses two thresholds to avoid overflow [9]. Some published works have proposed to integrate TM mechanism in the design of most effective schemes such as the integration of CAC and scheduling in a CDMA network [15]. In [16], a threshold on the buffer is used to decide when radio resources must be allocated to data, in such way that based on the buffer and radio resources occupancies it is decided whether

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some radio channels will be allocated to carry out data packets. The ongoing voice calls using the channels allocated to data service are forced to move to the macrocell. In [17], a threshold is also used into the buffer, but with the purpose of monitoring its occupancy in order to decide when to apply the Flow Control.

1.2. Contributions

For the purpose of this proposal, four service classes are assumed: handoff voice call, new voice call, *higher priority*, and *lower priority data packets*. In the Forth Generation (4G) wireless network, [7,18,19], these two data packet service classes may be user to cover data packet traffic coming from horizontal and/or vertical handoff data session (*higher priority data packet*) and data packet traffic coming from new data session (*lower priority data packet*).

The contributions of this work are three-fold:

1. Since there has been little study on the performance comparison of schemes for the design of multi-service wireless network in which TM mechanisms work collectively, we first present two models: FIFOBM and PQBM. FIFO with BM (FIFOBM) integrates CAC and BM to enhance the service differentiation between data service classes; Priority Queueing with BM (PQBM), which here integrates CAC, Scheduling, and BM. In both protocols, a guard channel based-CAC acts benefiting handoff voice calls over new voice call connections dedicating radio resources for their use (guard channel). In order to increase the utilization of the radio channels, the guard channels are completely shared between handoff voice calls and data packets, like [2]. A priority for handoff voice traffic ensures that its performance is not affected. By presenting their Markovian models and their performance metrics, we investigate their respective design tradeoffs. It is worthwhile to mention that only TM that are capable of avoiding and preventing congestion, i.e., CAC, scheduling, and BM [20] are considered here. Because of that, Flow Control is not taken into account in the proposed protocols.
2. Second, unlike previous works (e.g. [17,16]) in which the threshold into the buffer is used to indicate its occupancy, we use it to cope with data service differentiation.
3. Three, we also propose a model (PQBM) that integrates three TM mechanisms, which differs from previous works that integrate at most two.

1.3. Limitations

For the sake of simplicity we assume in this work that the wireless channel is error-free. Thus, the packet scheduling is simplified and we can focus our attention on the integration of TM mechanisms and on the queueing aspects of the PQBM scheme.

The remainder of this work is organized as follows: next section depicts the network architecture and traffic assumptions made. The Markovian models of FIFOBM and PQBM together with their performance metrics are presented in Section 3. Numerical results are presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Network architecture and traffic assumptions

A typical cellular mobile network with cells providing wireless access for mobile users throughout the Base Station (BS) is assumed. A total of N radio channels are available in each cell. Two service classes access the network: voice and data. Voice traffic is formed by new calls and handoff calls. Voice calls and data packets arrive in the system according to two Poisson processes, with parameters λ_v and λ_d, respectively. As voice service is composed by new calls and handoffs, their arrival rates are given by $\lambda_{n,v}$ and $\lambda_{h,v}$, respectively. Thus, $\lambda_v = \lambda_{h,v}+\lambda_{n,v}$.

Arrivals of data packets take place in the following way: $\lambda_d = \lambda_{h,d}+\lambda_{l,d}$; where $\lambda_{h,d}$ and $\lambda_{l,d}$ are *higher priority data packets* arrival rate and *lower priority data packets* arrival rate, respectively. The service times of voice calls and data packets follow exponential distributions with parameters μ_v and μ_d, respectively. We also assume that data packets will be transmitted using all available radio resources [21].

In this work we propose two schemes: FIFOBM and PQBM. The former has only one buffer to accommodate *higher priority* and *lower priority data packets*. Additionally, a threshold is used to manage the buffer occupancy in such a way that whenever the buffer occupancy is bellow this threshold both data packet service classes are accepted, but when it grows and becomes equal to or greater than the threshold only the *higher priority data packets* will be buffered. In the ordinary PQ there are two priority buffers, in such a way that incoming data packets are placed into different priority queues. Packets in lower priority buffer are scheduling only if the higher priority buffer is empty. In this proposal, the behavior of the PQ scheme is changed to enhance the QoS perceived by *higher priority data packets* in the following way: a threshold divides the lower priority buffer into two areas: one used to accommodate only *lower priority data packets* and another shared between both data packet service classes. Thus, when the higher priority buffer is full, *higher priority data packets* may be accommodated into lower priority buffer as long as there is available space into the shared area. Herein, that scheme is called PQBM. As aforementioned, a guard channel CAC is used to discriminate handoff voice calls from new voice calls. These guard channels are also shared with data packets in order to increase the utilization of the radio channels. A priority for handoff voice traffic ensures that its performance is not affected.

3. Markovian models

3.1. FIFOBM

The system has the thresholds Kv and Kd in the radio channels and in the buffer, respectively, used to differentiate handoff voice calls from new voice calls and *higher priority data packets* from *lower*, respectively. The number of guard channels is given by $N - Kv$. A two-dimensional Continuous Time Markov model of this scheme is developed, whose state is defined as: $\Psi = \{(v, b)/0 \leqslant v \leqslant N, 0 \leqslant b \leqslant B\}$, where v is the number of voice calls (new and handoff) and b is the number of *data packets* into the buffer.

Table 1 shows the state transitions of FIFOBM model. An arrival or a departure of a voice call changes the state variable v, that increases when a voice call arrives, and decreases when a voice call departures. For voice service, when the number of channels is less than the threshold Kv, new call and handoff call may be admitted into the system, but when the number of busy channels is either equal to or greater than that threshold, only handoff calls will be admitted. In the FIFOBM model, an incoming *lower priority data packet* will be admitted if the buffer occupancy b is bellow the threshold Kd. An incoming *higher priority data packet* will be admitted into the buffer while its occupancy is less than B. A data packet will be transmitted with rate $\min(N - v, b)\mu_{\mathrm{d}}$ if there are free radio resources [16,17].

3.1.1. Performance metrics

In order to analyze the performance of FIFOBM it is needed to evaluate performance metrics. In a multiservice wireless networks, when the system performance are addressed on call level for voice call and packet level for data packet, as suggested in [7], typical performance metrics are: handoff voice call and new voice call blocking probabilities; mean delay and blocking probability of data packet. In an analytical approach, these performance metrics are derived from the steady-state probability of the Markov chains of FIFOBM. Thus, let $\pi(v, b)$ be the steady-state probability of this continuous time Markov chain. Then, the new voice call

Table 1
FIFOBM, transitions from state $\Psi = (v, b)$

Successor state	Condition	Rate	Event
$(v+1, b)$	$v < Kv$	λ_{v}	Arrival of voice call (new call and handoff)
$(v+1, b)$	$Kv \leqslant c < N$	$\lambda_{\mathrm{h,v}}$	Arrival of handoff voice call
$(v, b+1)$	$b < \mathrm{Kd}$	λ_{d}	Arrival of data packet (*lower* and *higher priority*)
$(v, b+1)$	$Kd \leqslant b < B$	$\lambda_{\mathrm{h,d}}$	Arrival of *higher priority data packet*
$(v-1, b)$	$v > 0$	$v\mu_{\mathrm{v}}$	Departure of voice call
$(v, \mathrm{b}-1)$	$\min(N-v, b) > 0 \wedge b > 0$	$\min(N-v, b)\mu_{\mathrm{d}}$	Departure of data packet (*lower* and *higher priority*)

blocking probability (P_{nc}) is the probability that the number of voice connections (handoff or new call) being equal to or greater than the threshold Kv; on the other hand, the handoff voice call blocking probability (P_{ha}) is given by the probability of all radio channels are busy with voice connections.

$$P_{\mathrm{nc}} = \sum_{v \geqslant Kv}^{N} \sum_{b=0}^{B} \pi(v, b). \tag{1}$$

$$P_{\mathrm{ha}} = \sum_{b=0}^{B} \pi(N, b). \tag{2}$$

The *higher priority data packet* blocking probability is given by the probability of the buffer is full.

$$P_{\mathrm{hd}} = \sum_{v=0}^{N} \pi(v, B). \tag{3}$$

The *lower priority data packet* blocking probability is given by the probability of the buffer occupancy is equal to or greater than the threshold Kd

$$P_{\mathrm{ld}} = \sum_{v=0}^{N} \sum_{b=Kd}^{B} \pi(v, b). \tag{4}$$

The data packets throughput is computed from

$$X = \sum_{v=0}^{N-1} \sum_{\min(N-v,b)>0} \sum_{b>0} \min(N-v, b)\mu_{\mathrm{d}}\pi(v, b), \tag{5}$$

and, by Little's law, the mean delay of data packets is

$$W_{\mathrm{d}} = \frac{\sum_{v=0}^{N}\sum_{b=1}^{B} b\pi(v, b)}{X}. \tag{6}$$

3.2. PQBM

The system has two buffers: one for *higher priority data packets* and another for *lower priority data packets* with sizes Bh and Bl, respectively. A multidimensional Continuous Time Markov model of this scheme is developed, whose state is defined as: $\Omega = \{(v, h, l)/0 \leqslant v \leqslant N, 0 \leqslant h \leqslant Bh, 0 \leqslant l \leqslant Bl\}$, where v is the number of voice calls (new and handoff); h is the number of *higher priority data packets* into the higher priority buffer; and l is the number of *lower priority data packets* into the lower priority buffer.

Table 2 shows the state transitions of PQBM model. The dynamic of the voice calls (state variable v) is equal to the FIFOBM. Changes in the state variable h are motivated by an arrival or a departure of a *higher priority data packet*. Likewise for l, but now if the higher priority buffer is full, all *higher priority data packets* may be accommodated into lower priority buffer as long as there is available space into the shared area

Table 2
PQBM, transitions from state $\Omega = (v, h, l)$

Successor state	Condition	Rate	Event
$(v+1, h, l)$	$v < Kv$	λ_{v}	Arrival of voice call (new call and handoff)
$(v+1, h, l)$	$Kv \leqslant v < N$	$\lambda_{\mathrm{h,v}}$	Arrival of handoff voice call
$(v, h+1, l)$	$h < Bh$	$\lambda_{\mathrm{h,d}}$	Arrival of *higher priority data packet*
$(v, h, l+1)$	$l < Bl$	$\lambda_{\mathrm{l,d}}$	Arrival of *lower priority data packet*
$(v, h, l+1)$	$h = Bh \wedge l < Bl - Kd$	$\lambda_{\mathrm{h,d}}$	Arrival of *higher priority* data packet in the lower priority buffer
$(v-1, h, l)$	$v > 0$	$v\mu_{\mathrm{v}}$	Departure of voice call
$(v, h-1, l)$	$min(N-v, h) > 0 \wedge h > 0$	$\min(N-v, h)\mu_{\mathrm{d}}$	Departure of *higher priority data packet*
$(v, h, l-1)$	$\min(N-v, l) > 0 \wedge h = 0 \wedge l > 0$	$\min(N-v, l)\mu_{\mathrm{d}}$	Departure of *lower priority data packet*

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($Bl - Kd$). A *higher priority data packet* will be transmitted with rate $\min(N - v,\, h)\mu_{\mathrm{d}}$ if there are free radio resources. Whenever the higher priority queue is empty and there are free radio resources, a *lower priority data packet* will be transmitted with rate $\min(N - v,\, l)\mu_{\mathrm{d}}$.

3.2.1. Performance metrics

Let $\pi(v, h, l)$ be the steady-state probability of the PQBM continuous time Markov chain. The new voice call blocking probability and the handoff voice call blocking probability follow the same idea aforementioned, but taking into account the random variable l,

$$P_{nc} = \sum_{v \geqslant Kv}^{N} \sum_{h=0}^{Bh} \sum_{l=0}^{Bl} \pi(v, h, l), \tag{7}$$

$$P_{ha} = \sum_{h=0}^{Bh} \sum_{l=0}^{Bl} \pi(N, h, l). \tag{8}$$

The *higher priority data packet* blocking probability is

$$P_{hd} = \sum_{v=0}^{N} \sum_{l \geqslant Bl-Kd}^{Bl} \pi(v, Bh, l), \tag{9}$$

and, *lower priority data packet* blocking probability is given by:

$$P_{ld} = \sum_{v=0}^{N} \sum_{h=0}^{Bh} \pi(v, h, Bl) \tag{10}$$

The throughput of *higher priority* and *lower priority data packets* are, respectively, given by:

$$X_{hd} = \sum_{v=0}^{N-1} \sum_{\min(N-v,h)>0} \sum_{h>0} \min(N - v, h)\mu_d \pi(v, h, l), \tag{11}$$

and

$$X_{ld} = \sum_{v=0}^{N-1} \sum_{\min(N-v,l)>0} \sum_{l>0} \min(N - v, l)\mu_d \pi(v, 0, l). \tag{12}$$

Again, by means of Little's law, the mean delay of *higher priority* and *lower priority data packets* may be, respectively, computed from:

$$W_{hd} = \frac{\sum_{v=0}^{N} \sum_{h=1}^{Bh} \sum_{l=0}^{Bl} h\pi(v, h, l)}{X_{hd}}, \tag{13}$$

and

$$W_{ld} = \frac{\sum_{v=0}^{N} \sum_{h=0}^{Bh} \sum_{l=1}^{Bl} l\pi(v, h, l)}{X_{ld}}. \tag{14}$$

4. Numerical results

In this section we present some numerical results to assess the relative merits of the proposed protocol. We first present a sensitivity analysis of the FIFOBM and PQBM, discussing how the ratio $\lambda_{\mathrm{h,d}}/\lambda_{\mathrm{l,d}}$ can impact on their performance for different values of thresholds. In doing so, it is assumed that $\lambda_{\mathrm{h,d}} + \lambda_{\mathrm{l,d}} = 0.3$ and $\lambda_{\mathrm{h,d}}/\lambda_{\mathrm{l,d}} = 0.25$, 0.5, 1, 2, 3, 4, 6, 8, and 10. The proper selection of the threshold Kd plays a key role in the design of FIFOBM since it directly impacts on performance of data service controlling the QoS perceived by *higher priority* and *lower priority data packets*. Hence, we choose $Kd = 25\%$, 50%, 75%, and, of course, 100% of B, which corresponds to the FIFO scheme without BM. In the same way, we set the threshold Kd

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on PQBM equal to 75%, 85%, 95%, and 100% of *Bl* that corresponds to the PQ scheme without BM. Next, we compare the performance of FIFOBM and PQBM.

For performance evaluation we assume that there are 30 radio channels and the average service times for voice calls and data packets are 120 and 2 s, respectively. We set the threshold *Kv* equal to 28, which results on two guard channels shared by handoff voice traffic and data packet traffic. We also choose the voice call arrival rate equal to 0.15 calls/s and the percentage of new calls and handoffs as 70% and 30%, respectively, which results into new voice call and handoff voice call blocking probabilities of 8.63×10^{-3} and 2.37×10^{-4}, respectively. The sizes of the buffers of both FIFOBM and PQBM are set the same, so that $B = Bh = Bl = 50$.

4.1. Sensitivity analysis of FIFOBM

Fig. 1 shows the performance of FIFOBM for different values of *Kd*. It can be seen that the proper selection of *Kd* greatly affects the performance of this scheme in such a way that for larger *Kd*, lower the *lower priority data packet* blocking probability, and higher the *higher priority data packet* blocking probability. Both probabilities converges towards FIFO, i.e, when $Kd = 100\%$ of *B*. The reason for this is that larger the *Kd*, more the space available in the buffer to accommodate both data packet service classes, and less the space left to accommodate only the *higher priority data packets*; thus, when $Kd = 100\%$ of *B*, the buffer is equally shared among both data packet service classes. Therefore, there is a performance trade off between the QoS perceived by the *higher* and the *lower priority data packets*, so that by means of the selection of the *Kd*, it is possible to decrease the *higher priority data packet* blocking probability at the cost of an increase in the *lower priority data packet* blocking probability.

4.2. Sensitivity analysis of PQBM

The results from Fig. 2 show that, under the assumptions and the configurations made, the *lower priority data packet* blocking probability is unaffected when the ratio $\lambda_{\mathrm{h,d}}/\lambda_{\mathrm{l,d}}$ increases and the total offered data traffic keeps unchanged. However, the QoS perceived by *higher priority data packets* is drastically improved as the threshold *Kd* decreases. The reason of this is that smaller the *Kd*, larger is the shared area on the lower priority buffer, so that more *higher priority data packets* may be stored on that buffer when the higher priority buffer is full.

4.3. Performance comparison study

In general, Fig. 3 reveals that from blocking's standpoint, splitting data traffic into different priority buffers is better than accommodating it into only one buffer. However, the presence of a BM mechanism in FIFOBM

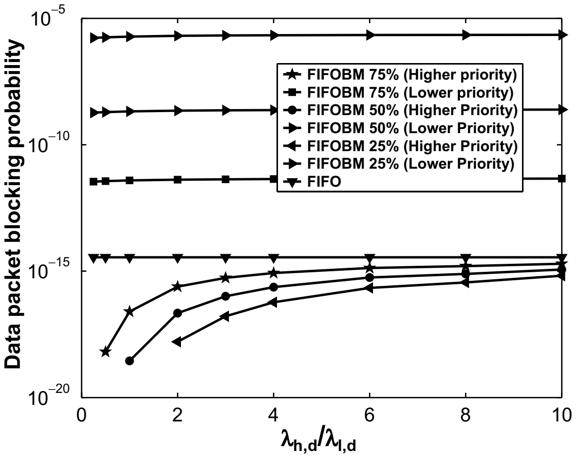

Fig. 1. Data packet blocking probability versus $\lambda_{\mathrm{h,d}}/\lambda_{\mathrm{l,d}}$.

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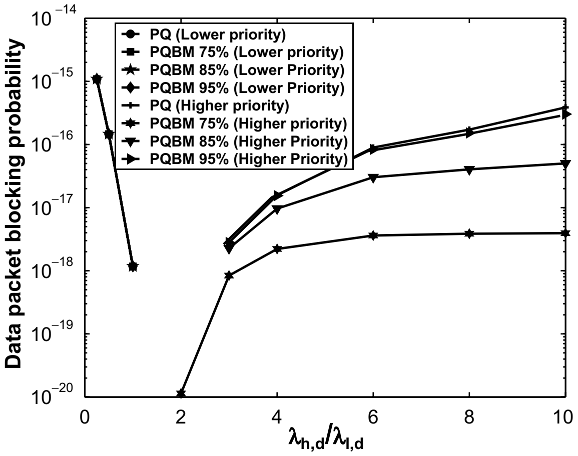

Fig. 2. Data packet blocking probability versus $\lambda_{h,d}/\lambda_{l,d}$.

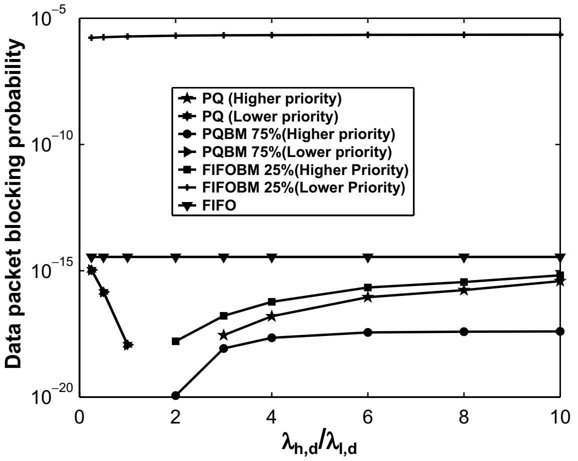

Fig. 3. Data packet blocking probability versus $\lambda_{h,d}/\lambda_{l,d}$.

can approach the QoS perceived by *higher priority data packets* on this scheme to the PQ in terms of blocking probability. Thus, by setting the threshold *Kd* on FIFOBM equal to 25% of its buffer size, we see that the *higher priority data packet* blocking probability on FIFOBM becomes close to the PQ, but because the existing performance tradeoff between data packets service classes in FIFOBM, the *lower priority data packet* blocking probability is much higher in FIFOBM than in PQ. However, since data service can tolerate some degree of degradation, the result in terms of blocking probability is acceptable. We also can see in that Figure that the BM mechanism in PQBM can increase the difference between the performance of *higher priority data packet* in PQBM and FIFOBM, improving the QoS perceived by that data packet service class, and, at the same time, keeping lower the *lower priority data packet* blocking probability. Still in that Figure, we highlight that although FIFO cannot deal with data service classes differentiation, its performance is attractive since it keeps the same low blocking probability for both service classes irrespective of the ratio $\lambda_{h,d}/\lambda_{l,d}$. Additionally, it is simple to manage and, this way, arise as an alternative to be deployed by wireless network operators in multi-service scenarios.

Fig. 4 shows that both data packet service classes in FIFOBM perceive the same mean delay perceived by a packet into the higher priority data buffer of PQBM irrespective of the ratio $\lambda_{h,d}/\lambda_{l,d}$. It also shows that the

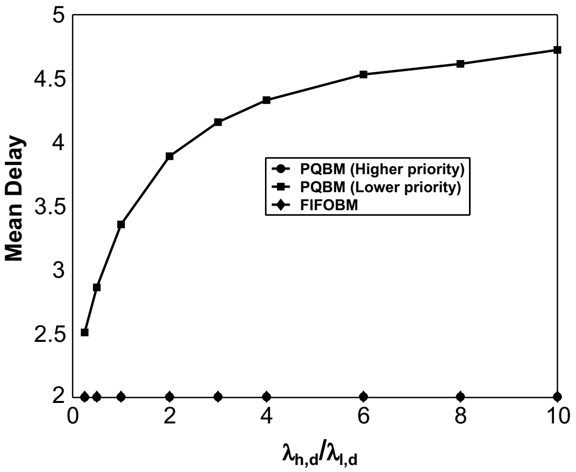

Fig. 4. Mean delay versus the $\lambda_{h,d}/\lambda_{l,d}$.

mean delay perceived by *lower priority data packets* in PQBM increases as the *higher priority data packet* traffic increases. The reason of this is the scheduling discipline employed by PQ, which ties the transmission of a data packet in the lower priority buffer to the occupancy of the higher priority buffer.

5. Conclusion

This work investigates the performance of FIFOBM and PQBM in a multi-service wireless network. The proposed protocols can cope with service classes differentiation by integrating TM mechanism in order to ensure the QoS requirements of each service class. Numerical results showed that FIFO only with guard channel based CAC may be deployed by wireless network operators in multi-service scenarios when simplicity is desired on the design and maintenance of the system. However, when service differentiation in the packet level is really needed, FIFO cannot cope with, so FIFOBM may be perfectly used as long as the performance tradeoff between the QoS perceived by the data packet service classes in this scheme being respected. This tradeoff dictates that an improvement on the QoS perceived by *higher priority data packets* results in a QoS degradation perceived by the *lower priority data packets*. In spite of it, both service classes perceive the same mean delay which is an advantage of FIFOBM.

With respect to the performance of PQBM, it was showed that it outperforms FIFOBM. Additionally, the presence of BM into the lower priority buffer results in a substantial improvement on the QoS perceived by *higher priority data packets* without seriously affecting the QoS perceived by *lower priority data packets*. Thus, PQBM may be viewed as a very attractive candidate in current (2.5G and 3G) and next (4G) multi-service wireless networks.

There are a number of issues that will be considered in our future research:

1. The guard channel based-CAC presented in this work is static. We are currently considering using the dynamic call admission control scheme such as the one presented in [8] to handle multi-service systems.
2. As aforementioned, the wireless channel used in this work is error-free. However, it is well-known that wireless networks have an unreliable channel that experiences bursty errors. In order to make the PQBM more realistic, we are currently considering using the widely studied Gilbert-Elliot channel model [22,23]. That channel model has two states: good or bad, in such a way that when the channel is in the bad state, transmission of a packet results in packet loss and requires re-transmission.
3. In order to avoid bandwidth monopolization of *higher priority data packets* in PQBM, we are currently considering using a second threshold in the lower priority buffer in such a way that if its occupancy is equal to or greater than this threshold, the available radio resources will be shared by both data packet service classes.

4. The proper selection of the thresholds in the buffer plays a key role in the design of FIFOBM and PQBM and may be viewed as an optimization problem. We are currently considering using a Markov decision process to derive the optimal setting.

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References

[1] Li B, Li L, Li B, Sivalingam KM, Cao X-R. Call admission control for voice/data integrated cellular networks: performance analysis and comparative study. IEEE J Select Areas Commun 2004;22(4):706–18.

[2] Chen W-Y, Wu J-LC, Liu H-H. Performance analysis of radio resource allocation in GSM/GPRS networks. Proceedings of vehicular technology conference 2002:24–8.

[3] Cgung S-P, Chien S-C. Analysis of multiservice cellular networks with asymmetrical traffic and handoff queue. Comput Commun 2005;28(8):864–79.

[4] Diederich J, Zitterbart M. Handoff prioritization schemes using early blocking. IEEE Commun Surveys Tutor, Second Quarter 2005;7(2):26–45.

[5] Wey Y, Lin C, Ren F, Raad R, Dutkiewiez E. Dynamic handoff scheme in differentiated QoS wireless multimedia networks. Comput Commun 2004;27(10):1001–11.

[6] Yavuz EA, Leung VCM. A pratical method for estimating performance metrics of call admission control schemes in wireless mobile networks. Proceedings of Wireless Communications and Networking Conference 2005:1254–9.

[7] Niyato D, Hossain E. Call admission control for QoS provisioning in 4G wireless networks: issues and approaches. IEEE Network 2005(September/October):5–11.

[8] Ogbonmwan SE, Li W. Multi-threshold bandwidth reservation scheme of an integrated voice/data wireless network. Comput Commun 2006;29:1504–15.

[9] Janevski T. Traffic analysis and design of wireless IP network. Artech House; 2003.

[10] Lu S, Bharghavan V, Srikant R. Fair scheduling in wireless packet networks. Proceedings of ACM SIGCOMM'97 1997:63–74.

[11] Kim N, Yoon H. Wireless packet fair queueing algorithms with link level retransmission. Comput Commun 2005;28(7):713–25.

[12] Staica I, Ng TSE, Zhang H. Packet fair queuing algorithms for wireless networks with location-dependent errors. Proceedings of IEEE INFOCOM'98 1998:1103–11.

[13] Vaidya N, Bahl P, Gupta S. Distributed fair scheduling in a wireless LAN. Proceedings of ACM MOBICOM'OO 2000:167–78.

[14] Yao W-M, Chen Y-C. An enhanced buffer management scheme for fast handover protocol. Proceedings of distributed computing systems workshops 2004:896–901.

[15] Huang Y, Fapejuwo AO. Integrated call admission control and packet scheduling for multimedia direct sequence code division multiple access (DS-CDMA) wireless networks. Proceedings of vehicular technology conference 2004:2673–7.

[16] Meo M, Marsan MA. Resource management policies in GPRS systems. Perform Evaluat 2004;56(1–4):73–92.

[17] Lindemann C, Thummler A. Performance analysis of the general packet radio service. Comput Networks 2003;41(1):1–17.

[18] Kang RJ, Chang HP, Chang RC. A seamless vertical handoff scheme. Proceedings of firts international conference on wireless internet 2005:64–71.

[19] Frattasi S, Fathi H, Fitzek FHP, Prasad R, Katz MD. Defining 4G technology from the user's perspective. IEEE Network 2006(January/February):35–41.

[20] Kim J, Jamalipour A. Traffic management and QoS provisioning in future wireless IP networks. IEEE Pers Commun 2001;8(5):46–55.

[21] Song W, Jiang H, Zhuang W, Shen XS. Resource management for QoS support in cellular/WLAN interworking. IEEE Network 2005(September/October):12–8.

[22] Gilbert EN. Capacity of a burst-noise channel. Bell Sys Techn J 1960(39):1253–65.

[23] Elliot EO. Estimates of error rates for codes on burstnoise channels. Bell Syst Techn J 1963(42):1977–97.

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