QoS Evaluation of Cellular Wireless Networks with Non-Classical Traffic and Queuing Handoff Requests

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Abstract. In this paper, a model is proposed for the QoS evaluation of cellular wireless networks by queuing handoff requests instead of reserving guard channels. Usually, prioritized handling of handoff calls is done with the help of guard channel reservation. Using the proposed model, the performance of the networks is estimated considering gamma inter-arrival and general service time distributions. The performance is evaluated with different mobility and compared with that of guard channel scheme.

Keywords: Cellular wireless networks, non-classical traffic, mathematical model, guard channel, queuing, handoff.

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1 Introduction

The convenience of use and freedom to move anywhere at anytime making the cellular wireless networks popular among the users. Mobility of the users also poises a challenge to the network engineers for achieving the desired quality of service (QoS). Hence, mobility add new dimension in traffic patterns in terms of handoff. Wireless connectivity also influence different factors like the arrival and the departure of the calls of the system due to propagation condition and irregular user behaviour. So, the classical traffic model, in which both the inter-arrival and service times are assumed to be exponential, may not evaluate the performance of the cellular wireless networks correctly. Chlebus and Ludwin [3] have shown that handoff traffic is Poisson in non-blocking condition and claimed to be non-Poisson in a real environment due to blocking condition. In spite of that, they applied Erlang loss formula to calculate the blocking probability assuming Poissonian traffic and agreed that the results obtained are very good approximation. In [9], the authors showed that the cell traffic is smooth which implies that the inter-arrival time distribution cannot be exponential. Empirical studies of measured traffic traces have led to the wide recognition of non exponential time distribution for both arrival and departure [14, 2, 12]. Boggia *et. al.* [2], from the empirical data analysis, have reported (shown in Table 1) that in a well-established cellular wireless network, many phenomena (like propagation condition, irregular user behavour) become more relevant in addition to channel availability in influencing the call drop.

Table 1: Occurrence of call-dropping causes other than lack of channel in a cell. Source:Boggia *et. al.* [2]

Drop Causes	*Occurance*(%)
Electromagnetic causes	51.4
Irregular user behavior	36.9
Abnormal network response	7.6
Others	4.1

Therefore, all attempted calls cannot be successful to reach to the switching center for channel allocation. Under this situation, the call attempts may be assumed to follow Poisson distribution but the inter-arrival time of calls that need channel allocation in the switching center will not follow the exponential distribution [12, 11]. In [12], gamma inter-arrival and lognormal service time distributions have also been observed from the analysis of real-life empirical traffic data collected from the mobile switching center (MSC) of a service provider. In [11], a traffic model is developed based on these observations.

Hong *et.al.* [5] has suggested the guard channel scheme for priority processing of the handoff calls. They have established that the guard channel scheme improves the probability of dropping of the handoff calls. However, it may affect the probability of the new calls droppings and also the channel efficiency. To reduce these effects, dynamic or adaptive guard channel schemes were developed by researchers. Different techniques like channel status check [13], mobility prediction [10, 6] and guard channel sharing [7], have been proposed for dynamic allocation of guard channels. [13] used channel status check technique for dynamic guard channel reservation. In [10], a handoff prediction scheme is developed based on Markov model whereas in [6], Jayasuriya developed a scheme of mobility prediction for dynamic guard channel reservation. In [7], Liu *et.al.* used guard channel sharing scheme between voice and data users to improve performance. Though dynamic guard channel schemes improve the system performance, this creates the possibility of idle guard channels even when the new calls are being dropped for non-availability of channels. Therefore, queuing of handoff calls provides better alternative for assigning priority to handoff calls [8]. Louvros *et.al.* [8] evaluated the system with multiple queues (i.e. one queue for each TRX in a cell) along with guard channels. They have used Markov model assuming exponential inter-arrivals as well as service time distributions. However, in this work, queue is used for priority processing of handoff calls without using any guard channels. The performance of the proposed system is evaluated using the traffic model with gamma inter-arrival and general service time distributions. The evaluation of the proposed scheme is done in a single tier architecture equipped with a single queue for the handoff requests with different mobility (slow or fast). It has been established in this work that the same level of performance, as that of the scheme with guard channel, for the handoff calls can be achieved with the help of queuing.

2 Proposed Call Admission Algorithm

A mobile host, that needs handoff, has to travel through the overlapping zone for certain time (Tq) before leaving the current base station. If the handoff process is initiated by sending a handoff request, at the time of the mobile host entering into the overlapping area, then the request can be queued for maximum Tq time. The handoff request can be served iff a channel becomes free within Tq time. The proposed call admission control algorithm, in this work, is given below. A first come first serve (FCFS) queue is used for priority processing of handoff calls.

1. Start admission control
2. Define queue size (B)
3. if a handoff request arrives
4. start timer
5. if a free channel available
6. assign the channel
7. stop and reset timer
8. else if Queue is not full
9. put the call in Queue
10. any channel released, assign to a queued handoff call on FCFS basis
11. if a queued handoff call timed-out or actually leave the current base station
12. drop the handoff call from queue
13. end if

```
    else
      drop the handoff call
    end if
  end if
end if
if a new call arrives then
  if Queue is empty then
     Allocate a free channel if available to the new call
  else
   Drop the new call
  end if
end if
Stop
```

3 Mathematical Analysis

3.1 Traffic Model

In order to analyze the performance of a cellular wireless network with gamma inter-arrival time distribution, the arrival process is generalized by removing the restriction of the exponential inter-arrival times. If X_i be the time between the i^{th} and the $(i-1)^{th}$ call arrivals, then $(X_i \mid i = 1, 2, 3 \ldots, n)$ will represent the sequence of independent identically distributed random variables and hence the process will constitute a renewal process [1]. Assume F is the underlying distribution of X_i and S_k represents the time from the beginning till the k^{th} call arrival. Then

$$S_k = X_1 + X_2 + X_3 + X_4 + \ldots + X_k \tag{1}$$

$F^{(k)}$(t) denote the distribution function of S_k. For simplicity, we define

$$F^{(0)}(t) = \begin{cases} 1, t \geq 0 \\ 0, t < 0) \end{cases} \tag{2}$$

The moment generating function of a variable Z, with probability density function (pdf) f(z), is

$$M_Z(t) = E(e^{tZ}) = \int_{-\infty}^{\infty} e^{tz} f(z) dz \tag{3}$$

When Z has gamma pdf, the moment generating function of Z is obtained as

$$M_Z(t) = \left[1 - \frac{t}{\lambda}\right]^{-n} \tag{4}$$

where λ is the average arrival rate and n is a real number. Now, X_1 and X_2 are two independent inter-arrival times with gamma pdf, the moment generating function of $S_2 = X_1 + X_2$ can be written
$M_{X_1+X_2}(t) = M_{X_1}(t) \cdot M_{X_2}(t)$

$$= \left[1 - \frac{t}{\lambda}\right]^{-(n_1+n_2)} \tag{5}$$

which shows that the distribution of S_2 and in turn the distribution of S_k follows gamma distribution.
Next we determine the number of calls N(t) in the interval (0, t). Then, the process (N(t) | $t \geq 0$) is a discrete-state, continuous-time renewal counting process. It is observed that N(t) = n if and only if $S_n \leq t \leq S_{n+1}$. Then, the probability of [N(t) = n], i.e.

$$\begin{aligned} P[N(t) = n] &= P(S_n \leq t \leq S_{n+1}) \\ &= F^{(n)}(t) - F^{(n+1)}(t) \end{aligned} \tag{6}$$

When $F^{(n)}(t)$ is a Gamma distribution [12], then

$$\begin{aligned} P[N(t) = n] &= F^{(n)}(t) - F^{(n+1)}(t) \\ &= \frac{(\lambda t)^n}{n!} \cdot e^{-\lambda t} \end{aligned} \tag{7}$$

This shows that the gamma inter-arrival time is also the outcome of Poisson arrival.
Let 'n' call attempts are generated from Poisson sources with arrival 'λ'. Each call has the independent probability 'v' of successfully reaching to the switching center. If 'k' calls out of 'n' call attempts, arrive to the switching center in t time interval, then a sequence of 'n' Bernoulli trials is obtained and can be written as

$$P[Y(t) = k | N(t) = n] = {}^n c_k \cdot v^k \cdot (1-v)^{(n-k)}, \tag{8}$$

$$k = 0, 1, 2 \ldots, n$$

which may be simplified as

$$P[Y(t) = k] = \frac{(\lambda t v)^k}{k!} \cdot e^{-\lambda t v} \tag{9}$$

Therefore, arrival of calls to the switching center can still be modeled as a Poisson process with modified arrival rate (λ_m). So, the modified arrival rate (λ_m) can be obtained from equation (9) as $\lambda_m = \lambda \cdot v$.
Again, assume call holding time follow independent general distribution G. It is known that for $n \geq 1$ occurred arrivals in the interval (0, t), the conditional joint pdf of the arrival times $T_1, T_2, T_3, \ldots, T_n$ is given by

$$f[t_1, t_2, t_3, \ldots, t_n | N(t) = n] = \frac{n!}{t^n} \tag{10}$$

When a call arrive at time $0 \leq y \leq t$, from equation (10), the time of arrival of the call is independently distributed on (0, t). i.e.

$$f_Y(y) = \frac{1}{t}, 0 < y < t \quad (11)$$

The probability that this call is still undergoing service at time t, when it has arrived at time 'y', is given by 1 - G(t - y).

Then the unconditional probability, that the call is undergoing service at time 't', is

$p = \int_0^t [1 - G(t-y)] f_Y(y) dy$

$$= \int_0^t \frac{1 - G(x)}{x} dx \quad (12)$$

If 'n' calls have arrived and each has the independent probability 'p' of not completing by time 't', then a sequence of 'n' Bernoulli trials is obtained as,

$P[X(t) = j | N(t) = n] = {}^n c_j \cdot p^j \cdot (1-p)^{(n-j)}$, $j = 0, 1, \ldots, n$

which is simplified as

$P[X(t) = j] = \sum_{n=j}^{\infty} {}^n c_j \cdot p^j \cdot (1-p)^{(n-j)} \cdot \frac{(\lambda_m t)^n}{n!} \cdot e^{-\lambda_m t}$

$$= \frac{(\lambda_m tp)^j}{j!} \cdot e^{-\lambda_m tp} \quad (13)$$

If the number of channels in a cellular wireless network is 'C', then the probability of all C channels remain busy can be estimated as

$$P[X(t) = C] = \frac{(\lambda_m tp)^C}{C!} \cdot e^{-\lambda_m tp} \quad (14)$$

this is the non-classical model in which the inter-arrival time distribution is gamma and service time distribution is general. If service times are exponentially distributed with average arrival rate μ, then the general distribution G(x) can be written as

$G(x) = 1 - e^{-\mu x}$

Therefore,

$$\int_0^t \frac{1 - G(x)}{x} dx = \frac{1}{\mu} - \frac{e^{-\mu x}}{\mu} \quad (15)$$

hence, for t$\rightarrow \infty, \lambda_m tp = \lambda'_m = \frac{\lambda_m}{\mu}$

and for a steady state the equation (14) can be rewritten as

$$P[X(t) = C] = \frac{\frac{\rho^C}{C!}}{\sum_{i=0}^{C} \frac{\rho^i}{i!}} \quad (16)$$

where the denominator in the right hand side in equation (16) is the normalization factor and ρ is traffic intensity given as $\frac{\lambda_m}{\mu}$. This is known as Erlang's B formula [11] as well as classical model.

3.2 Estimation of Call Drop Probabilities

The new call will be dropped only when all C channels in the system is busy with arrival rate (λ_m). However, λ_m = λ_{m_1} + λ_{m_2} where λ_{m_1} is the arrival rate of new calls and λ_{m_2} is the arrival rate of handoff calls. Therefore, the probability of blocking of the new calls (P_B) may be written as

$P_B = P[X(t) = C]$

$$P_B = \frac{(\lambda_m tp)^C}{C!} \cdot e^{-\lambda_m tp} \quad (17)$$

Now, consider a system with C channels and queue size B. The handoff requests will terminate when the system is in state C+B or the user of a queued handoff call actually moved into the coverage area of the neighbouring cell before any channel become free. So, the probability, that a handoff call will be forcefully terminated, is equal to the probability of the system being in state N(t) = (C+B) + the probability of drop of a handoff call from the queue because of non-availability of a free channel within queue time. The system will accept both the new and the handoff calls as long as all C channels are not busy. Only handoff calls will be accepted for queuing when C channels are busy and B is not full. Therefore, the probability of the forced termination (P_{FT}) of the handoff calls may be written as

$$P_{FT} = P[X(t) = C + B] + P[DropfromQueue] \quad (18)$$

Now,

$P[X(t) = C + B]$
$= P[C\ channels\ and\ B\ Queue\ are\ occupied]$

$$= \frac{(\lambda_m tp)^C}{C!} \cdot e^{-\lambda_m tp} \times \frac{(\lambda_{m_2} tp)^B}{B!} \cdot e^{-\lambda_{m_2} tp} \quad (19)$$

Again to evaluate the P[Drop from queue], it is required to determine the distribution of the waiting time in queue that explained below.

3.3 Waiting Time Distribution

Assume, 'W' represents the waiting time in the queue in the steady state and w(t) denote the probability distribution function of W. Suppose, a call just arrives into the system. On arrival, it finds already 'n', where n < C, calls exist in the system. In that condition, the call, that just arrives, does not have to wait in the queue and it will be in service immediately. If a just arrived call finds already 'n', where n $\geq$ C, calls exist in the system then (n - C) calls are waiting in the queue. In that case, the just arrived call has to wait until the completion of (n - C + 1) calls. When all the channels are busy, then the service rate is μC.

Therefore, the probability of the waiting time (W) of call, that just arrives into the system and finds already n existing calls in the system, can be written as

$W(t) = P[n\ calls\ in\ the\ system]$
$\times\ P[completing\ n\ calls\ within\ t]$
which leads to

$$w(t) = \sum_{n=0}^{C} p_n \cdot G'(t)\ +\ \sum_{n=C+1}^{C+B} p_n \cdot G'(t) \qquad (20)$$

where G' is the first order derivative of the service time distribution G.

$$w(t) = \sum_{n=0}^{C} \frac{(\lambda_m tp)^n}{n!} \cdot e^{-\lambda_m tp} \cdot G'(t) + \sum_{n=C+1}^{C+B} \frac{(\lambda_{m_2} tp)^{(n-C)}}{(n-C)!} \cdot e^{-\lambda_{m_2} tp} \cdot G'(t) \qquad (21)$$

Therefore, the probability of the handoff call waiting in a queue for maximum T_q unit of time can be estimated as w(T_q) and hence

$$P[Drop\ from\ Queue] = P[W > T_q | W > 0] = \frac{P[W > T_q]}{P[W > 0]} = \frac{1 - w(T_q)}{1 - w(0)} \qquad (22)$$

So, we have

$$P_{FT} = \frac{(\lambda_m tp)^C}{C!} \cdot e^{-\lambda_m tp} \times \frac{(\lambda_{m_2} tp)^B}{B!} \cdot e^{-\lambda_{m_2} tp} + \frac{1 - w(T_q)}{1 - w(0)} \qquad (23)$$

3.4 Estimation of Waiting Time in Queue

The cell dwelling time is the time a mobile user spends in a cell (handoff area + non handoff area) before it actually move to another cell. It depends on the speed of the mobile user and the size of the cell. The cell dwelling time (for cells circular in shape) can be calculated, as shown in [4], as

$$Mean\ cell\ dwell\ time = \frac{\pi r}{2s} \qquad (24)$$

where 'r' is the radius of the cell and 's' is the speed of the mobile user. It has also been shown by the same authors that the mean queue time depends on two parameters

a. The mean cell dwelling time.

b. The maximum cross-distance M, over the overlapping zone between two cells.

Hence, maximum permitted queue time

$$T_q = \frac{M}{100} \times mean\ cell\ dwell\ time \qquad (25)$$

4 Results and Discussion

The performance of the proposed scheme providing priority service to the handoff calls with the help of queuing is evaluated analytically. The results are compared with that obtained from the guard channel scheme reported in [11] and shown here in fig. 1-3. It is assumed, C = 21, mean service rate (μ) = 1.5, mean channel holding time = 40s, probability of failure (v) of a call attempt due to propagation or related reason = 0.05, probability of not completing a call in 1 min. interval p = 2/3. The maximum cross-distance M, over the overlapping zone between two cells is assumed 12The rate of call arrival (λ) is varied from 10 to 40 calls/min. The speeds of the fast and slow users are assumed to be 40-km/h and 80-km/h respectively.

The performance comparisons with guard channels, under classical (with original arrival rate) and non-classical (with modified arrival rate) arrivals, are shown in fig.1 and fig.2. It is observed from the figures that the forced termination probabilities of calls obtained from the non-classical model are less than that obtained from its classical counterpart. Also the forced termination probabilities obtained from non-classical model are closer to that obtained from the traffic under simulation. The non-classical model shows improvement because of its modified arrival rate that is reduced by a factor (v) than the classical call attempt rate. Also, it uses the probability (p) of not completing a call within time t instead of the mean service time.

If the priority is given to the handoff calls with the help of queue instead of guard channels, then the number of accessible channels for new calls increases. The blocking probability, shown in fig.3 and fig.4, of the new calls (for fast travelers) is reduced almost to the level that is achieved in [11] without guard channel.

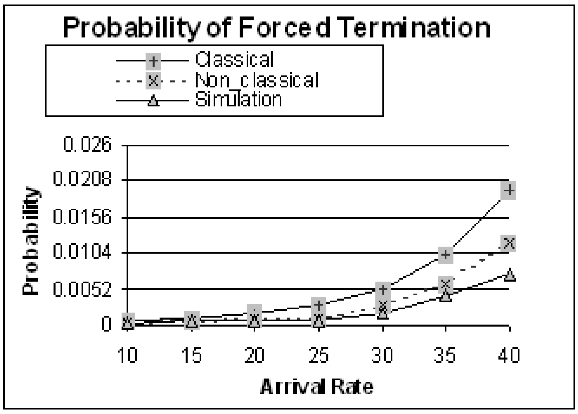

Figure 1: Probability of Forced Termination of HO calls with Guard Channel

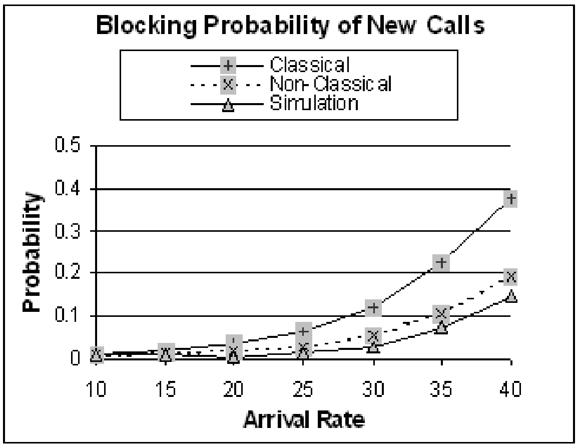

Figure 2: Blocking probability of New calls with Guard Channel

However, the blocking probability of the slow users is slightly more than that of fast users (fig.5) because slow handoff requests can wait in queue for longer period than fast handoff requests and hence cause more new calls to drop for slow users than fast users.

The results in fig.6 and fig.7 shows that the probability of forced termination for the fast users increases slightly than that obtained from the guard channel scheme (fig.1), whereas the probability of forced termination for the slow users is maintained at the same level that obtained from the guard channel scheme.This indicates that the idle time of guard channels are reduced and queuing method can efficiently assign channels to hand-

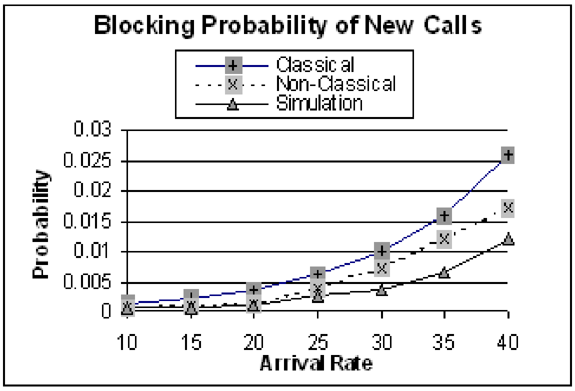

Figure 3: Blocking probability of New calls with Queue and without Guard Channel for fast users

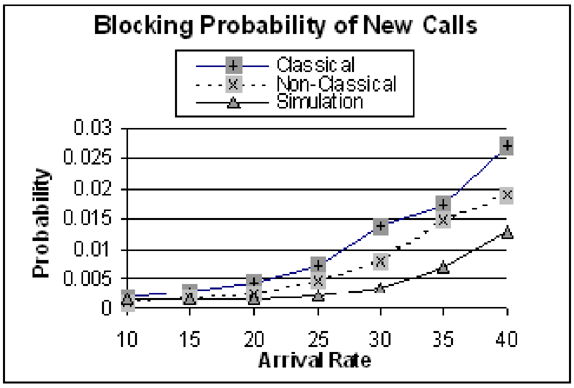

Figure 4: Blocking probability of New calls with Queue and without Guard Channel for slow users

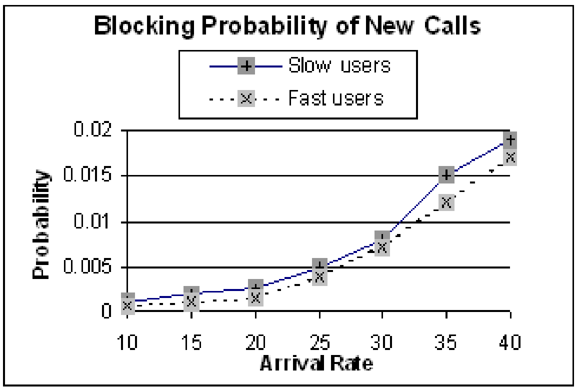

Figure 5: Blocking probability of new calls using Non-Classical model with Queue

off calls for slow users. The probability of forced termination for the fast users is slightly larger than that of the slow users (fig.8) because fast users have less waiting time in queue and hence higher probability of leaving the queue without getting a channel.

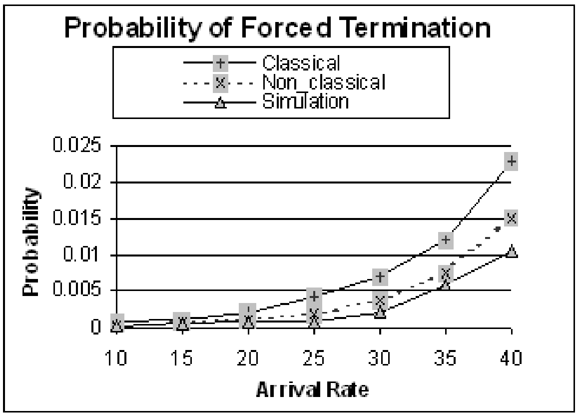

Figure 6: Probability of Forced Termination of HO calls with Queue and without Guard Channel for fast users

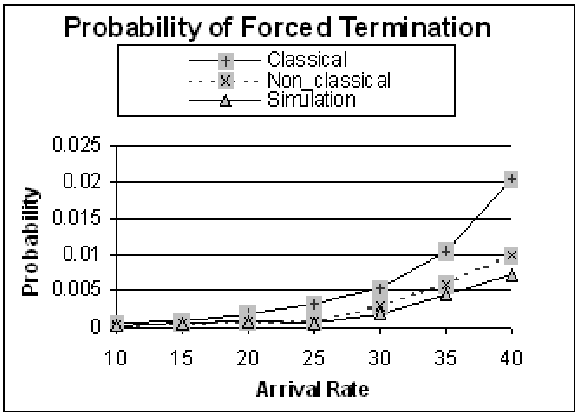

Figure 7: Probability of Forced Termination of HO calls with Queue and without Guard Channel for slow users

The effects of different queue size on blocking probability are also shown in fig.9 and fig.10. The blocking probability increases with the increase in queue size up to a certain value after which the probability remains constant. Initially as the queue size increases, more handoff requests can be waiting in the queue. Therefore, any channel becoming free after servicing a call will be assigned to the handoff call waiting in the queue. So, the probability of blocking a new call is increased up to a certain queue size after which the waiting time in queue becomes more than the time an user can stay

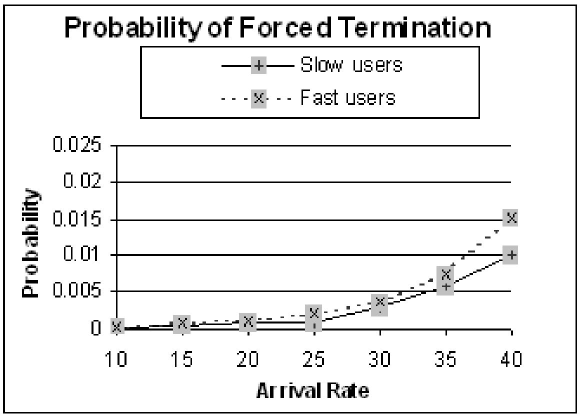

Figure 8: Probability of forced termination with Queue using Non-Classical model

in the overlapping zone. Hence, handoff call requests will leave the queue without getting channels as soon as it moves out of the overlapping zone. The slow users can wait in queue for a longer period than the fast users. So, the blocking probability of slow users reaches to the constant value at a larger queue size than the fast users as can be seen from fig.11.

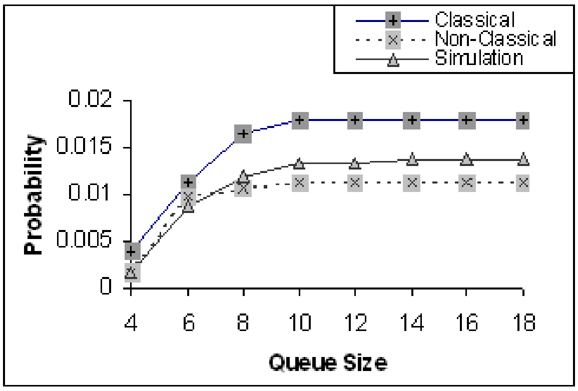

Figure 9: Blocking probability of New calls of fast users with different Queue size

The effects of different queue size on the probability of forced termination are shown in fig.12 and fig.13. The probability of forced termination decreases with the increase in queue size up to a certain value after which the probability remains constant. Initially, as the queue size increases, more handoff requests can be waiting in the queue.

Therefore, any channel becoming free after servicing a call will be assigned to the handoff call waiting

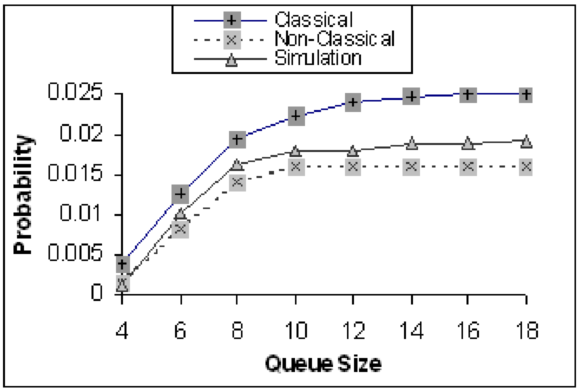

Figure 10: Blocking probability of New calls of slow users with different Queue size

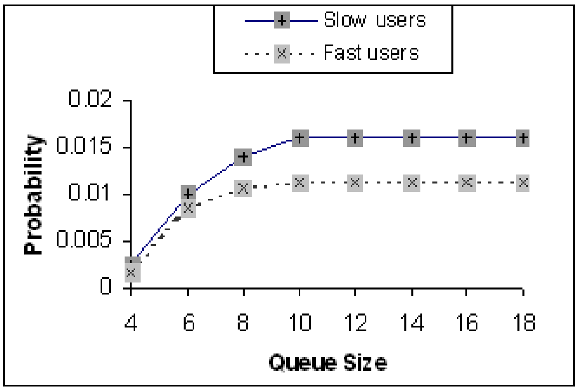

Figure 11: Blocking probability of New calls with different Queue size and speed using Non-Classical model

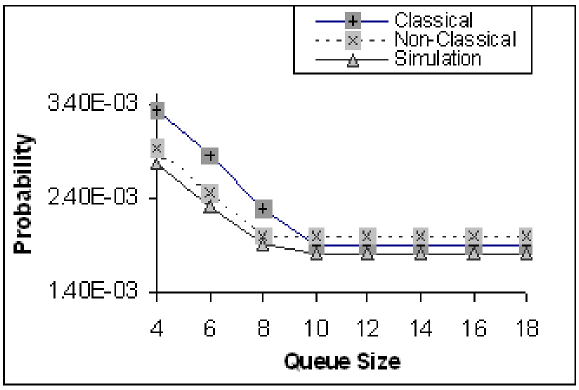

Figure 12: Probability of Forced Termination of HO calls of fast users with different Queue size

in the queue. So, the probability of forced termination of a handoff call decreases up to a certain value of queue size after which the waiting time in queue becomes more than the time an user can stay in the overlapping zone of the neighboring cell. Hence, handoff call requests are forced to leave the queue without getting channels as soon as it moves out of the overlapping zone. The slow users can wait in queue for a longer period than the fast users. So, the probability of forced termination of slow users reaches to the constant value at a larger value of queue size than the fast users as can be seen from fig.14.

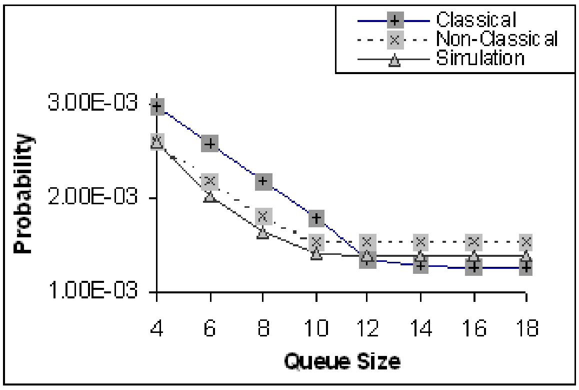

Figure 13: Probability of Forced Termination of HO calls of slow users with different Queue size

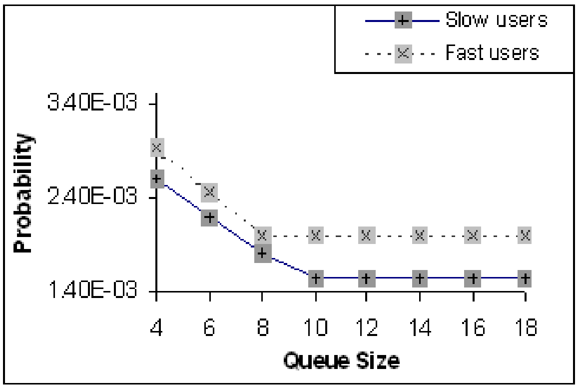

Figure 14: Probability of forced termination of HO calls with different Queue size using Non-Classical model

It can also be observed from the figures (12 and 13) that the constant value of the probability of forced termination obtained from classical model for both slow and fast users is less than that obtained from non-classical model. Classical model have higher arrival rate. So, the number of handoff request arriving into the queue within a time interval will be more than that of the non-classical model. More number of handoff requests in queue means higher probability of getting a channel and hence lower probability of forced termination. Initially, the non-classical model has lower probability than classical model because the number of waiting space available in the queue is less than the number of required space. So, an arrival from the classical model (with higher arrival rate than non-classical model) has higher probability of watching full queue on arrival than an arrival from the non-classical model. So, initially the classical model has higher probability of forced termination than non-classical model.

5 Conclusions

In this work, a new approach has been developed for QoS evaluation in cellular wireless network by queuing the handoff requests instead of reserving guard channels. The electromagnetic propagation failure or whimsical user behaviour have also been considered to estimate the system performance in terms of the probability of blocking of new calls and the probability of forced termination of handoff calls. It is observed from results that the scheme with queuing handoff requests can also achieve better performance in terms of the probability of forced termination whereas the probability of blocking of new calls reduced significantly. Different mobility (slow or fast) of the users has also been considered. Therefore, it can be concluded that a model with queuing handoff requests than that with guard channel can be adopted for optimum QoS and channel utilization.

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