

The Effect of Channel Holding Time Distribution on Handoff Failure Probability and Call Termination Probability

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Abstract: Handoff failure probability in cellular systems is defined as the probability that a handoff request is denied for lack of resources, and premature call termination probability is defined as the probability that an accepted ongoing call is terminated due to lack of resources, are two of the main parameters used to study and analyze several cellular system performance measures. Further, they are the main parameters that are used in quality of service studies and teletraffic analysis of such a network during the planning and development stages. To evaluate the handoff failure probability, premature call termination probability, and other system performance measures such as call dropping probability, several statistical distributions have been used in the literature to model the channel holding time distribution in 3rd and 4th generations cellular systems, such as exponential, Erlang, Gamma, and generalized Gamma, hence, the complexity of the analytical and simulation models introduced in literature varies based on the assumed channel holding time distribution in addition to other assumed parameters. In this paper the effect of the statistical distribution used to model the channel holding time on handoff failure probability and premature call termination probability are investigated using analytical and simulation models, where the main goal of the research is to determine the level of complexity of the statistical distribution used to model the channel holding time to accurately evaluate the handoff failure probability and premature call termination probability.

Index Terms: cellular system, handoff failure probability, premature call termination

I. INTRODUCTION

RECENT advance in wireless communications and cellular systems make it possible for cellular networks to support a wide variety of services to the user on the move. 4G systems and future wireless networks enable the user to make voice, data, multimedia calls, or make an internet connection to surf the web, and retrieve data. These advance services have motivated the study of network's quality-of-service (QoS), in cellular networks. The following QoS measures are the most important measures used to specify the quality of the services:

- New call blocking probability P_n : defined as the probability that a new call request be denied for lack of resources.

- Premature call termination probability P_{ct} : defined as the probability that an accepted on going call is terminated due to lack of resources.
- Call dropping probability P_{cd} : defined as the probability that a call will experience either premature call termination or new call blocking.
- Handoff failure probability P_{hf} : defined as the probability that a handoff request is denied for lack of resources.

Some of these measures may be specified in the design, for example, in second generation cellular systems, the premature call termination probability is lower than 5%, and the handoff failure probability is lower than 2% for voice calls [1]. Many previous literature introduced techniques and expressions to evaluate handoff failure probability, premature call termination probability, number of handoff probability and handoff rate. In early literature the following assumptions are commonly used: the call holding time, the cell residence time, and the channel holding time are assumed to be exponentially distributed, and calls arrival is a Poisson process [2,3,4,5]. However, because of technological advances and the growing interest in personal communication services, and because of new marketing service plans (e.g. flat-rate service), mobile users behavior pattern was changed such that they use their mobile devices for longer period of time and more frequently. Hence, the exponential distribution may no longer appropriately models the service time or the interarrival time of practical 3G and 4G networks [6,7,8,9]. In recent literature, several techniques were introduced to determine number of handoff probability and handoff failure probability where more general call holding time, cell residence time, and channel holding time distributions were assumed [1,10,11], hence, based on the used distributions the complexity of the introduced analytical and simulation models varies. In this paper the effect of the statistical distribution used to model the channel holding time on handoff failure probability and premature call termination probability is investigated using analytical and simulation models, where the main goal of the research is to determine the level of complexity of the statistical distribution used to model the channel holding time to accurately evaluate the handoff failure probability and premature call termination probability. The rest of this paper is organized as follow: In section 2, an analytical model to evaluate handoff failure probability and premature call termination probability is investigated. In section 3, the simulation model used to validate the analytical results is introduced. In section 4, the results and discussion are presented, and finally the conclusion is in section 5.

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II. THE ANALYTICAL MODEL

The cellular system considered is presumed to have N channels in each cell, of which S channels are reserved for handoff only and the remaining $N-S$ channels are used to serve both new calls and handed-off calls. The assumed system is connection-oriented. Once a channel is assigned to a particular user, that channel cannot be used by any other user until the channel is released either when the call is completed or when the user moves to another cell. Whenever a new call arrives at an arbitrary cell (origination cell), if there is a free channel (out of the $N-S$ channels) available to support the call, the call will be accepted and remains in that cell until it is completed or handed-off to next cell. On the other hand, if there is no channel available to support the newly arrived call, it will be blocked. Whenever there is a handoff request, the call will be handed-off to the next cell if there is a free channel in the next cell to accept the handed-off call; otherwise, the call will be dropped. Based on this scenario, one can consider the system under modeling as a birth and death process in which blocked calls are cleared (no queue) [12]. To determine expression for P_{hf} , one must clearly understand the definitions of the call holding time, the channel holding time, and the cell residence time that are illustrated in Fig. 1. The call holding time is defined as the period from the instant the accepted call starts to the instant the call completes. The channel holding time is defined as the period from the instant an active call occupies the channel to the instant the active call releases the channel. The cell residence time in the origination cell is defined as the time that the mobile user travels from the point where the call originated to the edge of the cell. In any subsequent cell, the residence time is defined as the time that the mobile user travels through the cell (edge to edge).

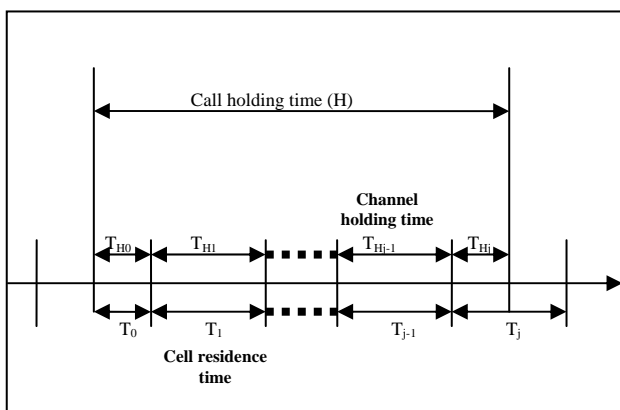


Fig. 1. Timing diagram for a call ended at j -th cell

From the above definitions, it can be concluded that the service time for any particular call in any cell is the channel holding time. The channel holding time is found as $\min(RH_i, T_i)$, $i = 0, 1, \dots$, where T_i is the residence time in a cell that is reached after i handoff, and RH_i is the remainder of the call holding time at the time when the call enters the cell. In the origination cell, we have $\min(RH_i, T_i) = \min(H, T_0)$, where H is the call holding time, as shown in Fig. 1. In order to simplify the analysis, in deriving analytical expression in this research for P_{hf} it is assume that

the call interarrival time follows a negative exponential distribution (which is usually the case in real world) [12], [13-15]. The scenario presented in this Section suggests that there are two call arrival processes in the system under study namely, new call arrival process and handoff call arrival process. Note that the active calls in any cell may be divided into two groups. The first group includes calls that will end in that cell itself so that such calls from this group will not affect the handoff call arrival process to next cell.

The second group includes calls that travel through the cell and will issue a handoff request to next cell when they reach the edge of the current cell; hence, the calls in this group represent the handoff arrival to next cell. For a call from the second group, the channel holding time in the current cell may be found as $\min(RH_i, T_i) = T_i$ (the cell residence time). Based on this, one may conclude that the arrival process of handoff calls depends on the distribution of the cell residence time. Therefore, in order to evaluate P_{hf} we need to verify that for the assumed cell residence time model, the distribution of the interarrival time of handoff calls may be approximated accurately by the negative exponential distribution. In fact, the assumption that the distribution of the interarrival time of calls in PCS systems can be approximated accurately by a negative exponential distribution, even though the channel holding time and the cell residence time have distributions other than exponential, agrees with the results obtained from empirical data collected from working PCS systems and presented in [14], [16].

A. Basic Assumptions

In the present analysis, the following commonly used assumptions are assumed: New call arrival is a Poisson process with average arrival rate λ_n , [12-16]. The handoff call arrival may be accurately approximated by a Poisson process with average arrival rate λ_h , [12]. The number of channels per cell is N . The number of channels per cell reserved for handoff is S . At equilibrium, all cells have a similar behavior. The users are uniformly distributed in each cell. The call duration H is a random variable with finite mean with probability density function denoted by $f_H(t)$. The cell residence time in the first cell is modeled by a random variable T_0 , and the cell residence times in all other cells are modeled by a random variable T_i . The cell residence times are independent, and the cell residence times in all cells where calls are handed-off (T_i) are identical.

B. Determination of Handoff Failure Probability (P_{hf})

The number of channels reserved for handoff would affect the handoff failure probability. In general, there are two main scenarios that may be used in cellular system: (i) No handoff priority scenario and (ii) prioritized handoff scenario. In the following, the procedure to determine P_{hf} in these scenarios is discussed.

i. No Handoff Priority Scenario

Assume that the average channel holding time in a cell is η , the new call arrival rate is λ_n , and the handoff arrival rate is λ_h . Consequently, the mean of the overall arrival process (new calls and handed-off calls) can be found as $\lambda = \lambda_n + \lambda_h$ [12], [14]. Since a blocked-calls-cleared approach is followed in the present system, it is possible to model call-handling events in the system as a birth and

death process as long as the channel holding time has a finite mean [13]. If no channel is reserved for handoff (i.e. $S=0$), then the handoff failure probability P_{hf} may be found as

$$P_{hf} = \frac{(\eta\lambda_n + \eta\lambda_h)^N}{N!} \sum_{k=0}^N \frac{(\eta\lambda_n + \eta\lambda_h)^k}{k!} \quad (1)$$

ii. *Prioritized Handoff Scenario*

Consider a cell with guard channels reserved for handoff (i.e. $S \neq 0$). Since handed-off calls have higher priority than new calls, then they will be cleared from the system if there is no idle channel available in the cell, whereas new calls will be cleared from the system if there are less than $S+1$ idle channels. Then, handoff failure occurs when there are N busy channels, which can be written as

$$P_{hf} = \frac{(\eta\lambda_n + \eta\lambda_h)^{(N-S)} (\eta\lambda_h)^{(S)} P^*}{N!} \quad (2)$$

where η is the average channel holding time, and P^* is defined as

$$P^* = \left[\sum_{k=0}^{N-S} \frac{(\eta\lambda_n + \eta\lambda_h)^k}{k!} + (\eta\lambda_n + \eta\lambda_h)^{(N-S)} \sum_{k=N-S+1}^N \frac{(\eta\lambda_h)^{k+S-N}}{k!} \right]^{-1} \quad (3)$$

To evaluate P_{hf} using (1) and (2) we need first to determine the average channel holding time η and the average handoff arrival rate λ_h . This is done in the following subsections.

C. *Determination of Average Channel Holding Time (η)*

The cell residence time model, as mentioned earlier, comprises two components. The first is the residence time in the origination cell, modeled by the random variable T_0 . The second is the residence time in subsequent cells where calls are handed-off, modeled by the random variable T_i ($i=1, 2, 3, \dots$). From the above definitions, the channel holding time in the first cell (T_{H0}), may be determined as the smaller of the call duration and the residence time in that cell [3], [14]. The channel holding time in a subsequent cell i ($i=1, 2, 3, \dots$), where a call is handed-off, (T_{Hi}) is either the cell residence time if the remaining call holding time is longer than the cell residence time, or the remaining call holding time if the call will be completed in that cell. The cdf of the channel holding time in the first cell can be derived as

$$T_{H0} = \min(H, T_0). \quad (4)$$

Then

$$F_{T_{H0}}(t) = \Pr(T_{H0} < t) = 1 - \Pr(T_{H0} > t).$$

Since T_{H0} is greater than t if and only if $H > t$ and $T_0 > t$, then

$$F_{T_{H0}}(t) = 1 - \Pr(H > t, T_0 > t). \quad (5)$$

Since H and T_0 are independent, then

$$F_{T_{H0}}(t) = 1 - \Pr(H > t) \Pr(T_0 > t) \quad (6)$$

and

$$F_{T_{H0}}(t) = 1 - [1 - F_H(t)][1 - F_{T_0}(t)]. \quad (7)$$

Therefore,

$$F_{T_{H0}}(t) = F_H(t) + F_{T_0}(t)[1 - F_H(t)]. \quad (8)$$

From (8), the pdf of the channel holding time in the first cell can be expressed as

$$f_{T_{H0}}(t) = f_H(t) - F_{T_0}(t)f_H(t) + f_{T_0}(t)[1 - F_H(t)], \quad (9)$$

where $f_{T_0}(t)$, $F_{T_0}(t)$, $f_H(t)$, and $F_H(t)$ are the pdf of the origination cell residence time, the cdf of the origination cell residence time, the pdf of the call holding time, and the cdf of the call holding time, respectively. After passing the first cell, the remaining average call holding time may be found as $E[H] - E[T_0]$. Based on the assumptions, the average number of cells a handed-off call will pass through until the call is completed, if the call does not drop due to handoff failure, is [17]

$$M = \left\lceil \frac{E[H] - E[T_0]}{E[T_i]} \right\rceil, \quad (10)$$

where $\lceil x \rceil$ is the "CEIL" function which returns the smallest integer greater than or equal to x , $E[T_0]$ is the average cell residence time in origination cell, $E[H]$ is the mean call duration, and $E[T_i]$, ($i=1, 2, \dots$) is the mean of residence time in subsequent cells where calls are handed off, with

$$E[T_1] = E[T_2] = \dots = E[T_i] \quad i = 1, 2, \dots \quad (11)$$

Therefore, the average channel holding time in any cell other than the origination cell $E[T_{Hi}]$ may be found as

$$E[T_{Hi}] = \frac{E[H] - E[T_0]}{M}. \quad (12)$$

The average channel holding time η is obtained as a weighted combination of the average channel holding time in the first cell and the average channel holding time in subsequent cells, and the weight of each component is given by [12]

$$K_1 = \frac{\lambda_n(1 - P_n)}{\lambda_n(1 - P_n) + \lambda_h(1 - P_{hf})}, \quad (13)$$

$$K_2 = \frac{\lambda_h(1 - P_{hf})}{\lambda_n(1 - P_n) + \lambda_h(1 - P_{hf})}. \quad (14)$$

From (12), (13), and (14), the average channel holding time η is obtained as [12]

$$\eta = K_1 E[T_{H0}] + K_2 E[T_{Hi}], \quad (15)$$

where $E[T_{H0}]$ may be found from (9) as

$$E[T_{H0}] = \int_0^\infty t f_H(t) dt - \int_0^\infty t F_{T_0}(t) f_H(t) dt + \int_0^\infty t f_{T_0}(t) [1 - F_H(t)] dt. \quad (16)$$

D. *Determination of Average Handoff Arrival Rate (λ_h)*

The determination of the average arrival rate of handed-off calls λ_h is greatly simplified if the call duration and/or the channel holding time have a memoryless distribution.

The memoryless property implies that the remaining time of a call has the same distribution as its duration [12]. For a call duration distribution that does not possess the memoryless property, the determination of the average arrival rate of handoff calls is more complicated. One may start by assuming that for a stationary observer in a particular cell, ongoing calls (on average) experienced l successful handoffs before reaching that cell, where

$$l = \left\lfloor \frac{M+1}{2} \right\rfloor, \quad (17)$$

and M is given in (10). At equilibrium, λ_h can then be determined from [12]

$$\lambda_h = \lambda_n(1 - P_n) \Pr(H > T_0) + \lambda_h(1 - P_{hf}) p_{l-1}, \quad (18)$$

where $\lambda_h(1 - P_{hf}) p_{l-1}$ represents the number of calls handed-off successfully to cell $l-1$ that has call holding time long enough to reach the edge of that cell and request a handoff to cell l , and p_{l-1} is defined as

$$p_{l-1} = \frac{a(l-1)}{a(l-2)}, \quad (19)$$

where $a(j)$ is given by

$$a(j) = \Pr(H > G_j) \quad j=0,1,\dots,l-1,l,\dots \quad (20)$$

and

$$G_j = \begin{cases} T_0 + \sum_{i=1}^j T_i & j=1,2,\dots \\ T_0 & j=0. \end{cases} \quad (21)$$

Solving (18) for λ_h , we have

$$\lambda_h = \frac{\lambda_n(1 - P_n) \Pr(H > T_0)}{1 - (1 - P_{hf}) p_{l-1}}. \quad (22)$$

As a special case, when H follows the exponential distribution, p_{l-1} does not depend on l ; and since it is assumed that T_1, T_2, \dots, T_{l-1} are i.i.d. random variables, (20) can be written as

$$a(j) = \Pr(H > T_0) \frac{\Pr(H > T_0 + T_1)}{\Pr(H > T_0)} \dots \frac{\Pr(H > T_0 + T_1 + \dots + T_j)}{\Pr(H > T_0 + T_1 + \dots + T_j)}. \quad (23)$$

Then, using the memoryless property of the exponential distribution, (23) becomes

$$a(j) = \Pr(H > T_0) \Pr(H > T_1)^j. \quad (24)$$

From (24), it is observed that

$$p_{l-1} = \frac{a(l-1)}{a(l-2)} = P(H > T_1). \quad (25)$$

Note that, substituting (25) in (22) agrees with [12]. However, when H has a distribution that does not possess the memoryless property, the evaluation of λ_h using (22) requires the knowledge of the pdf of G_j , which will be discussed in the next section.

Note that P_n, P_{hf}, η , and λ_h are interdependent. Therefore, an iterative technique must be used to evaluate them. One may start by assuming initial (estimated) values for P_n and P_{hf} , and calculate η and λ_h using equations (15) and (22), respectively. The calculated values of η and λ_h are then used as inputs to equation (2), to update the value of P_{hf} . These steps are repeated until the values of P_{hf} converge.

E. Approximating the pdf of G_j

Let $f_{G_j}(t)$ denote the pdf of the random variable G_j .

The determination of $f_{G_j}(t)$ requires j -fold convolution and, to the best of our knowledge, analytically it is not known exactly. An approximation of $f_{G_j}(t)$ may be found using central limit theorem. However, since G_j is the sum of non-negative random variables, one may apply a causal form of the central limit theorem. This is based on the fact that the Gaussian approximation for $f_{G_j}(t)$ as $j \rightarrow \infty$ will not yield a causal distribution no matter how large the mean of G_j . It is appropriate, therefore, that for sufficiently large j , $f_{G_j}(t)$ may be approximated by a two parameters gamma distribution

$$f_{G_j}(t) \cong \frac{t^{z_j-1} e^{-t/b_j}}{b_j^{z_j} \Gamma(z_j)} u(t), \quad (26)$$

where $\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt$ is the gamma function and the

parameters z_j and b_j are given by

$$z_j = \frac{(E[G_j])^2}{\sigma_{G_j}^2} = \frac{(E[T_0] + jE[T_i])^2}{\sigma_{T_0}^2 + j\sigma_{T_i}^2} \quad i=1,2,\dots \quad (27)$$

and

$$b_j = \frac{\sigma_{G_j}^2}{E[G_j]} = \frac{\sigma_{T_0}^2 + j\sigma_{T_i}^2}{E[T_0] + jE[T_i]} \quad i=1,2,\dots \quad (28)$$

where $\sigma_{G_j}^2$ is the variance of G_j , $\sigma_{T_0}^2$ is the variance of T_0 , and $\sigma_{T_i}^2$ is the variance of T_i .

F. Determination of Premature Call Termination Probability (Pct)

One should understand that P_{hf} and P_{ct} are not the same; while P_{hf} is the probability that an arbitrary handoff request is denied, " P_{ct} has a long-term flavor denoting the probability that a call will be terminated at some point during its life time", hence, premature call termination probability may be determined once the handoff failure probability are evaluated. The definition of probabilities P_{ct} may be found as:

$$P_{ct} = \Pr(H > T_0) P_{hf} + \sum_{j=1}^\infty P_{hf} (1 - P_{hf})^j a(j) \quad (29)$$

From the above analysis we can see that the type of the statistical distribution of the channel holding time has no impact on handoff failure probability or premature call termination probability, instead, the average channel holding time (which is a constant value that depends on the parameters of the system such as the design layout and users distribution in the service area regardless of the type of distribution used to model the channel holding time) has direct impact on the handoff failure probability and premature call termination probability. In the next section, a simulation model will be discussed to validate the result that

was concluded from the analysis that was presented in this section.

III. SIMULATION MODEL

The developed simulation model is an event-driven model that is highly modular and flexible. The arrival of new call event is activated based on the inputs and the assumptions of the simulation. The following actions may result when the arrival of new call occurs:

- Block the call and clear it if no channel is available to carry the new call
- Assign a channel to the call if there is an available channel
- Generate the call holding time based on the assumed distribution
- Generate the residence time in the first cell only
- Increment the counter for new calls
- Increment the counter for new blocked calls if the new call blocked and cleared.

The arrival of handoff call event will be activated when the remaining residence time of any call in any cell is zero. The following actions may result when the arrival of handoff call occurs:

- Remove the call from the current cell and free the used channel
- Assign a new channel in the next cell to carry the call if a free channel is available in the next cell
- Drop the call if there is no free channel available in the next cell
- Generate the cell residence time in the next cell where call is handed-off
- Increment the counter for handoff requests
- Increment the counter for handoff failure if the call is dropped.

The call completion and removal events are activated when the remaining call holding time of any call is zero. The following actions may result when the call completion and removal occur:

- Remove the call from the system and free the channel used in the current cell
- Increment the counter of successfully completed calls

The impact of various parameters of the cellular system on the performance can be easily investigated, including the number of channels in each cell, the arrival rate of new calls, the arrival rate of handed-off calls, the distribution of call duration, and the cell residence time. The functions used in the simulation may be classified into two groups. The first group includes the functions that scan the occurrence of the events and accordingly schedules the next event. The second group includes the function that performs the actions that result when an event occurs.

IV. RESULTS AND DISCUSSION

As we mention earlier the type of the statistical distribution of the channel holding time has no impact on handoff failure probability or premature call termination

probability, and by using the analytical model and the simulation model presented in section 2 and 3 respectively, Fig. 2 and 34 show that the analytical results and the simulation result are in a great agreement, where, in Fig. 2 the handoff failure probability is presented as a function of new call arrival rate. From the figure we can see that as the new call arrival rate increases the handoff failure probability increases due to lack of available channel. In Fig. 3, the premature call termination probability is shown as a function of new call arrival rate, and the premature call termination probability shows the same behavior as the handoff failure probability in both analytical and simulation model, which can be seen directly from (29).

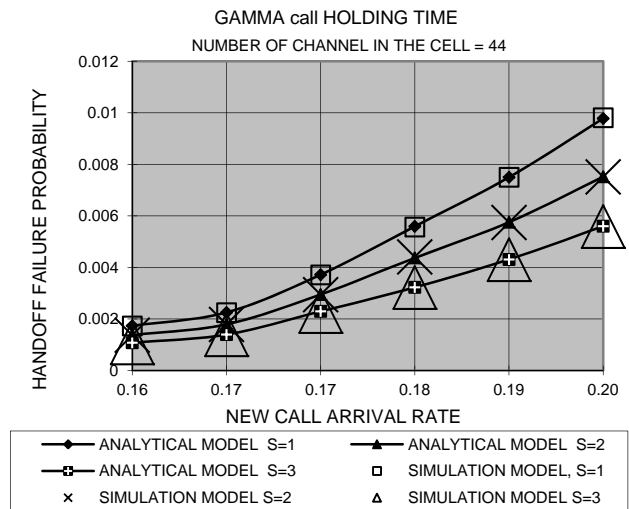


Fig. 2. Handoff failure prob. vs. new call arrival rate

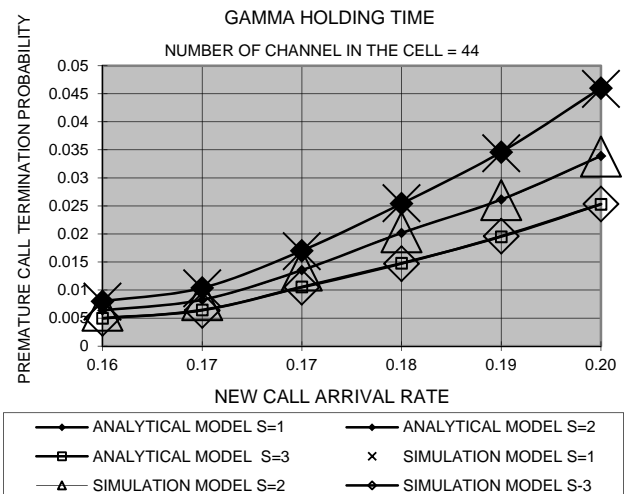


Fig. 3. Premature call termination Prob. vs. new call arrival rate

V. CONCLUSION

In this paper we investigate the impact of the type of the statistical distributions used to model channel holding time in cellular system on handoff failure probability and premature call termination probability. The analytical model investigated in this research shows that the type of the channel holding time distribution has no impact on the handoff failure probability and premature call termination probability. Instead, the mean of the channel holding time which is a constant value that depends on the parameters of the system such as the design layout and users distribution

in the service area, regardless of the type of distribution used to model the channel holding time, has direct impact on the handoff failure probability and premature call termination probability. The result obtained from the analytical model is validated using simulation. Based on the results, the research recommends that to study the performance of a cellular system the researchers may use any statistical distribution to model the channel holding time as long as it leads to simplifying the developed model and produce a close form solution. However, the values of the parameters of the distribution used in the analysis or the simulation must be selected very carefully such that the moments of the used distribution reflect the moments of the practical system (usually the first three moments are enough).

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