Teletraffic Estimation of Various Cellular Systems (1G to 4G)

[1]Ch Venkata Rao, [2]G Sasibhushana Rao, [3]K Satya Prasad

[1]Research Scholar, [2,3]Professor
[1,3]Department of Electronics and Communication Engineering, JNTU, Kakinada, India
[2]Department of Electronics and Communication Engineering, Andhra University, Visakhapatnam, India

Abstract—**Cellular communication networks face serious challenges in providing good Quality of Service (QoS) to the users. In order to provide better QoS, network operators have to make effective use of their available resources, which leads to the effective network design and planning. The dominant parameter used for effective network design and network planning is the blocking probability. It is determined from the number of available channels and traffic in Erlangs. In this paper, the blocking probability of various multiple access techniques (FDMA, TDMA, CDMA, and OFDMA) that are used in cellular communication systems is investigated for assessing their network's QoS. The blocking probability of FDMA and TDMA based systems is estimated by using the Erlang-B formula. The blocking probability of OFDMA is estimated using a proposed dynamic algorithm which is based on the Signal to Interference plus Noise Ratio (SINR) of users and other parameters such as the power transmitted by the base station to each sub-carrier.**

Index Terms: **Blocking probability, FDMA , TDMA, CDMA, OFDMA.**

I. INTRODUCTION

CDMA and OFDMA are two multiple access techniques for the next generation wireless communication systems. In 3G systems, Code Division Multiple Access(CDMA) is used and in 4G, OFDMA technique is used. Recently, Wideband Code Division Multiple Access (WCDMA) is being used in 3G systems because it uses a wide bandwidth (5MHz) and it provides more services [1],[2]. The received Walsh codes are orthogonal in the downlink WCDMA transmission. This orthogonality property is lost in multipath propagation, which results in inter-symbol interference (ISI). To mitigate this problem, a new multiple access technique, Orthogonal Frequency Division Multiple Access (OFDMA) is proposed and implemented for the LTE-downlink communication (4G). It provides high data rate transmission with efficiency for high band width, operates in multipath radio environments and efficiently shares limited resources, which are the advantages of OFDMA system.

The dominant parameter, used for effective network design and planning, is the blocking probability. The blocking probability is defined as the probability of service being denied to users due to the non-availability of radio resources. Blocking probability of Global System for Mobile communications (GSM) is determined by the Erlang-B formula [4]. In GSM, a user is blocked if all the time or frequency channels are unavailable. In CDMA, an incoming user is blocked by establishing a blocking condition such that (1) the incoming call is blocked when the interference level is above a threshold value and (2) the available number of users is more than the system capacity. The uplink blocking probability of OFDMA based cellular networks is analyzed in few studies [7] ,but it is not useful because the uplink of OFDMA has more peak to average power ratio (PAPR). Thus, instead of it we are using SC-FDMA [7]-[9]. In this paper, the downlink teletraffic of OFDMA system is analyzed.

II. TELETRAFFIC ESTIMATION OF CELLULARCOMMUNICATION SYSTEMS

The measure of economic usefulness of any communication system depends on the traffic (Erlang) that can be supported by the blocking probability. Hence, the quality of service of any cellular system depends on blocking probability estimation.

A. *Blocking Probability of FDMA and TDMA*

In FDMA and TDMA systems, the traffic channels are allocated to users as long as the channels are available, after which all incoming users (traffic) are blocked until the channel becomes free. The blocking probability is obtained from the classical Erlang analysis of the M/M/S/S queue [1].

The Erlang-B formula gives the blocking probability under the above conditions.

$$P_{blocking} = \frac{(\lambda/\mu)^s/S!}{\sum_{k=0}^{s}(\lambda/\mu)^k/k!} \quad (1)$$

Where S is the number of channels or servers, λ is the arrival rate of calls, and μ is the holding time of calls.

B. Blocking Probability Estimation of CDMA

In Code Division Multiple Access (CDMA) systems, all users share a common spectral efficiency over the time. Hence, in a CDMA system, the new users can be accepted as long as the processors are available to service them [3] [4]. The blocking in CDMA system depends on

- interference level
- user activity factor
- background noise

In a CDMA system, interference increases for every additional user and hence the interference to noise ratio exceeds by a given threshold level $1/\eta$ (η =0.1 corresponding to 10dB), which leads to blocking and used for traffic load determination.

In the uplink of CDMA, blocking is defined by considering the following parameters

- Constant number of users C_u in every sector
- Each user transmitting continually and maintaining the same E_b/I_0 under all propagation conditions
- W=spread-spectrum bandwidth
- R=data rate
- E_b =bit energy
- N_0 =thermal noise density
- I_0 =maximum total acceptable interference density
- I_f =ratio of other cell interference (at base station for given sector)-to-own sector interference

The total number of users C_u is given by

$$C_u \leq \frac{W/R}{E_b/I_0} \cdot \frac{1-\eta}{1+I_f} \quad (2)$$

Where $\eta = N_0/I_0 = 0.1$

Then the total interference is determined as

Total interference =C_u + other cell interference + N_0

Hence the condition for non-blocking is given by

$$C_u E_b R(1+I_f) + N_0 W \leq I_0 W \quad (3)$$

However, none of the above assumptions hold since

a) The number of active users (calls) is a Poisson random variable with mean λ/μ

b) Each user is 'on' with probability ρ and 'off' with 1-ρ

c) Each user's E_b/I_0 ratio varies according to propagation conditions

$$\sum_{i=1}^{k} v_i E_{bi} R + \sum_{j}^{othercells} \sum_{i=1}^{k} v_{i(j)} E_{bi(j)} R + N_0 W \leq I_0 W \quad (4)$$

Where k is the number of users/sector, ν is the voice activity factor (binary random variable taking values 0 and 1).

$$P(v=1) = \rho$$

Let us assume $\xi = E_b/I_0$

Dividing the above equation (4) with $\xi = E_b/I_0$ then non-blocking condition becomes

$$Y = \sum_{i=1}^{k} v_i \xi_i + \sum_{j}^{othercells} \sum_{i=1}^{k} v_{i(j)} \xi_{i(j)} \leq (W/R)(1-\eta) \quad (5)$$

The blocking probability for CDMA is given by

$$P_{blocking} = Pr[Y > (W/R)(1-\eta)] \quad (6)$$

To evaluate this blocking probability, initially the distribution function of the random variable Y is determined, which depends on the other random variables ν, k and ξ.

$$Pr\ (k\ active\ users) = \frac{(\lambda/\mu)^k}{k!} e^{-\lambda/\mu} \quad (7)$$

Where λ is the call arrival rate and μ is the service rate

The E_b/I_o ratio of a single user depends on the power control mechanism which leads to equalization of the performance of all users. The inaccuracy in power control loops is approximately log-normally distributed (standard deviation of 1-2dB). The log-normal approximation is expressed as

$$\xi = 10^{x/10}$$

Where x is a Gaussian variable (mean α=7dB and standard deviation σ=2.5dB).

The first and second moments are given by

$$E(\xi) = E\left(e^{\beta x}\right) = exp[(\beta\sigma)^2/2]exp(\beta\alpha) \quad (8)$$

$$E(\xi^2) = E\left(e^{2\beta x}\right) = exp[2(\beta\sigma)^2]exp(2\beta\alpha) \quad (9)$$

Where $\beta = (\ln 10)/10$

The blocking expression for a single sector without considering interference from other cells is expressed as

$$P_{blocking} < Min_{\substack{s>0\\ \tau>0}}\ exp\left\{\rho\left(\frac{\lambda}{\mu}\right)\left[E\left(e^{s\xi_T'}\right)-1\right]-sA\right\}+\rho\left(\frac{\lambda}{\mu}\right)Q\left(\frac{\tau}{\sigma}\right) \quad (10)$$

Where

$$G \triangleq \frac{(W/R)(1-\eta)}{exp(\beta\alpha)} = \frac{(W/R)(1-\eta)}{E_b/I_0\,_{medium}}$$

$$E\left(e^{s\xi_T'}\right) = \int_{-\infty}^{\tau/\sigma} exp\left[se^{\beta\sigma\zeta}\right]e^{-\zeta^2/2}\ d\zeta/\sqrt{2\pi}$$

and $\quad Q(\tau/\sigma) = \int_{\tau/\sigma}^{\infty} e^{-\zeta^2/2}\ d\zeta/\sqrt{2\pi}$

By using central limit theorem, Y is approximated and its mean and variance are computed. Then the Blocking condition can be expressed as

$$P_{blocking} \approx Q\left[\frac{G - E(Y')}{\sqrt{Var(Y')}}\right] \quad (11)$$

Where

$$Y' = Y/exp\ (\beta\sigma) = Y(E_b/I_0)_{medium}$$

Y' is the sum of k random variables (k is itself a random variable).

Let $\xi' = \xi/exp(\beta\sigma)$

$$E(Y') = E(k)E(\nu\xi') = (\lambda/\mu) \quad (12)$$

$$Var(Y') = E(k)Var(\nu\xi') + Var(k)[E(\nu\xi')]^2 \quad (13)$$

Since k is a Poisson variable, $E(k) = Var(k) = \lambda/\mu$

So that

$$Var(Y') = \lambda/\mu\,[E(\nu\xi')^2] = (\lambda/\mu)E(\nu^2)E(\xi^2) = (\lambda/\mu)exp[2(\beta\sigma)^2] \quad (14)$$

By considering other cell interference, the same log-normal distribution is assumed for users of the desired cell. Here, the average power is equivalent to that of kI_f users. The mean power will be same but the variance will change (reduced), with a large number of users. Hence, the mean and variance are simply increased by the factor $(1+I_f)$.

Now blocking probability is

$$P_{blocking} \approx Q\left[\frac{G - E(Y')}{\sqrt{Var(Y')}}\right] \quad (15)$$

Where

$$E(Y') = (\lambda/\mu)\rho\left(1+I_f\right)exp[(\beta\sigma)^2/2]$$

$$Var(Y') = (\lambda/\mu)\rho\left(1+I_f\right)exp[(\beta\sigma)^2/2]$$

From (8)

$$x\gamma^4\left[Q^{-1}\left(P_{blocking}\right)\right]^2 = [G - x\gamma]^2 \quad (16)$$

Where

$$x = (\lambda/\mu)\rho(1+I_f) \quad and \quad \gamma = exp[(\beta\sigma)^2/2]$$

Then the solution is

$$x = \frac{A}{\gamma}\left[1 + \frac{\gamma^3 H}{2}\left(1 - \sqrt{1 + \frac{4}{\gamma^3 B}}\right)\right] \tag{17}$$

Where

$$H = \frac{[Q^{-1}(P_{blocking})]}{G} = \frac{(E_b/I_0)_{medium}\,[Q^{-1}(P_{blocking})]^2}{(W/R)(1-\eta)} \tag{18}$$

From (17) and (18), Erlang Capacity formula can be expressed as

$$\frac{\lambda}{\mu} = \frac{(1-\eta)(W/R)F(H,\sigma)}{\rho(1+I_f)(E_b/I_0)_{medium}} \text{Erlangs/sector} \tag{19}$$

Where

$$F(H,\sigma) = exp[-(\beta\sigma)^2/2]\left\{1 + (H/2)exp\frac{3(\beta\sigma)^2}{2}\left(1 - \sqrt{1 + 4exp\left[-\frac{3(\beta\sigma)^2}{2}\right]/H}\right)\right\}$$

$F(H,\sigma)$ is a function of H for several values of σ, the standard deviation (in dB) of the power controlled E_b/I_0.

III. OFDMA BLOCKING PROBABILITY

First, initialization of OFDMA system parameters is done to estimate the Cumulative distribution function of blocking probability with offered load using proposed algorithm and later, the carrier distribution is carried from available set of subcarriers [5], [6].

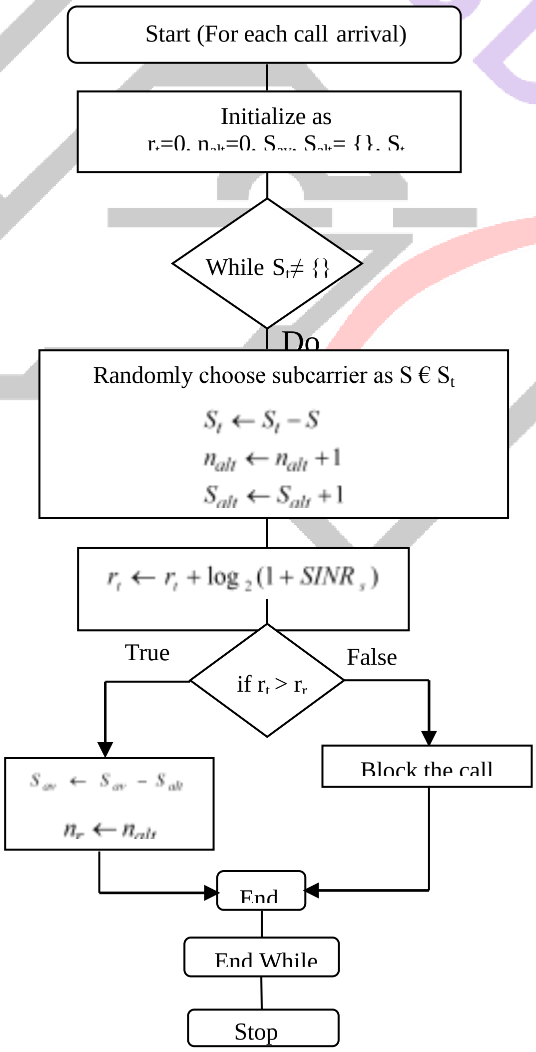

Figure: 1. Flowchart for subcarrier distribution

First, initialization of OFDMA system parameters is done to estimate the Cumulative distribution function of blocking probability with offered load using proposed algorithm and later, the carrier distribution is carried from available set of subcarriers [5], [6]. For each subcarrier allocation, the interference and simultaneous SINR is calculated [7]. From this SINR, the data rate is calculated for every allocation of subcarriers (data rate $R=\log_2(1+SINR)$). This process is repeated till the total available set of subcarriers becomes empty. The calculated data rate is compared with the required data rate. From the comparison of data rates, and power transmitted by BSs, the incoming calls will be blocked and blocking probability is calculated.

Where r_t is temporary rate required, n_{alt} is number of subcarriers allotted, S_{av} is set of subcarriers available, S_{alt} is number of subcarriers allotted and S_t is temporary set of subcarriers.

IV. Results And Discussions

Consider the conventional FDMA based Advanced Mobile Phone System(AMPS) with 30KHz channels, frequency reuse factor 7 and number of sectors in a cell is equal to 3.

Then the number of channels (servers) in 12.5MHz is

$$S = 12.5MHz/ ((30\ KHz) \times (7) \times (3)) \approx 20 \text{ channels/sector}$$

From this, we estimate the FDMA based AMPS system's traffic (Erlang capacity) with blocking probability by using the Erlang-B formula.

Consider the conventional 3-slot TDMA based AMPS system with 30KHz channels, frequency reuse factor 7 and number of sectors in a cell is equal to 3.

Then the number of channels (servers) in 12.5MHz is

$$S = 12.5MHz/((30KHz)x(7)x(3))x\ 3= 60 \text{channels/sector.}$$

From this, we estimate the TDMA based AMPS system's traffic with blocking probability by using the Erlang-B formula.

The variation of offered load with blocking probability for FDMA and TDMA based system is shown in Fig. 2.

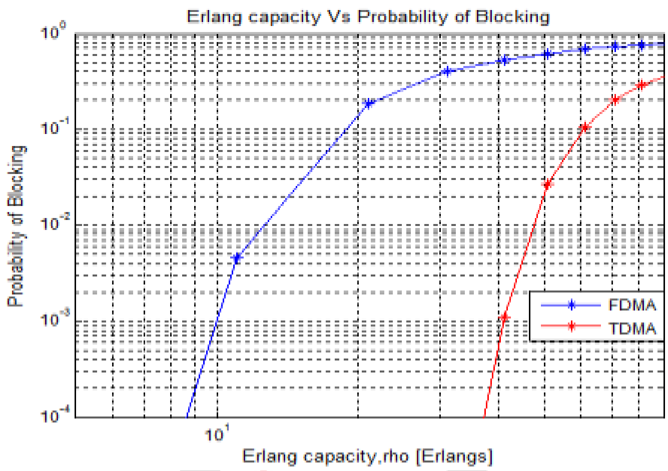

Figure: 2.Variation of Blocking Probability with Traffic for FDMA and TDMA

The variation of offered load with blocking probability for CDMA is shown in Fig. 3

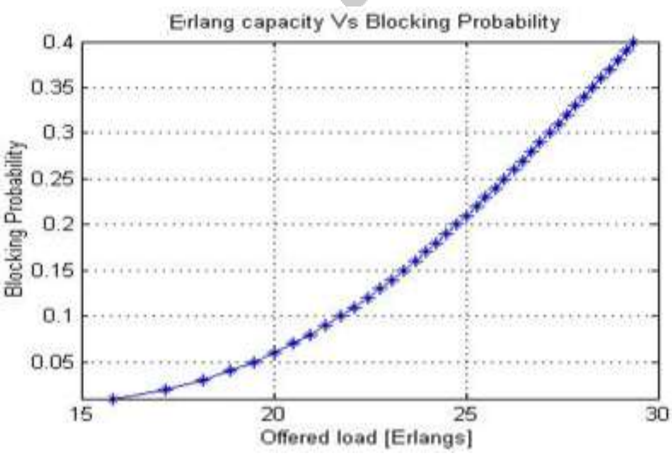

Figure: 3. Variation of Blocking Probability with Traffic Load for CDMA

To estimate the OFDMA cumulative distribution function of blocking probability with traffic, the following parameters are considered

Total number of clusters= 7,
Rate required= r_r = 8Kbps,
Number of subcarriers=N = 512,
Power transmitted by base station per subcarrier P_{tx} = 10dBm,
Distance between the BS and MS (BS is in reference cell and MS is in neighbour cell) d =1000m,
Path loss exponent= η = 3.5,
Total number of users = 100,
Thermal noise level=N_0 = -100dBm,
Shadowing on the BS-MS link ξ is Gaussian with mean 0 and standard deviation σ, hence this value for every link considered as any random value.The variation of offered load with blocking probability for OFDMA is shown in Fig. 4.

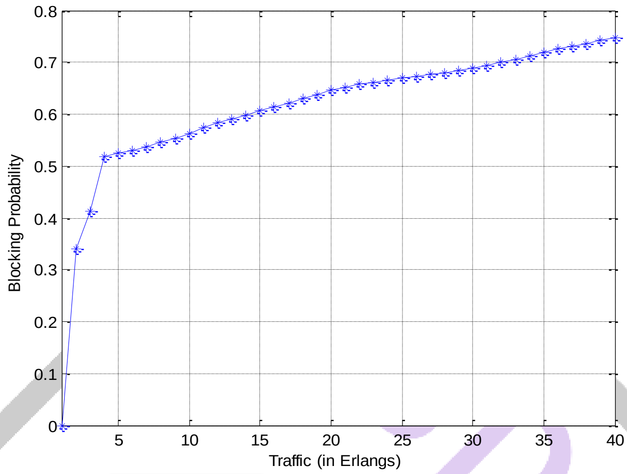

Figure: 4. Variation of Teletraffic with Blocking Probability for OFDMA

Table 1: Traffic Vs Blocking Probability

Traffic[in Erlangs]	Blocking Probability
2	0.3378
3	0.4095
4	0.5155
5	0.5264
10	0.5641
15	0.6079
20	0.6476
25	0.6687
30	0.6875
35	0.7174
40	0.7474

From Table 1, it shows that, if the traffic increases from 2 to 40 Erlangs, then the blocking probability of cellular OFDMA increases from 0.3378 to 0.7474.

For multi service applications the base station has to transmit different powers to different mobile station users. For this purpose the Erlang capacity of downlink cellular OFDMA is also analyzed with the help of power transmitted by BSs to different sub carriers of mobile station users for different blocking probabilities(1%, 3% and 5%) is shown in Fig. 5.

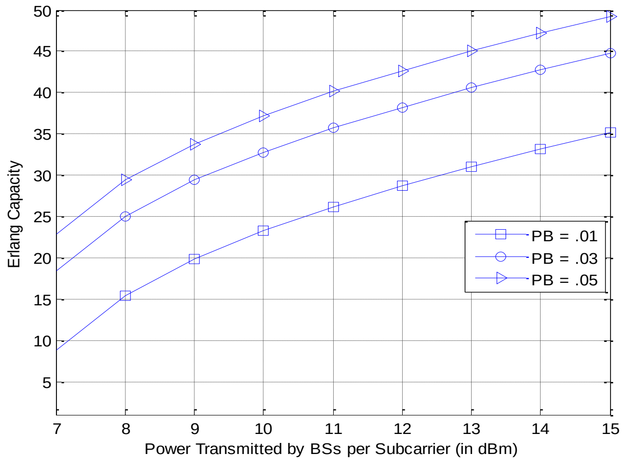

Figure: 5. Variation of Erlang Capacity with Transmitted Power for OFDMA

Table 2: Erlang Capacity Vs Transmitted Power for P_B =1%, 3% and 5%

Transmitted Power (dBm)	Erlang Capacity(Erlangs)		
	P_B=0.01	P_B=0.03	P_B=0.05
7	8.8279	18.3703	22.8073
8	15.4444	24.9868	29.4238
9	19.8272	29.3697	33.8066
10	23.2557	32.7981	37.2351
11	26.1514	35.6938	40.1308
12	28.7066	38.2490	42.6860
13	31.0252	40.5676	45.0046
14	33.1697	42.7121	47.1491
15	35.1808	44.7233	49.1602

From Table 2, it shows that the Erlang capacity of cellular OFDMA increases from 35.1808 to 49.1602Erlangs with increase in power transmitted by base station per sub carrier of mobile users for 15dBm.

V.CONCLUSION

The accurate estimation of blocking probability plays a major role in the design of cellular systems (from 1G to 4G). Blocking probability is the key parameter in all cellular systems for assessing their network's QoS. OFDMA blocking probability is estimated by an efficient algorithm which depends on the distribution of sub carriers and other parameters used for transmission. Teletraffic of OFDMA based cellular system increases with increase in blocking probability and power transmitted by base station(BS) per sub carrier.

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