COMPARATIVE ANALYSIS OF CONGESTION CONTROL MODELS FOR CELLULAR WIRELESS NETWORK

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Abstract

Cellular wireless systems like GSM suffer from congestion resulting in overall system degradation and poor service delivery. When the traffic demand in a geographical area is high, the input traffic rate will exceed thecapacity of the output lines. This work focused on homogenous wireless network (the network traffic and resource dimensioning that are statistically identical) such that the network performance evaluation can be reduced to a system with single cell and a single traffic type. Such system can employa queuing model to evaluate the performance metric of a cell in terms of blocking probability.

Five congestion control models were compared in the work to ascertain their peculiarities, they are Erlang B, Erlang C, Engset (cleared), Engset (buffered), and Bernoulli. To analyze the system, an aggregate one-dimensional Markov chain wasderived, such that it describes a call arrival process under the assumption that it is Poisson distributed. The models were simulated and their results show varying performances, however the Bernoulli model (Pb5) tends to show a situation that allows more users access to the system and the congestion level remain unaffected despite increase in the number of users and the offered traffic into the system.

Keywords

Congestion, Blocking probabilities, queuing systems, steady state , stochastic.

1. INTRODUCTION

Wireless network system has undergone tremendous growth not only in terms of increase in number of users but alsoin areas of data flow. This has resulted in increase of resource requirements.In any network, many users share the services of a central unit or base station or channels. Therefore, a system designer taking cognizes of this fact to develop a system where congestion is reduced to barest minimum or completely eliminated to improve the quality of service (QoS) and overall system performance. Whether the number of users in the system varies or remains fixed, wireless systems can be divided into two broad categories. The first category consists of systems with fixed number of users(finite) called fixed-user systems while the second category employinfinite numbers of users and the number of users are varied with time [9].The relationship between offered traffic and the carried traffic to the system depends on the design of the system and the user behavior.

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Therefore, in this paper three models were deployed based on the two categories mentioned above. These are (a) callers whose call-attempts are rejected (go away and never come back). Such a system is referred to as loss network, (b) callers whose call-attempts are rejected (try again within a fairly short space of time), and (c) the system allows users to wait in queue until a circuit becomes available.Several tele-traffic models have been proposed on congestion correction and control and even many schemes and policies have been deployed. One of the models, based it's evaluation on infinite number of sources such that the rate of calls being offered to the system is not affected by how many calls that are currently in the system[1]. Such procedure is developed to avoid congestion, so that the new calls that are arriving without channel availability is blocked or cleared(these calls are loss permanently). Also the analysis of the blocking probability proceeded by noting the relationships between the probabilities of possible system states (numbers of calls in the system, occupying one or more channels) at different times. Another proposal in which the channel is filled up allows the arriving calls to be blocked andnot cleared but offered opportunity again after some random delays. The analysis of such system is done as with the clear call but with the exception that the incoming rate of calls are computed in terms of the originally offered rate and the argument of the blocking probability is computed as a function of the probability itself [1], [2].The proposition of [3], [4], [5], is carried out with the assumptions that, the inter-arrival time of a traffic, the call holding time, and the channel holding time are all assumed to be exponentially distributed in order to obtain some analytical results. In wireless network, the importance of Call Blocking Probability (CBP) as a QoS parameter cannot be overemphasized because, the quality of call connections is used for the quality of service characteristic and is also specified in the design. Therefore to evaluate the performance of a wireless network this performance metric is of great importance [8].

This paper adopted the assumptions proposed in [3], [5] and the single cell, single traffic type queuing model [6] to develop models for congestion avoidance schemes. These models were simulated and the results were compared to understand their peculiarities

2. CONGESTION CONTROL SCHEMES

Five congestion schemes in cellular (GSM) wireless networks models were employed in this work. Assumption is made of Poisson call arrival processes for each model, where M users are modeled as having a combined average rate of generating calls. This is denoted by λ and the arrival times of these first attempts to place a call are assumed to be independent. Hence a Poisson distribution for the number of calls generated in a given time interval, T can be employed and the number of resources (channels) is given as N, the call holding time is exponentially distributed with mean μ^{-1} and the offered traffic load is defined as $A = \lambda \mu^{-1}$. Since the calls generated by the users are in a random manner (stochastic process), the user attempts to place calls through a system that has N channels with each channel occupied with a call for the mean duration time, $\tau = 1/\mu$.

If a channel is constantly in use, the number of call completions in time T is a Poisson random variable given by P {n calls completed in T } = $\frac{(\mu T)^n e^{-\mu T}}{\mu}$ $n \geq 0$ ………(1)The probability that a given channel, if occupied, will complete a call in the interval dt is P_r{service completion in one channel in dt } $= \mu dt$ ……….. (2)

3. BLOCKING PROBABILITIES CALCULATION

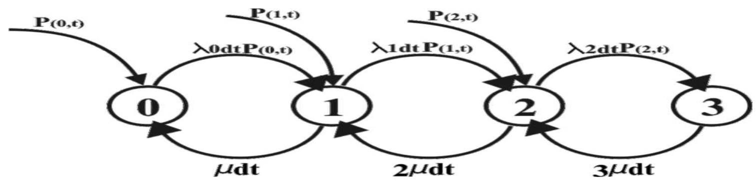

Fig. 1 DTMC for a small system

Consider the discrete time Markov chain (DTMC) for infinite users for a small system in fig. 2, the probability of being in state j, and with j channels occupied, can be found by solving the "balance equation" (at equilibrium, the rate of moving into a state is equal to the rate of moving out of a state). The blocking probability is obtained from the relationship between probabilities of possible system states (number of calls in the system, occupying one or more channels) at different times.Let $\Pr\,[k,t]$ denote the probability at time t that there are k calls in the system, from equations (1) and (2).

$$P(0,t+dt) = (1-\lambda dt)P(0,t) + \mu dtP(1,t) \tag{3}$$

$$P(1,t+dt) = \lambda dtP(0,t) + (1-\lambda dt - \mu dt)P(1,t) + 2\mu dtP(2,t) \tag{4}$$

$$\vdots$$

$$P(k,t+dt) = \lambda dtP(k-1,t) + (1-\lambda dt - k\mu dt)P(k,t) + (k+1)\mu dtP(k+1,t) \tag{5}$$

$$P(N,t+dt) = \lambda dtP(N-1,t) + (1-N\mu dt)P(N,t) \tag{6}$$

At equilibrium, the time derivative of these probabilities is assumed to vanish. Normalized requirement isto solve the probability expression given by,

$$P(k) = Pb1(A,N) = \frac{A^k}{k!}\left[\sum_{n=0}^{N}\frac{A^n}{n!}\right]^{-1}, \quad 0 \le k \le N \tag{7}$$

where $k = N$, which isthe blocking probabilities for cleared calls and infinite number of sources.This is called Erlang's Loss Formula or Erlang B formula for blocking probability.

In this scheme instead of putting limitation on the number of calls by clearing all other incoming calls when the number of calls is equal to the number of channel as in Erlang B, the incoming call are held in a queue of a particular size with the remainder cleared. When up to Q blocked calls are held (delayed) in a queue, with the remainder cleared, the analysis of the transition of probabilities follows the same procedure as above and leads to the probability expression given as

$$P(k) = \frac{A^N}{N!}\left[\frac{A}{N}\right]^{k-N} T^{-1}, \quad N \le k \le N+Q \tag{8a}$$

$$P(k) = 0, \quad k > N+Q \tag{8b}$$

where

$$T=\sum_{n=0}^{N}\frac{A^n}{n!}+\frac{A^N}{N!}\sum_{n=N+1}^{N+Q}\left(\frac{A}{N}\right)^{n-N}=\sum_{n=0}^{N}\frac{A^n}{n!}+\frac{A^N}{N!}.\frac{(A/N)[1-(A/N)]^{Q}}{1-(A/N)} \qquad (9)$$

For an infinite source and queued call,the CBP is given by

$$P(N)=\frac{\frac{A^N}{N!}\,\frac{1-\left(A/N\right)^{Q+1}}{1-\left(A/N\right)}}{\sum_{n=0}^{N-1}\frac{A^n}{n!}+\frac{A^N}{N!}\cdot\frac{1-\left(A/N\right)^{Q+1}}{1-\left(A/N\right)}} \qquad (10)$$

Using equations (9) and (10), it becomes:

$$Pb2(A,N)=\frac{\frac{A^N}{N!}\left(\sum_{n=0}^{N}\frac{A^n}{n!}\right)^{-1}}{1-\frac{A}{N}+\frac{A^N}{N!}\left(\sum_{n=0}^{N}\frac{A^n}{n!}\right)^{-1}.\left(\frac{A}{N}\right)} \qquad (11)$$

4. BLOCKING ANALYSIS FOR FINITE NUMBER OF SOURCES, M AND N CHANNELS

For Cleared Calls,when there are finite numbers, M sources (users), the amount of offered traffic load is affected by the number of users whose calls are already in the system [1]

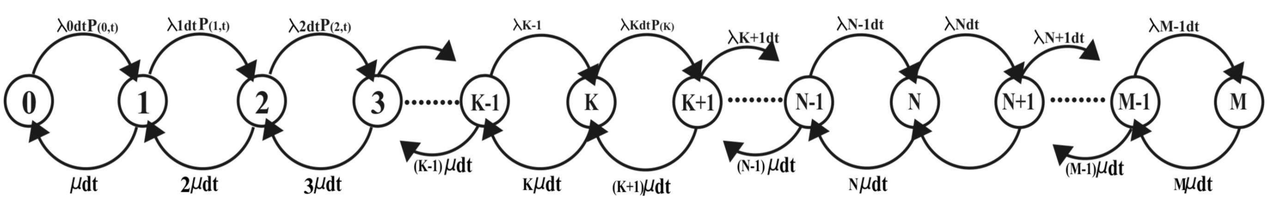

Fig. 2: DTMC for finite user M

Let $\lambda_0\delta t,\lambda_1\delta t,\cdots,\lambda_k\delta t$ to $\lambda_m\delta t$ be the state dependent transition rates at time, δt and $\mu\delta t, 2\mu\delta t,\ldots,(k-1)\mu\delta t, k\mu\delta t,(k+1)\mu\delta t,\ldots,m\mu\delta t$ are the mean holding rate at time, dt . Also, $P(0,t+\delta t),P(1,t+\delta t),\ldots,P(k-1,t+\delta t),P(k,t+\delta t),P(k+1,t+\delta t),\ldots,P(k+1,t+\delta t)$ are the probability functions at time, dt for state 0 to $j_{\max}$. λ_a is the average call arrival rate for an individual source that is free to make call, therefore with k users' calls in the system the state dependent call arrival rate is

$$\lambda_k=(M-k)\lambda_a \qquad (12)$$

Cleared/Blocked calls take into account the dependence of the call arrival rate on the number of calls in the system, the probability equations become

$$P(k) = \begin{cases} \begin{bmatrix} M \\ k \end{bmatrix} \rho^k \left\{ \sum_{n=0}^{N} \begin{bmatrix} M \\ n \end{bmatrix} \rho^n \right\}^{-1}, & 0 \le k \le N \text{ and } M > N \text{ and} \\ 0 \end{cases}$$

$$Pb3(\rho, M, N) = \frac{\binom{M}{N} \rho^N}{\sum_{n=0}^{N} \binom{M}{n} \rho^n}, \qquad k > N \tag{13}$$

These probabilities form the Engset or Truncated Bernoulli probability distribution.

For Held (buffered) calls, using equation (12)and assuming also that the total buffer size to hold calls is given as $Q = M - N$. The Probability transition equation for a finite number of sources and buffered calls are obtained from the transition rate diagram of fig. 3. Using recursion formula given by

$$P(k) = \begin{bmatrix} M \\ k \end{bmatrix} \rho^k (T_m)^{-1} \tag{14}$$

$$\text{with} T_m = \sum_{n=0}^{N} \begin{bmatrix} M \\ n \end{bmatrix} \rho^n + \begin{bmatrix} M \\ N \end{bmatrix} \rho^n \sum_{n=1}^{M-N} n! \begin{bmatrix} M-N \\ n \end{bmatrix} \left(\frac{\rho}{N} \right)^n$$

Then, $P(k)$ which is CBP for a finite number of sources withheld or buffered calls is given as

$$Pb4(\rho, M, N) = \frac{\frac{N^N}{N!} \sum_{n=N}^{M} n! \begin{bmatrix} M \\ n \end{bmatrix} \left(\frac{\rho}{N} \right)^n}{\sum_{n=0}^{N-1} \begin{bmatrix} M \\ n \end{bmatrix} \rho^n + \frac{N^N}{N!} \sum_{n=N}^{M} n! \begin{bmatrix} M \\ n \end{bmatrix} \left(\frac{\rho}{N} \right)^n} \tag{15}$$

4.1 Blocking analysis for a finite Number of sources, M and N channels;for Held (buffered) calls (Bernoulli Approach)

In this approach, the appearance and disappearance of held calls on the queue is treated in the same manner as carried calls as if there were M channels, although the system is said to be blocked if there are N or more channels occupied and a call is said to be held (not lost) if N or more channels are occupied when a call arrives from a free source (call congestion).Solving the transition equations againand we obtained

$$P(k) = \begin{bmatrix} M \\ k \end{bmatrix} \rho^k (1+\rho)^{-m} \quad \text{for } 0 \le k \le M$$

Therefore $P(k)$ which isCBP for a finite number of sources withheld or buffered calls (using Bernoulli approach) is given as

$$B = Pb5(\rho, M, N) = \frac{\sum_{n=N}^{M} \begin{bmatrix} M \\ N \end{bmatrix} \rho^n}{(1+\rho)^m} \qquad (16)$$

5. SIMULATION RESULTS AND DISCUSSION

The formulas derived for $Pb1$, $Pb2$, $Pb3$, $Pb4$, and $Pb5$ were used to plot CBP against the offered traffic for a given number of channels N. The plot of CBP againstoffered trafficfor infinite sources (users) with cleared calls for $Pb1$ with varying values of channel N is shown in fig. 4(a). The plots of CBP versus offered traffic for infinite sources (users) Pb2 withheld call by varying values of channel N is shown in fig. 4(b). The plot of CBP versus offered traffic for infinite sources (users) $Pb3$ with M finite user cleared callsfor channel $N = 8$ isshown in fig. 4(c). The plot of CBP versus offered traffic for infinite sources (users) $Pb4$ with M finite user (held call)for channel $N = 8$ is shown in fig 4(d). The plots of CBP versus offered traffic for infinite sources (users) $Pb5$ (Bernoulli) with finite user (held call) is shown in fig. 5(a).

It can be seen from the derived expressions that $Pb1$ and $Pb2$ are independent of the number of users within the system.Hence, the rate of call being offered to the system is not affected by how many calls are currently in the system. From the plots, it can be observed that the CBP (a measure of performance) increases with increase in offered traffic. All held calls expressions,($Pb2$, $Pb4$, and $Pb5$) produce values that are independent or relatively independent of N in the neighborhood of $A = N$.

For all values of channel N used in $Pb4$, and $Pb5$,(held call) the performance of the system is optimal when CBP is equal to 1 or 100%. This implies that the channel capacity is full when the amount of offered traffic equals the number of channels. This implies that the plots of fig. 4(a) and fig. 4(d) show the bound approach capacity, exponentially.

The significant of these observations is that the selection of a formula for blocking probability is not as critical for small levels of traffic, but becomes more important as the level of traffic approaches the number of channels. As it relates to $Pb1$ and $Pb2$ it can be observed that as the channel increases call blocking probability decreases and as expected the offered traffic also increases. Fig. 5(a) compared various numbers of finite user, M for a given number channelsfor $Pb5$. When $M = 55$, the curve deviated from when $M = 10000$ and above, this shows that $Pb5$ can accommodate large number of user unlike $Pb1$ and $Pb2$.The profile of CBP against offered traffic for $Pb3$, $Pb4$ and $Pb5$ is shown in fig. 5(b), Held (buffered) calls (Bernoulli Approach)attained the probability of 1, even before $Pb5$ when the offered traffic is equal tothe number of channels.

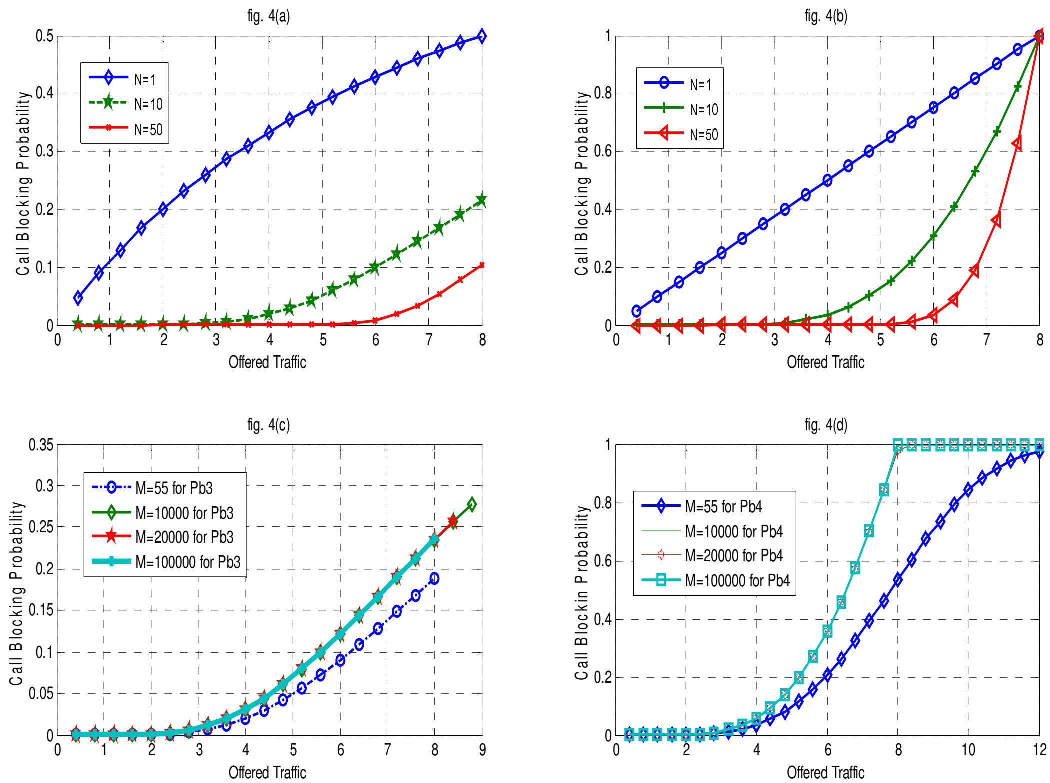

Fig. 4 Plots of call blocking probability versus offered traffic for infinite sources for $Pb1$, $Pb2$, $Pb3$,and $Pb4$ (withheld call) withvarious values of channel N for M users.

6. CONCLUSION

In this paper, five congestion control models were investigated and modeled for cellular (GSM) wireless network. The one dimensional Markov chain model was adopted for these models to simplified the analytical approach. The models were simulated and the results showed varying performances of each model. However, theheld (buffered) calls Bernoulli model (Pb5) tends to show a situation that allows more user access to the system for a particularnumbers of channel and the congestion level remain unaffected despite the large increase in number of user and offered traffic into the system. $Pb4$ profile also show a promising model for cellular network when the amount of offered traffic equals the number of channels.

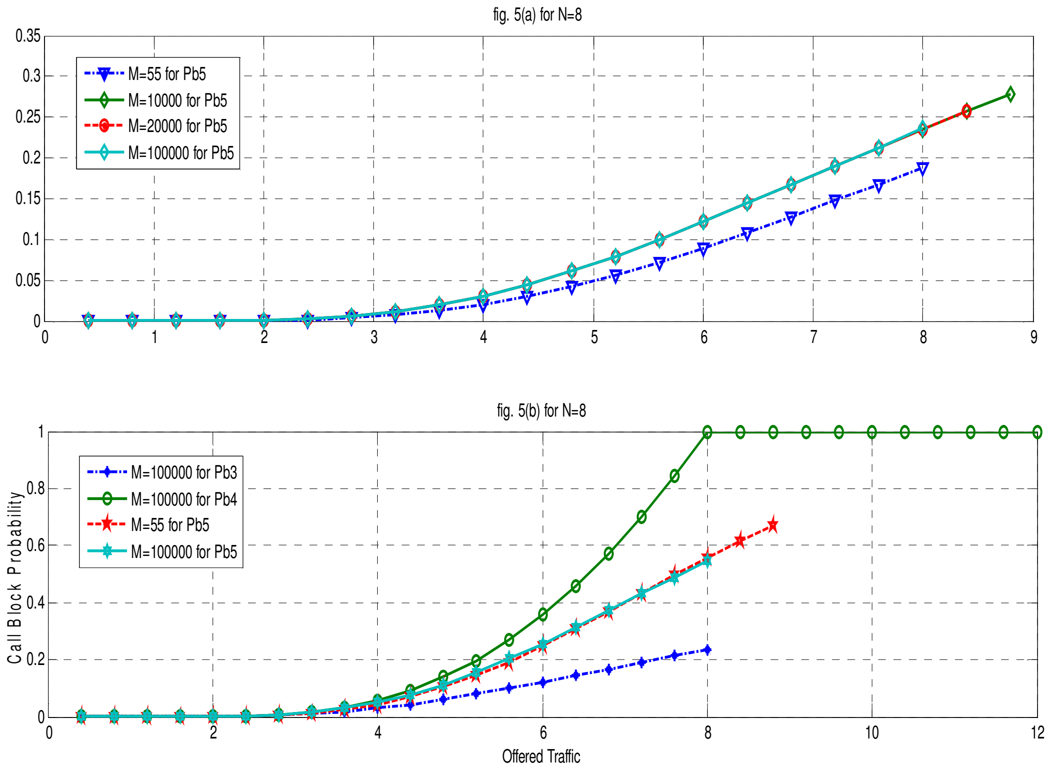

Fig. 5 Comparison of CBP against offered traffic for $Pb3$, $Pb4$, and $Pb5$ with different number of users.

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