# Optimizing the Performance of Mobile Communications Systems using a Queue-per-Transceiver Handover Priority Technique

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**Abstract.** This paper analyses an alternative traffic queuing model for mobile communications systems. According to the proposed model, the queue of handover calls is separated to each of the used transceivers of a base transceiver station that covers a particular area. Fixed Channel Assignment and TDMA are considered, while the proposed technique is compared to the classic queuing model. The comparison results show that the performance of the proposed model is optimized under low and normal traffic conditions.

## 1 Introduction

Cellular radio communication networks are based on the division of the entire service area into multiple adjacent cells, in order to reuse the same frequency band in distance cells. In every cell is allocated a fixed number of channels (Fixed Channel Assignment - FCA), each of those is divided in time, according to the Time Division Multiple Access (TDMA) technique. This access technique is widely used to second generation mobile networks (2G) around the world (such as GSM and TDMA IS -136), as long as to some of the new coming 3rd generation (3G) systems.

A new call originated in a cell may be blocked and cleared from the system, if all the channels assigned to the related base station are in use. A channel remains allocated to a mobile user until, either its call is completed in the cell, or it crosses the cell boundary, requiring a new channel frequency to continue. This procedure that transfers an ongoing call from one cell to another is called handover. Obviously, a handover attempt that finds all channels occupied in the target cell will be forced to terminate unsuccessfully, something that is clearly less desirable than the blocking of the new calling attempts.

Handover prioritization schemes result in a decrease of handover failures and in an increase of new call blocking probability that, in turn, reduces the total admitted traffic. The basic concept of these strategies is to reserve a number of channels called guard channels exclusively for handovers [1, 2, 3]. Yet, another effective handover priority scheme is the fractional guard channel policy, according to which free channels are assigned to new calls with a state-depended probability [4, 5].

The queuing of the blocked handover attempts, along with the use of guard channels, has been proved to be an efficient technique for the optimization of the call forced termination probability [1, 2, 3, 6, 8]. According to this technique, if a handover attempt finds all channels in the target cell occupied, then it can be queued. When a channel is released in the cell, it is assigned to the next handover call waiting in the queue, if any. If more than one handover call is in the queue, the first in - first out (FIFO) queuing discipline is used. Assuming that the queue size is finite, a handover call attempt that finds the queue fully occupied, will fail and drop by the system.

This paper analyses an alternative queuing method, based on the Architecture of FDMA/TDMA wireless networks, where a number of transceivers (TRX's) cover a particular area. In each of the TRX's, a frequency is registered. According to the TDMA access technique, each TRX frequency is divided in time, which results in the increment of the available channels in a cell. The basic concept of the proposed model is to separate the queuing of the blocked handover calls in each of the TRX's of the cell, instead of using one queue for the entire cell. Section 2 presents a brief description of the classical handover queuing policy is presented. The mathematical analysis of the proposed concept is described in section 3. In section 4, the efficiency of the proposed model, compared to the classical queuing policy is presented. Finally, section 5 presents the concluding remarks.

## 2 Handover Queuing Policy

It is assumed that both new and handover call attempts are generated according to a Poisson point process with mean rates per cell of $\lambda_n$ and $\lambda_h$ respectively. The ratio $\alpha$ of the average handoff attempt rate to the total average call origination rate is defined as:

$$\alpha = \frac{\lambda_h}{\lambda_h + \lambda_n} \tag{1}$$

The channel holding time $T_H$ is approximated to have an exponential distribution with mean $\overline{T}_H$ ($\triangleq 1/\mu_H$). Moreover, the offered load $p$ in the cell is defined as:

$$p = (\lambda_n + \lambda_h)/\mu_H \tag{2}$$

The time for which a mobile is in the handover area is defined as the dwell time of the mobile in the handover area and is denoted by the random variable $T_Q$. For simplicity of analysis, it is assumed that this dwell time is exponentially distributed with mean $\overline{T}_Q$ ($\triangleq 1/\mu_Q$). Let $E_j$ be the system state, when $j$ is the sum of the number of channels being used in the cell and the number of handover call attempts in the queue. Also, $P_j$ represents the steady-state probability that the system is in state $E_j$. Assuming that there are $C_h$ guard channels exclusively for the handover calls among the $C$ channels in total, then, as in the usual way for birth-death processes, the probability distribution $P_j$ is easily found to be [1]:

$$P_j = \begin{cases} \dfrac{p^j}{j!} P_0, & for \quad 0 \le j \le C - C_h \\ \dfrac{p^j a^{j-(C-C_h)}}{j!} P_0, & for \quad C - C_h + 1 \le j \le C \\ \dfrac{p^j a^{j-(C-C_h)}}{C! \prod_{i=1}^{j-C} \left( C + i \dfrac{\mu_Q}{\mu_H} \right)} P_0, & for \quad C + 1 \le j \le C + K \end{cases} \tag{3}$$

where $P_0$ is given by

$$P_0 = \left[ \sum_{j=0}^{C-C_h} \frac{p^j}{j!} + \sum_{j=C-C_h+1}^{C} \frac{p^j a^{j-(C-C_h)}}{j!} + \sum_{j=C+1}^{C+K} \frac{p^j a^{j-(C-C_h)}}{C! \prod_{i=1}^{j-C} \left( C + i \frac{\mu_Q}{\mu_H} \right)} \right]^{-1} \tag{4}$$

The probability of blocking for a new call, denoted as $P_B$, is the sum of the probabilities that the state number in the cell is larger than or equal to $C - C_h$. Hence:

$$P_B = \sum_{j=C-C_h}^{C+K} P_j \tag{5}$$

A given handover attempt that joins the queue will be successful if both of the following events occur: 1) all of the attempts that joined the queue earlier than the given attempt have been disposed, 2) a channel becomes available when the given attempt is at the first position in the queue so is the following to be served. All the above has to occur before the mobile moves out of the handover area. So, a given handover attempt will fail with probability $P_{fh}$, if either there is no free position in the queue (all $K$ positions of the queue are occupied) or, for any reason, it abandons the queue. Noting that arrivals that find $k$ attempts in queue enter position $k+1$, this can be stated mathematically as:

$$P_{fh} = P_{C+K} + \sum_{k=0}^{K-1} P_{C+k} P_r \{\text{attempt fails given it enters the queue in position k} + 1\} \tag{6}$$

Using the analysis presented in [1], the handover failure probability can be expressed as

$$P_{fh} = P_{C+K} + \sum_{k=0}^{K-1} P_{C+k} \frac{(k+1)\mu_Q}{C\mu_H + (k+1)\mu_Q} \tag{7}$$

A call that is not blocked, can either complete successfully, or be forced to terminate before its completion. This probability of a call forced termination $P_F$ represents the fraction of calls that succeed in each of the first $(k-1)$ handover, which they require, but fail during their $k^{th}$ attempt. In order to calculate this probability, it is necessary to define some other probabilities. The first one is the probability of a handover failure $P_{fh}$. Moreover, as long as not all calls that are initially assigned to a channel require handover, two probabilities that can be related to the system parameters are introduced. The probability $P_N$ represents the case that a non-blocked new call will require at least one handover before completion:

$$P_N = \Pr\{T_M > T_n\} = \int_0^\infty \left[1 - F_{T_M}(t)\right] f_{T_n}(t)dt = \int_0^\infty e^{-\mu_M t} f_{T_n}(t)dt \tag{8}$$

The probability $P_H$ represents the case that a call, which has already been handed off successfully, will require another handover before completion:

$$P_H = \Pr\{T_M > T_h\} = \int_0^\infty \left[1 - F_{T_M}(t)\right] f_{T_h}(t)dt = \int_0^\infty e^{-\mu_M t} f_{T_h}(t)dt \tag{9}$$

From the users point of view, the probability $P_F$ of a non-blocked call to be eventually forced to terminate, is more significant from $P_{fh}$. Therefore [1]:

$$P_F = \sum_{\nu=1}^{\infty} P_{fh}[P_N(1-P_{fh})^{\nu-1} {P_H}^{\nu-1}] = \frac{P_{fh}P_N}{1-P_H(1-P_{fh})} \tag{10}$$

Finally, the waiting time of a queued handover call is here defined as the time that an arbitrarily selected waiting handover call spends from the instant it is accepted by the system to the instant it successfully accesses a free channel. We denote $W_h(j)$ the waiting time of a queued handover call, given that the state of the system is $E_j, C \leq j \leq C+K-1$, when the call just arrives at the system and waits in the queue. The waiting time $W_h(j)$ can be obtained by [2]:

$$W_h(j) = -\frac{1}{\mu_Q} \ln \frac{C\mu_H}{C\mu_H + (j-C+1)\mu_Q} \tag{11}$$

where "ln" is the natural logarithmic function. Consequently, the average waiting time of a queued new call, denoted by $\overline{W_h}$, can be obtained by

$$\overline{W_h} = \frac{\sum_{j=C}^{C+K-1} P_j W_h(j)}{\sum_{j=C}^{C+K-1} P_j} \Rightarrow \overline{W_h} = \frac{\sum_{j=C}^{C+K-1} \left[ P_j \left( -\frac{1}{\mu_Q} \ln \frac{C\mu_H}{C\mu_H + (j-C+1)\mu_Q} \right) \right]}{\sum_{j=C}^{C+K-1} P_j} \quad \textbf{(12)}$$

## 3 The Proposed Queuing Model

In the proposed model, it is assumed that a number of $M$ transceivers (TRX) cover the same cell. In each of these $M$ Transceivers, there are guard channels and a finite storage waiting queue, assigned exclusively for the handover call attempts, while there is no similar queue for the new call attempts. The size of the $M$ waiting queues is equal, as the number of the guard channels in each TRX. Thus, assuming that according to the classic queuing policy, there are $C_h$ channels, among the $C$ channels of the cell, assigned exclusively for handover calls and $K$ positions in the queue, then, according to the proposed model, every TRX would offer $C_h / M$ channels assigned exclusively for handover calls and $K / M$ positions in the queue.

The separation of calls in each TRX occurs in a specific way. Every new call or handover attempt is classified and served in a random way by one of the $M$ TRX's, until all channels in a cell are occupied. At this point, an incoming new call is blocked, while every handover attempt enters sequentially one of the queues of the system. Supposing that there are $M$ handover attempts, these are shared one per queue. In the same way, the procedure continues, until all the $K$ positions of the $M$ queues are fully occupied, therefore every new handover attempt fails.

Because of the assumption that the $M$ TRX's are similar, hence they have the same number of channels and the same queue size, the expressions for the state probabilities $P_j$ are the same for each TRX. These expressions indicate the probability that one TRX is in state $E_j$. So, using the expressions (3) and (4), it is possible to find the state probabilities $P_{j1}$, $P_{j2}$, …, $P_{jM}$ for every TRX.

In order to calculate the overall new call and handover blocking probabilities, it is necessary to provide some extra concerns. A new call is blocked, if it can not enter service by none of the $M$ TRX's. This occurs, if the number of the available channels in every TRX is less than or equal to $C_h / M$, when the call is originated. Representing this probability by $P_{Bnew}$, then

$$P_{Bnew} = P_{B1} \cdot P_{B2} \cdot \cdots \cdot P_{BM} = \sum_{j1=\frac{C-C_h}{M}}^{\frac{C+K}{M}} P_{j1} \cdot \sum_{j2=\frac{C-C_h}{M}}^{\frac{C+K}{M}} P_{j2} \cdot \cdots \cdot \sum_{jM=\frac{C-C_h}{M}}^{\frac{C+K}{M}} P_{jM} \qquad \textbf{(13)}$$

As it is already mentioned earlier, a given handover attempt that joins one of the $M$ queues will be successful, if all of the attempts that joined the queue earlier have been disposed and a channel becomes available, when the given attempt is at the first position in the queue. Hence, a given handover attempt will fail if either there is no free position in none of the queues or if, for any reason, it abandons the queue.

To find the total handover failure probability for the proposed model, which is represented by $P_{fhnew}$, the way of allocation of the handover attempts in a queue has to be taken into account. As mentioned earlier, the $M$ queues are occupied with calls sequentially. Hence, a given handover attempt fails according to the following possible cases.

*Case I:* There is no free position for a handover attempt to enter any of the $M$ queues. In other words, every TRX is in state $E\frac{C+K}{M}$. Thus, the handover failure probability is equal with the term:

$$P_I = P_{\frac{C+K}{M},1} \cdot P_{\frac{C+K}{M},2} \cdots P_{\frac{C+K}{M},M} \qquad \textbf{(14)}$$

*Case II:* The $M$ queues have the same number of occupied positions $k$, where $0 \le k < \frac{K}{M} - 1$, so a handover attempt will enter position $k+1$ in one of the $M$ queues with equal probability. The handover failure probability is equal with the term of (7) about failure in $k+1$ position, multiplying by $M$ for the equal probability of entering in any of the $M$ queues, multiplying by the probability that every TRX is in state $E\frac{C+k}{M}$. Hence, the following term is concluded:

$$P_{II} = M \cdot P_{\frac{C+k}{M},1} \cdot P_{\frac{C+k}{M},2} \cdots P_{\frac{C+k}{M},M} \cdot \frac{(k+1)\mu_Q}{C\mu_H + (k+1)\mu_Q} \qquad \textbf{(15)}$$

*Case III:* One of the $M$ queues has one position more occupied than the other $(M-1)$, thus one queue has $k+1$ positions occupied and each of the other $(M-1)$ queues has $k$ occupied positions, $0 \le k < \frac{K}{M} - 1$. Assuming that this case can happen with equal probability for each of the $M$ queues, the result term is multiplied by $M$. In this case, the handover attempt will enter position $k+1$ in one of the $(M-1)$ queues that have $k$ positions occupied, with equal probability. Thus, the final term is multiplied by $(M-1)$. The handover failure probability is equal with the term of (7) about failure in $k+1$ position, multiplying by the state probabilities of the TRX. Because of the similarity of the TRX's, it is assumed randomly that the TRX No1 has $k+1$ positions occupied in the queue. Finally, the following term is produced:

$$P_{III} = (M-1)\cdot M \cdot P_{\frac{C+k+1}{M},1} \cdot P_{\frac{C+k}{M},2} \cdots P_{\frac{C+k}{M},M} \frac{(k+1)\mu_Q}{C\mu_H + (k+1)\mu_Q} \tag{16}$$

*Case IV:* $m$ of the $M$ queues, $2 \le m < M$, have one position more occupied than the other $(M-m)$, thus $m$ have $k+1$ positions occupied and the other $(M-m)$ have $k$ positions occupied, $1 \le k < \frac{K}{M} - 1$. Assuming that this case can occur with equal probability for each of the $M$ queues, the result term is multiplied by $M$. The handover attempt will enter in position $k+1$ in one of the $(M-m)$ queues that own the fewest occupied positions, constrainedly. Thus, the handover failure is equal with the term of (7) about failure in $k+1$ position, multiplying by the state probabilities of the TRX. Because of the similarity of the TRX's, it is assumed that the first $m$ TRX's have $k+1$ positions occupied in their queue. Hence, the following term is derived:

$$\begin{aligned} P_{IV} &= (M-m)\cdot M \cdot P_{\frac{C+k+1}{M},1} \cdot P_{\frac{C+k+1}{M},2} \cdots P_{\frac{C+k+1}{M},m} \cdot P_{\frac{C+k}{M},m+1} \cdots \\ &\cdots P_{\frac{C+k}{M},M} \frac{(k+1)\mu_Q}{C\mu_H + (k+1)\mu_Q} \end{aligned} \tag{17}$$

Finally, the cases above can be combined in order to find the expression for the handover failure probability for the proposed model. Specifically, the desired probability comprises by the sum of $P_{II}$, $P_{III}$ and $P_{IV}$, for every possible position $k$ of a call in the queue ($0 \le k < \frac{K}{M} - 1$). In this sum, the term $P_I$ is added, to represent the case that all the queues are fully occupied. Hence:

$$\begin{aligned} P_{fhnew} &= P_I + \sum_{k=0}^{\frac{K}{M}-1}\left(P_{II} + P_{III} + P_{IV}\right) \Leftrightarrow \\ P_{fhnew} &= P_{\frac{C+K}{M},1} \cdot P_{\frac{C+K}{M},2} \cdots P_{\frac{C+K}{M},M} + \\ &+ \sum_{k=0}^{\frac{K}{M}-1}\left\{\left(M \cdot P_{\frac{C+k}{M},1} \cdot P_{\frac{C+k}{M},2} \cdots P_{\frac{C+k}{M},M} \cdot \frac{(k+1)\mu_Q}{C\mu_H + (k+1)\mu_Q}\right) + \right. \\ &\left. + \left(\sum_{m=1}^{M-1}(M-m)\cdot M \cdot P_{\frac{C+k+1}{M},1} \cdot P_{\frac{C+k+1}{M},2} \cdots P_{\frac{C+k+1}{M},m} \cdot P_{\frac{C+k}{M},m+1} \cdots P_{\frac{C+k}{M},M} \frac{(k+1)\mu_Q}{C\mu_H + (k+1)\mu_Q}\right)\right\} \end{aligned} \tag{18}$$

## 4 Numerical Examples and Discussion

In order to compare the proposed scheme with the classic queuing policy, it is assumed that there are 3 TRX's in a cell. Let each TRX has 7 traffic channels, 1 guard channel exclusively for the handover calls and a queue with one or three positions for the blocked handover calls. Hence, there are 21 channels in total ($C = 21$), 3 guard channels ($C_h = 3$) and two queue sizes of $K = 3$ and $K = 9$ for the blocked handover calls. The cell radius is considered to be $R = 1$ Km. The average unencumbered message duration was taken as $\overline{T}_M$ =90 sec and a maximum mobile speed of $V_{\max} = 80$ Km/h was assumed. According to the analysis in [1], the mean value of the channel holding time was obtained as $\overline{T}_H$ ($\triangleq 1/\mu_H$) =51sec. Also, the mean dwell time in the queue of a handover attempt was assumed to be $\overline{T}_Q (\triangleq 1/\mu_Q) = \overline{T}_H/10$. We employ the fixed-point method to determine the values of $a$, using the following procedure:

- An initial guess for $a$ is chosen, i.e. $a = 0{,}2$. Then, the state probabilities $P_j$ are calculated for this value of $a$ from (3).
- The new value of $a$ is computed, considering that in the steady-state of the system, the handover arrival rate equals the handover departure rate:

$$\lambda_h = \sum_{j=0}^{C+K} P_j \min[j, C]\mu_H \tag{19}$$

Note that in (19), the factor $\min[j, C]\mu_H$ accounts for the rate of handover calls moving out of the cell, when there are $C$ calls in progress or $(j - C)$ blocked handover calls waiting in the queue.

Using (1) and (2), equation (19) converts to

$$\alpha = \frac{1}{\mu_H p} \sum_{j=0}^{C+K} P_j \min[j, C]\mu_H \tag{20}$$

- The old value of $a$ is compared with the one from (20). If their difference is greater than $10^{-4}$, then the computation process is repeated until the two values of $a$ converge.

Figure 1 shows the new call blocking probabilities $P_B$, $P_{Bnew}$ for the classic and the proposed queuing method, respectively, as functions of the offered load $p$, for two different values of queue size $K$. It is obvious that there is a significant improvement to the new call blocking probability using the proposed technique.

In figure 2, the Forced Termination Probabilities $P_F$, $P_{Fnew}$ as functions of offered load $p$, for two different values of queue size $K$, are shown. The proposed technique proves here to be quite efficient too, but only to low and medium traffic conditions. As it is shown in figure 2, as the offered traffic load of the system increases, there is a worsening for the forced termination probability.

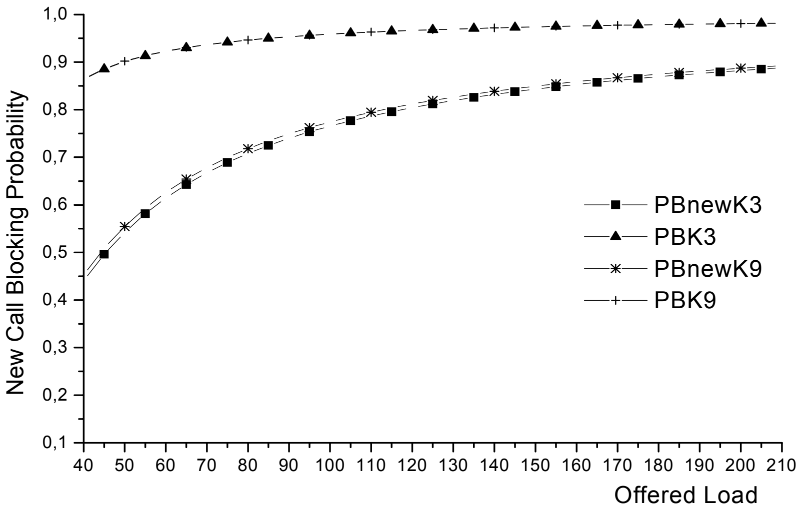


**Fig. 1.** New Call Blocking Probability for the proposed and the classic model.

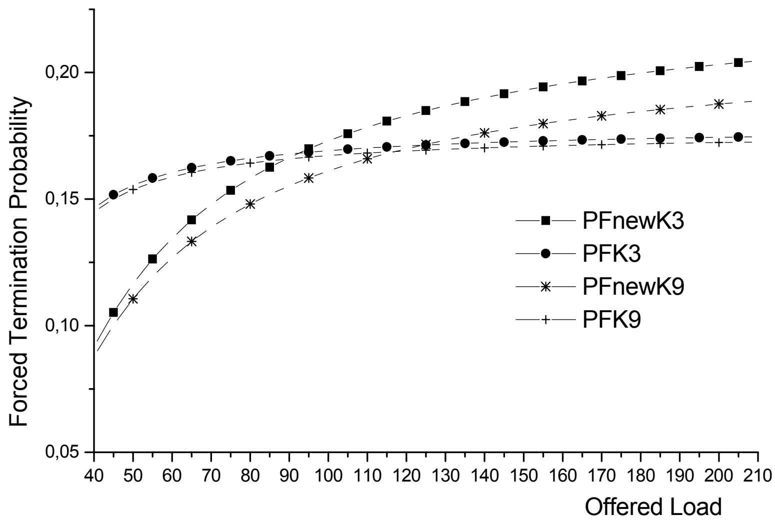


**Fig. 2.** Forced Termination Probabilities for the proposed and the classic model

Despite of the worsening to the forced termination probability, the system quality of service (QoS) is sufficiently improved with the proposed technique. The QoS is mainly determined from a cost function, which is often used in bibliography to infer the best utilization of the resources in a cell. This cost function is defined as the weighting sum of the new call blocking probability and the forced termination probability and can be expressed by the following formula:

$$CF = wP_F + (1 - w)P_B \tag{21}$$

The parameter $w$ is within the interval [0,1] and because of the more importance of the forced termination probability, it is usually set greater than 0,5. In figures 3 and 4, the cost functions for $w = 0{,}6$ and $w = 0{,}85$, respectively are plotted. The value $w = 0{,}6$ means that the QoS of the system is measured giving an importance to the performance of the handover calls, however taking into serious account the blocking of new calls too. In this case, the QoS of the proposed technique gives an excellent performance for all traffic conditions, compared to the classic queuing technique, as shown in figure 3.

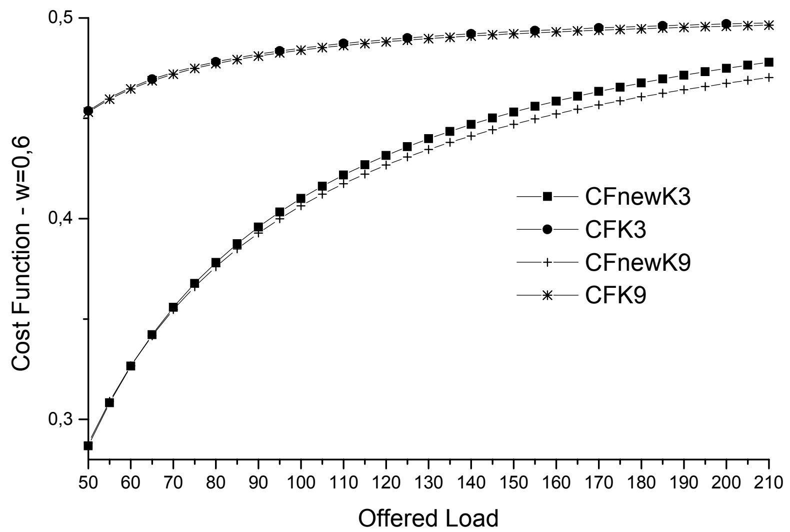


**Fig. 3.** QoS cost function for the proposed and the classic model for $w = 0{,}6$.

Setting a higher value for the parameter $w$, i.e. $w = 0{,}85$, more priority is given to the handover call blocking than the new call blocking, in order to measure the system QoS. As shown in figure 4, there is still a very sufficient improvement to the QoS under low, medium and normal traffic conditions, especially for a large queue size (i.e. $K = 9$).

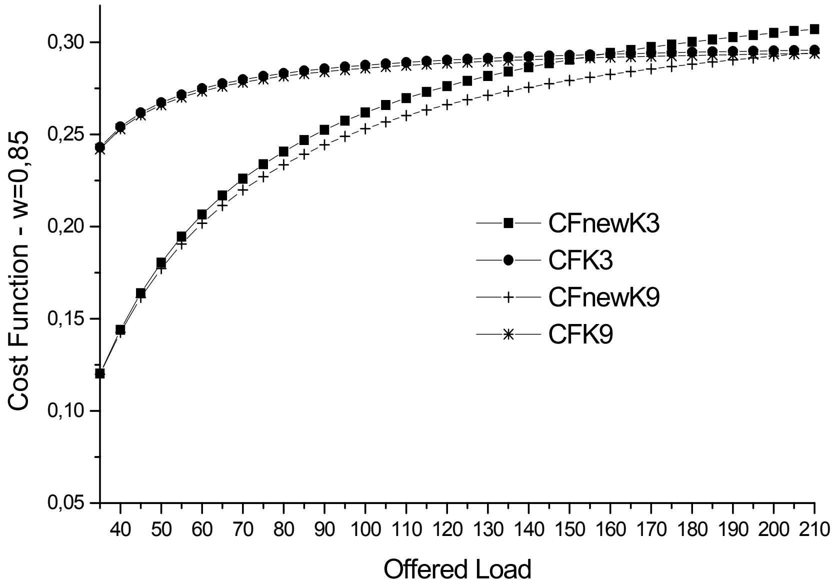


**Fig. 4.** QoS cost function for the proposed and the classic model for $w = 0{,}85$

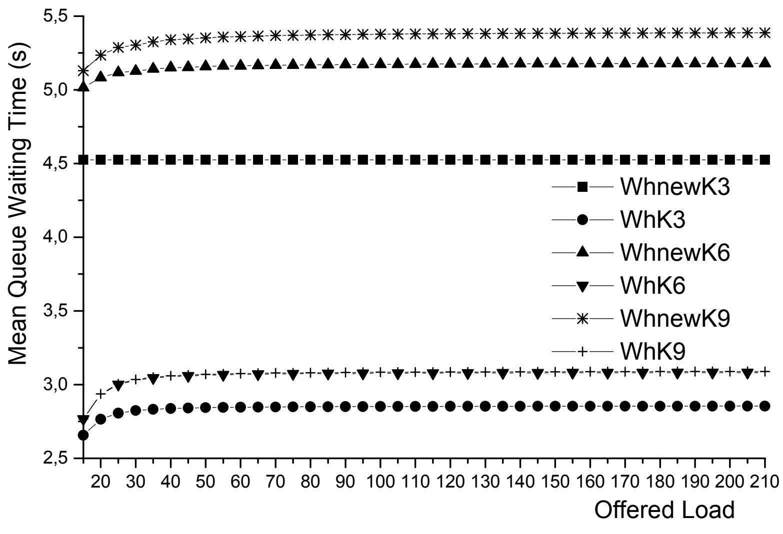


**Fig. 5.** Mean Call Waiting Time vs. Offered Load

Figure 5 shows the average waiting times of queued handover calls $\overline{W}_h$, $\overline{W}_{hnew}$ for the two techniques, as functions of the offered load $p$ for three different values of the queue size $K$. It is shown from this figure that the waiting time $\overline{W}_{hnew}$ for the proposed technique is larger than the time $\overline{W}_h$ for the classic technique. Specifically, the mean waiting times for the proposed technique are larger by a mean value of 2.5, 2.15 and 1.75 sec for $K = 9$, $K = 6$ and $K = 3$, respectively. This occurs due to the fact that in every TRX in the proposed technique, there are 7 channels, while in the classic technique there are 21 channels in total. Hence, in the proposed technique, a call enters service when one channel among seven becomes available, in regard to the one among 21 channels that has to become available for a call in the classic technique. Also, as the queue capacity for handover calls $K$ increases, $\overline{W}_h$ becomes larger for both techniques.

## 5 Conclusion

The behavior of an alternative queuing method for mobile radiotelephone systems with cellular structure, frequency reuse and handover, compared with the classical queuing policy, has been considered in this study. In both models, a number of channels are used exclusively for handover calls, while the remaining channels are used for both new and handover calls. Blocked calls are cleared from the system immediately. Handover call attempts can be queued for the time duration in which a mobile dwells in the handover area between cells. The difference between the two models is that in the proposed one, the queuing of the blocked handover calls is equally shared among the transceivers that cover a cell.

The comparison between the two models was made using the probabilities that qualify the performance of the system, as functions of the offered load. Specifically, the probability of blocking for the new call attempts, the probability of failure for the handover attempts and a cost function, which is the weighting sum of the above mentioned probabilities. It was figured that the performance probabilities are less for the proposed technique, for low, medium and normal values of the offered load. As the offered load becomes extremely high, the classical handover queuing model performs more efficiently. The average mean waiting times for the queued handover calls were also obtained and it was noticed that in the proposed model, the queued calls have to wait more seconds until they finally can be served. A large queue size leads also in to an increment of the waiting time in the queue; hence this size needs to be finite.

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