

Performance Analysis of Cellular Wireless Network by Queuing Priority Handoff calls

Raj Kumar Samanta, Partha Bhattacharjee and Gautam Sanyal

Abstract—In this paper, a mathematical model is proposed to estimate the dropping probabilities of cellular wireless networks by queuing handoff instead of reserving guard channels. Usually, prioritized handling of handoff calls is done with the help of guard channel reservation. To evaluate the proposed model, gamma inter-arrival and general service time distributions have been considered. Prevention of some of the attempted calls from reaching to the switching center due to electromagnetic propagation failure or whimsical user behaviour (missed call, prepaid balance etc.), make the inter-arrival time of the input traffic to follow gamma distribution. The performance is evaluated and compared with that of guard channel scheme.

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

I. 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 poses 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 [8] 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 [14], 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 [1], [7], [5]. Boggia *et. al.* [7], from the empirical data analysis, has reported (shown in Table I) that in a well-established cellular wireless network, many phenomena (like propagation condition, irregular user behaviour) become more relevant in addition to channel availability in influencing the call drop. Therefore,

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TABLE I
OCCURRENCE OF CALL-DROPPING CAUSES OTHER THAN LACK OF CHANNEL IN A CELL. SOURCE: BOGGIA *et.al.*, 2007 [7]

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

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 [5], [4]. In [5], 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 [4], a traffic model is developed based on these observations. Hong *et.al.* [10] 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 effect 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 [6], mobility prediction [3], [11] and guard channel sharing [12], have been proposed for dynamic allocation of guard channels. Samanta *et.al.* [6] used channel status check technique for dynamic guard channel reservation. In [3], a handoff prediction scheme is developed based on Markov model whereas in [11], Jayasuriya developed a scheme of mobility prediction for dynamic guard channel reservation. In [12], 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 [13]. Louvros *et.al.* [13] evaluated the system with multiple queues (i.e. one queue for each TRX in a cell) along with guard channels and compared the same with a single queue. 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. It has been observed in this work that the desired level of performance, as that of the scheme with guard channel, for the handoff calls can be achieved with the help of queuing.

This paper has been organized as following sections: Section II describes Proposed call admission control algorithm, Section III deals with mathematical analysis. Results and discussions are presented in Section IV and work is concluded in Section V.

II. PROPOSED CALL ADMISSION ALGORITHM

A mobile host, that needs handoff, has to travel through the overlapping zone for certain time (T_q) 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 T_q time. The handoff request can be served iff a channel becomes free within T_q 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
- 14) else
- 15) drop the handoff call
- 16) end if
- 17) if a new call arrives then
- 18) if Queue is empty then
- 19) Allocate a free channel if available to the new call
- 20) else
- 21) Drop the new call
- 22) end if
- 23) end if
- 24) Stop

III. MATHEMATICAL ANALYSIS

A. Traffic Model

In order to analyze the performance of a cellular wireless network with gamma inter-arrival time distribution, we'll generalize the arrival process 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 $(X_i | i = 1, 2, 3, \dots, n)$ will represent the sequence of independent identically distributed random variables and hence the process will constitute a renewal process [2]. 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

$$S_k = X_1 + X_2 + X_3 + X_4 + \dots + X_k \quad (1)$$

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

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

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

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

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

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

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

$$\begin{aligned} M_{X_1+X_2}(t) &= M_{X_1}(t) \cdot M_{X_2}(t) \\ &= \left[1 - \frac{t}{\lambda} \right]^{-(n_1+n_2)} \end{aligned} \quad (5)$$

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.

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

When $F^{(n)}(t)$ is a Gamma distribution [5], then

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

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' call, s 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

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

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

which may be simplified as

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

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 $T_1, T_2, T_3, \dots, T_n$ is given by

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

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,

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

which is simplified as

$$P[X(t) = j] = \sum_{n=j}^{\infty} {}^n C_j \cdot p^j \cdot (1 - p)^{(n-j)} \cdot \frac{(\lambda_m t)^n}{n!} \cdot e^{-\lambda_m t} \\ = \frac{(\lambda_m t p)^j}{j!} \cdot e^{-\lambda_m t p} \quad (13)$$

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

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

we call it 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, 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 $t \rightarrow \infty$, $\lambda_m t p = \lambda'_m = \frac{\lambda_m}{\mu}$ 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 [4] as well as classical model.

B. 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, $\lambda_m = \lambda_{m1} + \lambda_{m2}$ where λ_{m1} is the arrival rate of new calls and λ_{m2} is the arrival rate of handoff calls. Therefore, the probability of blocking of the new calls (P_B) may be written as

$$P_B = P[X(t) = C] \\ P_B = \frac{(\lambda_m t p)^C}{C!} \cdot e^{-\lambda_m t p} \quad (17)$$

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

$$P_{FT} = P[X(t) = C + B] + P[\text{Drop from Queue}] \quad (18)$$

Now,

$$P[X(t) = C + B] \\ = P[C \text{ channels are occupied and } B \text{ Queue are occupied}] \\ = \frac{(\lambda_m t p)^C}{C!} \cdot e^{-\lambda_m t p} \times \frac{(\lambda_{m2} t p)^B}{B!} \cdot e^{-\lambda_{m2} t p} \quad (19)$$

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

C. 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

$$W(t) = P[n \text{ calls in the system}] \times P[\text{completing } n \text{ calls within } t]$$

which leads to

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

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

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

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

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

So, we have

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

D. 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 [9], as

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

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

- The mean cell dwelling time.
- The maximum cross-distance M, over the overlapping zone between two cells.

Hence, maximum permitted queue time

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

IV. RESULTS AND DISCUSSION

The performance of the proposed scheme providing priority service to the handoff calls with the help of queuing is evaluated. It is assumed, $C = 21$, mean service rate (μ) = 1.5, mean channel holding time = 40s, probability of failure (ν) 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 12% of the cell size. The rate of call arrival (λ) is varied from 10 to 40 calls/min. The speeds of the users are assumed to be 80-km/h. The performance comparisons with guard channels, under classical and non-classical arrivals, are shown in Fig. 1 and Fig. 2. It is observed from the figures that the blocking probabilities of calls obtained from the model with non-classical model are less than that obtained from its classical counterpart. Also the blocking probabilities obtained from non-classical model are closer to that obtained from the traffic under simulation.

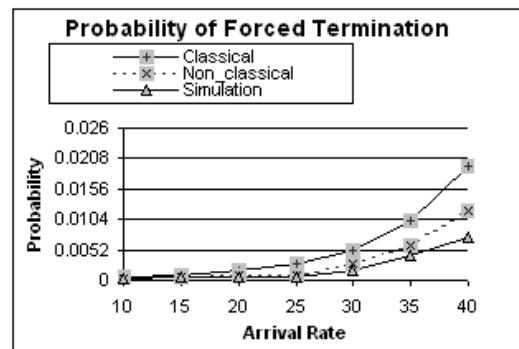


Fig. 1. Probability of Forced Termination of HO calls with Guard Channel

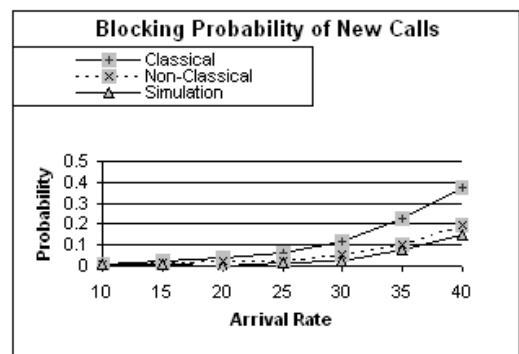


Fig. 2. Blocking probability of New calls with Guard Channel

Now, if the priority is given to the handoff calls with the help of queue instead of providing guard channels, then the number of accessible channels for new calls increases. The blocking probabilities, under two models, are shown in Fig. 3 and Fig. 4. In Fig. 3, it can be observed that blocking probability of the new calls is reduced than that obtained with guard channel. No guard channels means higher probability of getting a channel by a new call. However, there is some increase in the probability of forced termination of handoff call that is

not significant (Fig. 4). Therefore, proposed scheme reduced the idle guard channel and increase the channel utilization.

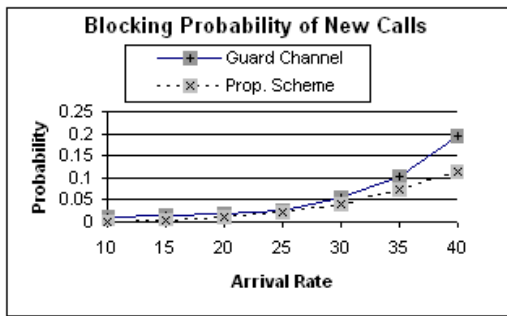


Fig. 3. Blocking probability of new calls for two models.

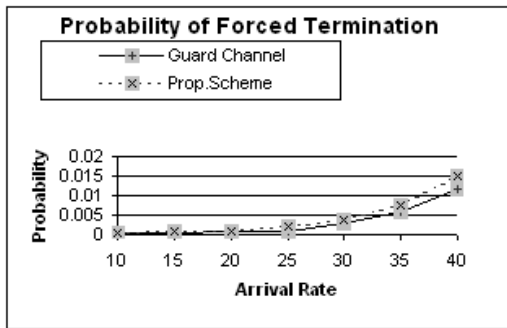


Fig. 4. Probability of Forced Termination of HO for two models

The performance of the proposed scheme with that of the scheme explained in [13] is also compared in Fig. 5 and Fig. 6. For evaluation of the scheme in [13], a single queue (Q) of size 4 and 5 guard channels (GC) are assumed. In [13] double protection (i.e. guard channel as well as queue) has been provided. Whereas, in this work, it is shown that desired level of performance for the handoff calls can be achieved by providing adequate queue. At the same time, as no guard channel is reserved, the performance of the new call blocking probability is improved significantly. This shows that proposed scheme improves the channel utilization by reducing the idle time of guard channels.

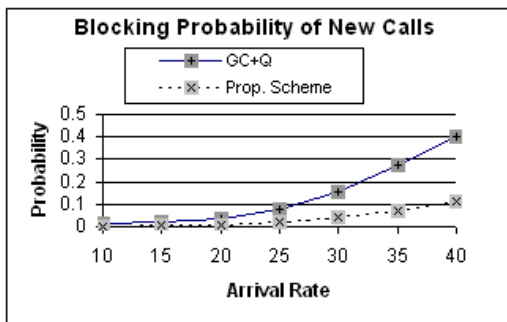


Fig. 5. Comparison of blocking probability of new calls of the proposed model with that of the model explained in [13] with guard channel + single queue.

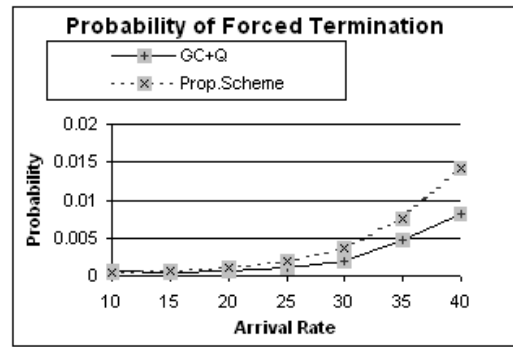


Fig. 6. Comparison of forced termination probability of HO calls of the proposed model with that of the model explained in [13] with guard channel + single queue.

V. CONCLUSIONS

In this work, a new approach has been developed for performance 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 integrated in this scheme 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 our results that the scheme with queuing handoff requests can achieve the probability of forced termination at the desired level almost as that obtained from the guard channel scheme 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 non-classical model with queuing handoff requests can be used for optimum system performance instead of classical model with guard channels.

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