

Assessment of Channel Unavailability Effect on the Wireless Networks Teletraffic Modeling and Analysis

Eman S. El-Din, Hesham M. El-Badawy, Salwa H. Elramly

Abstract—Whereas cellular wireless communication systems are subject to short-and long-term fading. The effect of wireless channel has largely been ignored in most of the teletraffic assessment researches. In this paper, a mathematical teletraffic model is proposed to estimate blocking and forced termination probabilities of cellular wireless networks as a result of teletraffic behavior as well as the outage of the propagation channel. To evaluate the proposed teletraffic model, gamma inter-arrival and general service time distributions have been considered based on wireless channel fading effect. The performance is evaluated and compared with the classical model. The proposed model is dedicated and investigated in different operational conditions. These conditions will consider not only the arrival rate process, but also, the different faded channels models.

Keywords—Cellular wireless networks, outage probability, traffic model, gamma inter-arrival distribution.

I. INTRODUCTION

WIRELESS services have become of great importance for its different categories and classes. This causes extensive growth rate of the network's sizes. Considerable studies have discussed the problem when the call is blocked due to insufficient radio resources (time, frequency or code) [1]–[2]. The performance evaluation of a certain mobile communication network as well as the call behavior characteristics are usually analyzed or simulated based on the assumption that the channel can reliably combat the signal degradation. So that the call level is not affected by the erroneous wireless channel.

In wireless communication systems, the received signal is subjected to the adverse effects of the channel in the form of short- and long-term fading, also known as shadowing [3]. Short-term fading arises from the existence of multiple paths between transmitter and receiver, shadowing is the result of the topographical terrains structure elements such as tall buildings, trees and other structures in the transmission path. Dropped calls are increased as a result of bad channel conditions. For instance, the main cause and criteria for handoff is essentially the weak signal power resulting from the severe channel degradation. Hence, it is more reasonable to study the call-level performance and packet-level performance with the effect of wireless channel impairment characteristics in the mobile network [4].

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In general, if the received signal-to-noise ratio (SNR) is becoming lower than a certain level (SNR threshold) for more than a specific period of time (time threshold) [2], the physical connection is considered as an unreliable link. A fresh call can be blocked or a handoff call can be dropped due to lack of resources or operational conditions.

Call arrivals are traditionally assumed to be independent Poisson process with a rate as that of call attempted or originated. In such an environment, the blocking probability can be estimated as a function of the traffic load of the originating calls, number of channels in a cell and the users' mobility using Erlang-B approximation [3]. Anand et.al. [4] evaluated the network performance distinguishing fresh and handoff calls. Hong et.al. [5], introduced the concept of guard channel for priority processing of the handoff calls. Nasser [6] estimates the drop-call probability considering a multimedia wireless network. An adaptive bandwidth allocation algorithm is exploited to improve system performance and to reduce, in particular, handoff-blocking probability. [7] analyzed the system performance with finite user population. In those papers, exponential inter-arrival and service times had been the basic assumption [8]. This concept is well suited for wireless networks like fixed telephone networks, in the present cellular wireless network, connectivity is provided by a radio link. In addition to the lack of channels, there are other reasons (like prepaid account balance, service plan subscribed, power supply of the mobile devices, the users mobility mechanism, electromagnetic propagation condition and handoff) that influence the drop or rejection of a call attempt [9]. In [10], the relationship between handover failure and call dropping is analyzed. Therefore, all attempted calls do not survive to be considered for channel allocation while passing through different phases like electromagnetic propagation, authentication and authorization and handoff. Hence, the arrival rate of calls that are considered for channel allocation may not be the same as the rate of call origination.

The current paper will focus on the evaluation of system performance in case of the lack of channel, propagation conditions and investigate most of call drop reasons such as user mobility.

A teletraffic model, with gamma inter-arrival time and general service time distributions, has been derived concerning the outage of wireless system in the form of short-and long-term fading. The system performance, in terms of blocking and forced termination probabilities, has been evaluated under guard channel mechanisms.

The rest of the paper is organized as follows: in section II, system model description is provided. Section III, discusses the assessment criteria. Numerical results and analysis is provided in section IV. Finally, the paper is concluded in section V.

II. SYSTEM MODEL

The system under investigation will be treated by means of studying two main models: channel model and teletraffic model.

A. Channel Model

The outage process due to the Gilbert–Elliot model will be considered [11]. (two-state Markov chain model) has widely been used to capture the periods of signal degradation as shown in figure (1), the state space of the wireless channel consists of $\Omega = \{\text{good}; \text{bad}\}$. The transition probabilities are defined as follows. Given that the current state is a good one, the probability that the next state is a good one is denoted by (P_{GS}), and the probability that the next state is a bad one is denoted by ($1 - P_{GS}$). On the other hand, given that the current state is a bad one, the probability that the next state is a bad one is denoted by (P_{BS}), and the probability that the next state is a good one is denoted by ($1 - P_{BS}$). Then, the channel is modeled by a sequence of alternating good and bad states. For this model, a channel cycle is defined as the continuous good state and its next consecutive bad state.

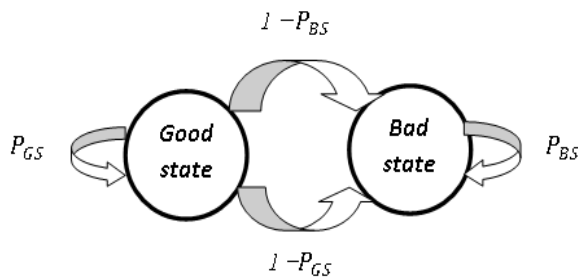


Fig. 1 Example Gilbert–Elliot model (two-state Markov chain model)

In the presence of bad state, the system will suffer from call outage probability for both of short and long-term fading. The short-term fading can be modeled using the Nakagami distribution and we can use the gamma pdf to describe the long-term fading. The presented work in [11] is used to deduce an expression for the blocking and forced termination probabilities. So, for various values of the short-term and long-term fading factors ϕ and ψ respectively, the average value of a gamma random variable y may be used to define the factor b which is expressed as $2\sqrt{\phi/y}$. Thus, in (1) the parameter Z_{av} is the average signal-to-noise ratio, expressed as [11]:

$$Z_{av} = \frac{4\psi\phi}{b^2} \quad (1)$$

When the signal-to-noise ratio fails to reach a threshold that is determined by the specific modulation format, multiple access scheme used, etc [11], the outage probability in terms of the compound pdf (superscript c of indicates that it is a compound pdf incorporating both short term fading and shadowing) model can be expressed by [11]:

$$P_{out}^c = \frac{\Gamma(\psi - \phi) \left(\frac{Z^T b^2}{4}\right)^\phi}{\Gamma(\psi)\Gamma(\phi + 1)} \times f\left(\phi, [1 - \psi + \phi, 1 + \phi], \frac{Z^T b^2}{4}\right) + \frac{\Gamma(\phi - \psi) \left(\frac{Z^T b^2}{4}\right)^\psi}{\Gamma(\phi)\Gamma(\psi + 1)} \times f\left(\psi, [1 - \phi + \psi, 1 + \psi], \frac{Z^T b^2}{4}\right) \quad (2)$$

In (2), f is the hypergeometric function for the outage probability calculations defined in [12].

B. Teletraffic Model

The Teletraffic performance assessment has become an important issue. Specially, if the inter-arrival and arrival processes will be described via more realistic models. So, in the current paper, the inter-arrival time will be considered as a gamma distribution. Whereas, the arrival process will be 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 $(X_i | i = 1, 2, 3 \dots, n)$, will represent the sequence of independent identically distributed random variables, and hence the process will constitute a renewal process [13]. Assume F is the underlying distribution of X_i , and S_M represents the time from the beginning till the k th call arrival. Then

$$S_M = X_1 + X_2 + X_3 + X_4 + \dots + X_K \quad (3)$$

$F^{(M)}(t)$ is the distribution function of S_M , we define:

$$F^{(0)}(t) = \begin{cases} 1; & t \geq 0 \\ 0; & t < 0 \end{cases} \quad (4)$$

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

$$M_Z(t) = E(e^{tZ}) = \int_{-\infty}^{\infty} e^{tZ} f(z) dz \quad (5)$$

When, Z has gamma pdf distribution, then the moment generating function of Z is obtained as [14]:

$$M_Z(t) = \left[1 - \frac{t}{\lambda}\right]^{-n} \quad ; \quad n > 0 \quad (6)$$

where, λ is the average arrival rate and n is an integer. Now, X_1 and X_2 are two independent inter-arrival times with gamma pdf, the moment generating function of $S_M = X_1 + X_2$ can be written:

$$M_{X_1+X_2}(t) = M_{X_1}(t) \cdot M_{X_2}(t) = \left[1 - \frac{t}{\lambda}\right]^{-(n_1+n_2)} \quad (7)$$

which shows that the distribution of S_2 and in turn the distribution of S_M follows gamma distribution. For N call attempts generated from Poisson sources with arrival rate λ .

If j calls out of N call attempts, if N calls have arrived and each has the independent probability due to noise effect (P_n) of not completing by time t , then a sequence of N Bernoulli trials is obtained and can be written as [14]:

$$P[Y(t) = j | X(t) = N] = \binom{N}{j} P_n^j \cdot (1 - P_n)^{(N-j)} \quad (8)$$

$$0 \leq j \leq N$$

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) as $\lambda_m = \lambda v$ (each call has the independent probability v of successfully reaching to the switching center). In such case, the inter-arrival time has a gamma pdf, in addition the distribution of the service time is considered as a general distribution and N call attempts are large, equation (7) may be rewritten as follows:

$$P[Y(t) = j | X(t) = N] = \frac{(\lambda_m t P_n)^j}{j!} \cdot e^{-\lambda_m t P_n} \quad (9)$$

In faded channel model, P_u the joint pdf and considered the overall channel degradation probability is obtained via the combination for both of two independent probabilities; namely P_{out}^c (the outage probability) due to fading effect & the noise effect probability P_n . Then the P_u can be written as:

$$P_u = P_n + P_{out}^c - P_n \cdot P_{out}^c \quad (10)$$

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

$$P[X(t) = C] = \frac{(\lambda_m t P_u)^C}{C!} \cdot e^{-\lambda_m t P_u} \quad (11)$$

“Non-classical” model is defined as the case of having the inter-arrival time distribution is gamma and service time distribution is general. On the other hand, if the service times are exponentially distributed with average arrival rate λ , this is known as Erlang’s B formula [6], which may be called “Classical model”. The probability for using of C channel can be determined as follow:

$$P[X(t) = C] = \frac{\frac{\rho^C}{C!}}{\sum_{i=0}^C \frac{\rho^i}{i!}} \quad (12)$$

where, the denominator in the right hand side in equation (12) is the normalization factor and ρ is traffic intensity. The traffic intensity is fraction of service rate (μ) and the modified arrival rate (λ_m), hence $\rho = \lambda_m / \mu$.

III. ASSESSMENT CRITERIA

A. Blocking Probability Due to Faded Channel model

Consider the case when priority is given to the handoff calls by reserving some channels exclusively for handoff calls. Let C be the total number of channels of a base station in cellular network. C_g is the allocated Guard Channels, which are reserved for handoff calls. Let N_1 represents the number of new calls and N_2 represents the number of handoff calls in the system arriving from independent Poisson processes with

modified arrival rates λ_{m1} and λ_{m2} respectively [14]. Hence, new calls will be blocked or forced termination of handoff calls will occur, when all the channels in the system are busy. i.e., $N_1 + N_2 = C$ as in [14].

$$P_B = \left(\left(1 - \sum_{n=0}^{C_g} \frac{(\lambda_{m2} t P_u)^n}{n!} \cdot e^{-\lambda_{m2} t P_u} \right) \cdot \frac{\sum_{j=0}^{C-C_g-1} \frac{(\lambda_{m1} t P_u)^j}{j!} \cdot e^{-\lambda_{m1} t P_u}}{\frac{(\lambda_{m1} t P_u)^C}{C!} \cdot e^{-\lambda_{m1} t P_u}} \right) + \left(\sum_{n=0}^{C_g} \frac{(\lambda_{m2} t P_u)^n}{n!} \cdot e^{-\lambda_{m2} t P_u} \right) \cdot \frac{(\lambda_{m1} t P_u)^{C-C_g}}{(C-C_g)!} \quad (13)$$

B. Forced Termination Probability due to Faded Channel model

Call forced-termination may result from either link unreliability or intercell handoff failure; but in general, a dropped call suffers h ($h = 0, 1, 2, \dots$) successful handoffs and one interruption (due to either a handoff failure or link unreliability) before it is forced to terminate. Thus, the call forced-termination probability can be expressed as [14]:

$$P_{FT} = \left(1 - \sum_{n=0}^{C_g} \frac{(\lambda_{m2} t P_u)^n}{n!} \cdot e^{-\lambda_{m2} t P_u} \right) \cdot \frac{\sum_{j=0}^{C-C_g-1} \frac{(\lambda_{m1} t P_u)^j}{j!} \cdot e^{-\lambda_{m1} t P_u}}{\frac{(\lambda_{m1} t P_u)^C}{C!} \cdot e^{-\lambda_{m1} t P_u}} \quad (14)$$

The form P_{FT} as classical model can be determined by using of the presented model in [14].

$$P_{FT} = \left(1 - \sum_{n=0}^{C_g} \frac{\frac{(\rho_2)^n}{n!}}{\sum_{i=0}^n \frac{(\rho_2)^i}{i!}} \right) \cdot \frac{\left(1 - \sum_{s=0}^{C-C_g-1} \frac{\frac{(\rho_1)^s}{s!}}{\sum_{r=0}^s \frac{(\rho_1)^r}{r!}} \right)}{\frac{(\rho)^C}{C!} \cdot \frac{(\rho)^J}{\sum_{j=0}^C \frac{(\rho)^j}{j!}}} \quad (15)$$

where, ρ is total traffic intensity $\rho = \rho_1 + \rho_2$, ρ_1 represents the traffic intensity of new calls is given by λ_{m1}/μ and ρ_2 represents the traffic intensity of handoff calls in the system is given by λ_{m2}/μ .

IV. NUMERICAL RESULTS AND ANALYSIS

In order to consider the validation of the obtained results, the system parameters have been chosen to match that of previously published work in [14]. Fig. 1 represents the blocking probability vs. arrival rates for new calls with guard channel under classical, non-classical and faded non-classical models.

The goal of the numerical evaluations presented in this section is to investigate and analyze the influence of link unreliability on system performance. The performance of the proposed scheme providing priority service to the handoff calls with the help of queuing is evaluated. It is assumed, $C = 30$, mean channel holding time = 40s. The original call attempt or arrival rate (λ) is varied from 10 to 40 calls/min. C_g is assumed to be 16.6 % of the total number of channels.

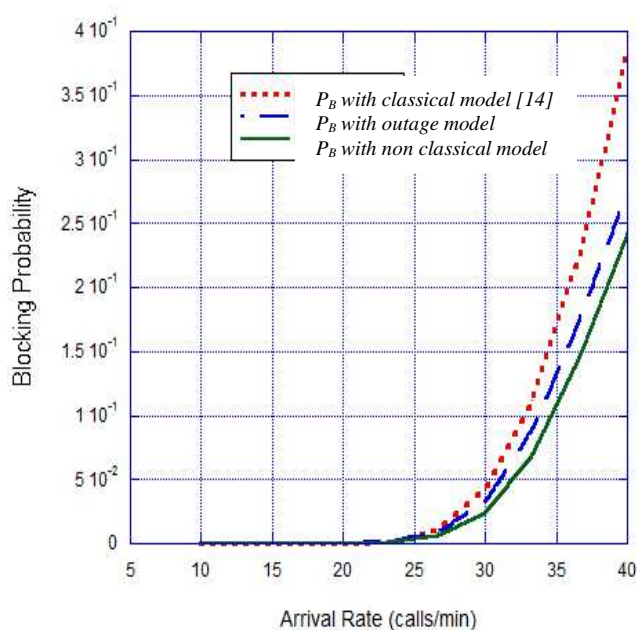


Fig. 2 P_B Versus Arrival Rates for Fading Channel with Fading Factors ($\psi=0.67$, $\phi=0.75$, $Z_{av}=20$ dB), and a comparison with the published work in [14].

The performance comparisons (P_{FT} and P_B) with guard channel, under three different algorithms noisy classical model, noisy non-classical model and faded non classical model at certain signal to noise ratio ($Z_{av} = 20$ dB) .

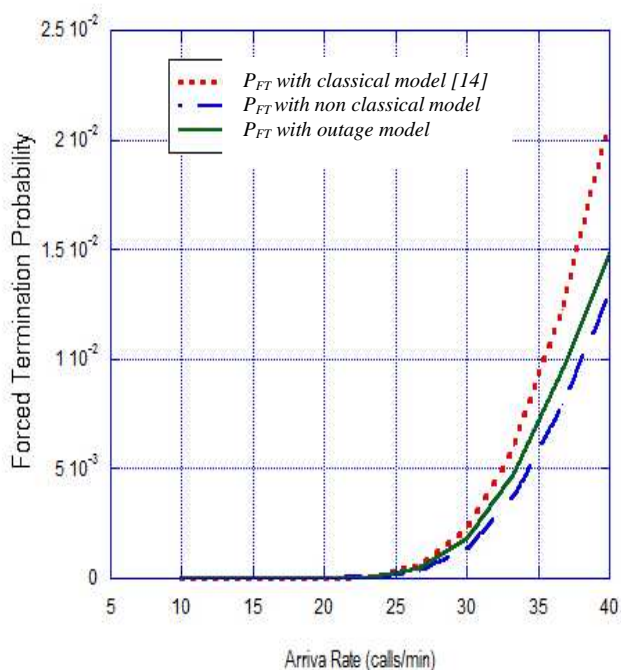


Fig. 4 P_{FT} Versus Arrival Rates for Fading Channel with Fading Factors ($\psi=0.67$, $\phi=0.75$, $Z_{av}=20$ dB).

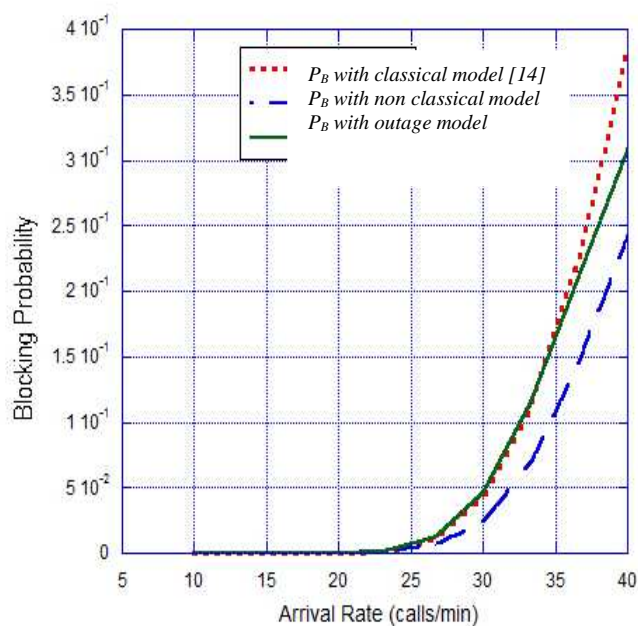


Fig. 3 P_B Versus Arrival Rates for Fading Channel with Fading Factors ($\psi=0.38$, $\phi=0.9$, $Z_{av}=20$ dB)

The model validation by comparing the obtained results in [14] at different fading factors for short and long fading are shown in Fig. 2,3,4,5,6 and Fig.7.

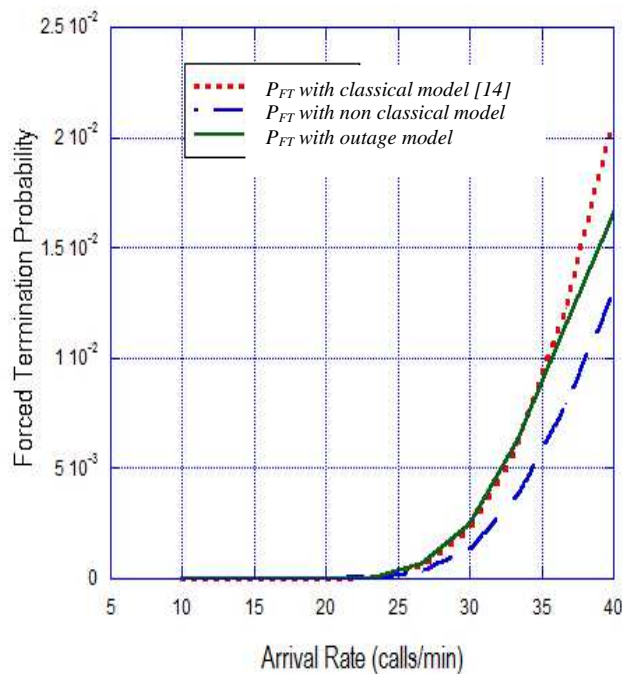


Fig. 5 P_{FT} Versus Arrival Rates for Fading Channel with Fading Factors ($\psi=0.38$, $\phi=0.9$, $Z_{av}=20$ dB).

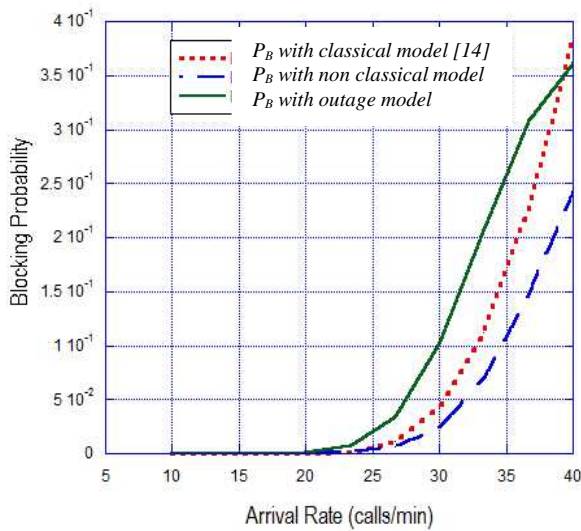


Fig. 6 P_B Versus Arrival Rates for Fading Channel with Fading Factors ($\psi=0.2$, $\phi=0.6$, $Z_{av}=20$ dB).

The obtained results presented in figures 2, 3, 4, 5, 6 and 7 are in consistence with the non classical model which had been presented in [14]. It is shown that the obtained results give higher blocking and forced termination probabilities. This is due to the consideration of the outage probability as well as the teletraffic effects. But generally, both of the obtained results and that of [14] are monotonically the same. The obtained performance in such figures are representing higher blocking probabilities (forced termination probabilities), when the arrival rate is becoming ($\lambda > 20$). This phenomena may be explained as a result of having network teletraffic intensity ($\rho > 80\%$). So, the system will be dominated by aggressive call requests. Figure 8, shows the blocking probability for new calls as a function of different arrival rates and different signal to ratio (SNR) for noisy and faded non classical channel model.

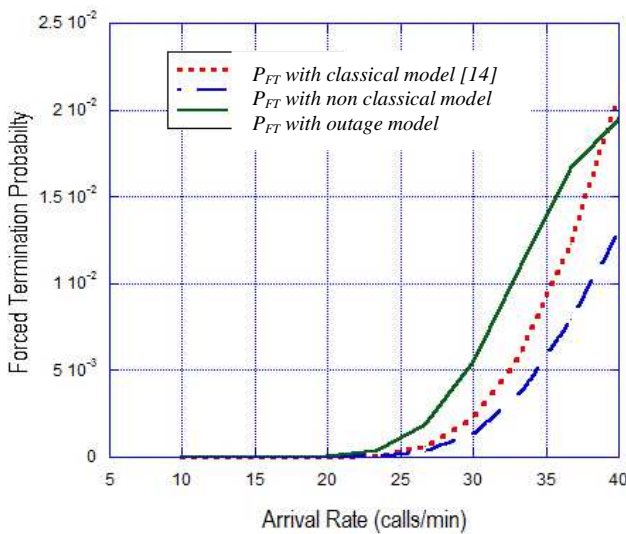


Fig. 7 P_{FT} Versus Arrival Rates for Fading Channel with Fading Factors ($\psi=0.2$, $\phi=0.6$, $Z_{av}=20$ dB).

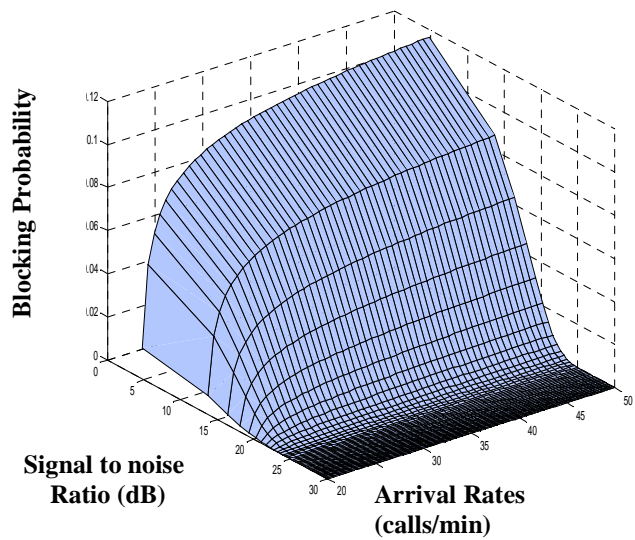


Fig. 8 P_B Versus Arrival Rates and Signal to Noise Ratio for Fading Channel with Fading Factors ($\psi=0.38$, $\phi=0.9$).

Figure 9 shows the forced termination probability for hand off call as a function of different arrival rates and different signal to ratio (SNR) for noisy and faded non classical model. Fig 8, 9 are illustrating the resultant effect due to both of the outage and teletraffic operational parameters on the system performance. Signal to noise ratio ranges ($SNR < 5$ dB) will be dominant factor. Whereas moderate SNR ranges ($10 < SNR < 20$ dB) will not be the dominant factor but the higher arrival rates ($\lambda > 30$ calls/min). In addition, by having large SNR ranges ($SNR > 30$ dB), the system may be immuned against the system failures. Also, the lower SNR ranges will lead to more system performance degradations. This degradation will happen in spite of the teletraffic operational parameters.

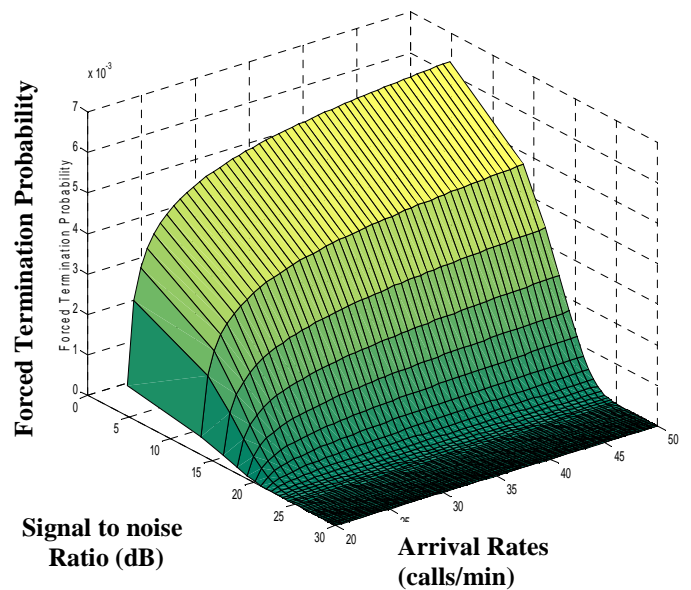


Fig. 9 P_{FT} Versus Arrival Rates and Signal to Noise Ratio for Fading Channel with Fading Factors ($\psi=0.38$, $\phi=0.9$).

V. CONCLUSION

The current paper studies the system performance evaluation of cellular wireless networks where an analytical teletraffic model has been developed using gamma inter-arrival time and general service time distributions, due to shadowing and fading channel model used to calculate the probability of blocking of new calls and the probability of forced termination of handoff calls which used to evaluate the overall performance. This is done in conjunction with the desired signal strength and the interference undergoes short-term fading and shadow simultaneously. The proposed scheme can provide more accurate estimation of required channels for the desired quality of services (QoS) in terms of P_{FT} and P_B .

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