ERLANG CAPACITY EVALUATION IN GSM AND CDMA CELLULAR SYSTEMS

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ABSTRACT

Interference is the important capacity limiting factor in cellular systems. The main source of interference is Co-Channel Interference (CCI) that comes from base stations operating in same frequency band. In this paper a novel method is introduced to evaluate erlang capacities for GSM and CDMA cellular networks. The probability of CCI is considered for capacity evaluation and Rayleigh distributions is used for approximating CCI probability. This evaluation method can be applied for systems where maximum number of interferers is known. Erlang capacity results are evaluated and compared for GSM and CDMA for different number of co-channel interferers. It is observed that erlang capacity per cell increases as number of co-channel interferes decreases and vice versa. For probability of 0.1 CCI erlang capacity per cell increases from 3.58 erlangs/cell to 12erlangs/cell in TDMA and 24 erlangs/cell to 78 erlangs/cell in CDMA as number of interfering sources decreases from 10 to 3.

KEYWORDS

CCI, GSM, CDMA, Erlang Capacity, Rayleigh distribution.

1. INTRODUCTION

The GSM makes use of narrowband Time Division Multiple Access technique (TDMA) for transmitting signals over the air interface. It was developed using digital technology. The data rate carried by this technology is 64 kbps to 120 Mbps. GSM supports many subscribers, for about 210 countries the mobile subscribers supported by this are more than one billion. It provides advanced voice and data services including Roaming service. The ability to using GSM phone number in another GSM network is called roaming. The data is digitized and compressed and then sends it down the channel with two additional streams of user data, each with individual time slot. The GSM standard is most widely accepted standard and offers International Roaming. The method of providing multiple access capability by transmitting signals simultaneously in a non overlapping time slots is called Time Division Multiple Access (TDMA).

Since spectrum efficiency FDMA systems became insufficient the TDMA systems were developed. In digital systems, transmission is not required continuously since users do not use the chosen bandwidth all the time. It allows several users to share the same frequency band by dividing the time scale into different time slots which are periodically allocated to each mobile user for the duration of a call.TDMA systems divide the radio spectrum into time slots and each

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user is allowed to either transmit or receive in each time slots (i.e. different users can use the same frequency in the same cell but at different times). Digital 2G cellular systems that used the TDMA technology are GSM, IS-136, PDC and DECT standard for portable phones.

In this paper, the parameters of TDMA system are chosen according to GSM (Global System for Mobile) standard. The spectrum allocation for GSM is 890-915MHz in uplink (mobile to base station) and 935-960 MHz in downlink (base station to mobile). The channel bandwidth is 200 KHz; data rate is 270.8333 Kb/s and Gaussian minimum shift keying (GMSK) is used in data modulation. The co-channel protection ratio α is fixed to minimum $(C/I)_s$=9dB.

The method of providing multiple access capability based on a spread spectrum system is called Code Division Multiple Access (CDMA). All users share same frequency and at the same time, but each user has own spreading code to encode data. The spectrum efficiency in CDMA is increases by using spread spectrum technique [1, 2, and 3]. The 2G CDMA cellular technology is also known as IS-95, this competes with the GSM technology. CDMA cellular systems operate in the 800 MHz and 1.9 GHz PCS bands.

In this paper IS-95 is chosen for CDMA system. The parameters of IS-95 are, spectrum allocation for uplink is 824-849MHz and down link is 869-894MHz. The bandwidth is 1.23MHz; chip rate is 1.228Mc/s, modulation chosen for digital data is either QPSK (quadrature phase shift keying) or OQPSK (offset quadrature phase shift keying). The multiple access scheme used is CDMA, FDD.

The CDMA mobile phones and Base Stations (BS) use minimum amount of power to communicate with each other. They use accurate power control to reduce users' transmission power. By decreasing a user's transmission power, the mobile phone has added battery life, increased talk time, and smaller batteries.

There are three types of codes generally used, Walsh code, Short PRN code and Long PRN codes.

- Walsh codes are orthogonal codes. The Spreading on forward link is 1.2288Mbps and on reverse link is 307.2kbps. 64 bit Walsh codes are used in IS 95A and IS 95B. 128 bit Walsh codes are used in CDMA2000.
- Short PRN code (16 bit) is used to identify the BS and the cell.
- Long PRN code (42 bit code) are used to identify mobile station on reverse link.

This paper mainly describes an evaluation procedure for the capacity in GSM and CDMA systems with the consideration of co-channel interference. The probability of co-channel interference is considered for the capacity evaluation. Rayleigh distribution is considered for the analysis of probability of CCI in a given cellular network. The capacity results evaluated and compared for different number of active co channel interferers for GSM and CDMA systems. It is observed that the erlang capacity of a CDMA system is more as that of a GSM system.

2. CO-CHANNEL INTERFERENCE AND ITS PROBABILITY

The crosstalk from two different radio transmitters using the same frequency is called Co-channel interference or CCI. The CCI is major source of interference which limits the quality and capacity (number of users) of wireless networks. It arises due to frequency reuse concept i.e. using the same set of carrier frequencies in different cells [4]. Almost all co-channel interference originates from the closest neighbouring reuse cells. The average CCI levels can be regulated with cellular network planning. If the level of CCI is high, the cluster size can be increased however this would limit the capacity. This inevitable trade-off between system capacity and quality of service is always present.

In cellular CDMA systems, the majority of co-channel interference comes from the desired cell (intra-cell interference) and part of the interference comes from the neighbouring cells (inter-cell interference). Intra-cell and inter-cell interferences can also be called multiple access interference (MAI) because they consist of the cross-correlation products of simultaneously active users' spreading codes. The capacity of a CDMA system is interference limited and the number of co-channel interferers is typically very large.

The CDMA system applies to universal one-cell frequency reuse pattern [3], because the reuse factor is usually one. The frequency reuse factor is greater than one in GSM (TDMA) cellular networks. This means that CCI comes from adjacent reuse cells. Also, the numbers of effective CCI sources are typically quite small. In a cellular system, the signal to-noise ratio (S/N) is a significant factor in determining the quality of service experienced by the user.

In reference [6] co-channel interference (CCI) probabilities for Rayleigh distributed signals have been derived. The co-channel interference probability is defined as

$$F(I_c) = \sum F(I_c | n) F_n(n) \qquad (1)$$

Where *Fn* (*n*) is the probability of *n* co-channel interferers being active and *F* (*Ic* |*n*) is the corresponding conditional CCI probability. Conditional CCI probability can be defined as

$$F(I_c | n) = P\left(\frac{p_d}{p_n} < \alpha \right) \qquad (2)$$

Where, p_d is instantaneous power of desired signal, p_n is joint interference power from *n* active channels and α is specified co-channel interference protection ratio. When only Rayleigh fading is considered then conditional co-channel interference can is derived as [6]

$$F(I_c | n) = 1 - \left(\frac{1}{\alpha \cdot {}^{p_o}\!/\!_{p_{od}} + 1} \right)^n \qquad (3)$$

where p_0 is the local mean power of the interferers and p_{0d} is the mean power of the desired signal. If the quality of service measure is set according to the outage P_{out} at co-channel interference probability, the following equation can be derived [6]. F_n (*n*) can be represented by binomial distribution in terms of carried traffic per channel.

$$F_n(n) = \binom{N}{n} a_c^n (1 - a_c)^{N-n} \qquad (4)$$

where *N* is the number of co-channel interferers taken into account and *ac* = *m*1 /*m* is carried traffic per channel [Erlang/channel].

3. RADIO CAPACITY

In this paper spectrum efficiency measurements are based on the radio capacity *m* introduced by W.C.Y. Lee [1,3,4]. The radio capacity of Omni-cell system is defined as

$$m = \frac{B_t}{B_c\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)_S}} = \frac{M}{\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)_S}} = \frac{M}{K_{CS}} \text{ [carriers/cell]} \quad (5)$$

where B_t is the total allocated spectrum for the system, B_c is the carrier bandwidth, $(C/I)_S$ is the minimum required carrier-to-interference ratio, M is the total number of carrier frequencies and K_{cs} is the number of cells in the cluster (cluster size).The total number of traffic channels M depends on the multiple access method. In GSM system which uses TDMA, M_t must be multiplied by the number of TDMA slots per carrier. In the case of GSM, the result would be $M_t = 8M$ traffic channels. The capacities of uplink and downlink are same but are not comparable because uplink capacity is mainly related to number of users, and downlink capacity is related to transmitted power of BS.

The parameters for the TDMA system have been chosen according to the GSM standard. This means that the carrier separation is 200 kHz, the raw channel bit rate is 270.833 bit/s and Gaussian minimum shift keying (GMSK) is used for data modulation. The co-channel interference protection ratio a has been fixed to the minimum required carrier-to-interference ratio $(C/I)s = 9$ dB, which should be sufficient when slow frequency hopping is employed [4].Otherwise, a $(C/I)s$ value of 11 dB is required. The CDMA and WCDMA capacities are mainly determined by the processing gain and required signal-to-noise ratio.

Other parameters which impact on capacity are based on:

- Structure of the radio-network: Cell size and formation which determine the interference value and it is also important to stress on sectoring, if isolated sector-cell or multi sectorised system is observed.

- The user distribution whether it is uniform or not. The user position is determined in relative to its jammers and the base station position or the direction of its signal coverage.

- Type of services used whether real-time or non-real-time. Real-time applications needs guaranteed minimum transmission rate which requires reservation of system capacity. The multi-service environment impacts on activity factor and also on required signal-to-noise ratio.

- The characteristics of BS receiver (for the uplink) and its antenna system: The signal processing of BS is the most important thing for capacity. The antenna construction and antenna's parameters significantly impact on the capacity.

- Power control (perfect or imperfect): Since capacity of cellular network is interference-bound, the study of capacity characteristics focuses primarily on method of reducing interference. CDMA and WCDMA offer fast and precise power control. Power control reduces interference by minimizing the effects of near-far problem.

Consider a cell with K active users which simultaneously access network on the same frequency. Every user has its own PN sequence. So, if the P is carrier power, the relation between (S/N) received and (E_b/N_o) is a network is given by

$$\left(\frac{E_b}{N_0}\right)=\left(\frac{S}{N}\right)\left(\frac{W}{R}\right) \tag{6}$$

$$\left(\frac{E_b}{N_0}\right)=\left(\frac{S}{N}\right)G_p \tag{7}$$

If power of signals of all active users has the same value then

$$\left(\frac{N}{S}\right)=\frac{(K-1)P}{P}$$

$$K=1+\frac{G_p}{\left(E_b/N_0\right)} \tag{8}$$

where E_b/N_o=Energy per bit to noise power spectral density ratio, G_p= Processing gain, R= base band information bit rate, W= chip rate. The equation (8) is known as the basic formula for capacity of CDMA and WCDMA system. By considering the parameters background noise, voice activity, power control, antenna parameters and cell sectoring, the capacity of CDMA and WCDMA can be written as

$$K=1+\frac{G_p\cdot A_b\cdot D}{E_b/N_0}\frac{\sigma}{v}-\frac{\eta}{S} \tag{9}$$

where A_b=antenna gain ratio, η= background thermal noise, S=signal power, σ=power control deviation, v=voice activity factor and D= number of sectors in a cell.

4. RESULTS AND DISCUSSION

The erlang capacity is evaluated from for GSM (TDMA) and CDMA systems with the following assumptions, radio capacity is limited by co-channel interference only (adjacent channel interference and thermal noise neglected), three leaf clover hexagonal layout is used for each cell, Rayleigh distribution is considered and number of active co-channel interferers (N=3, 5, 7 and 10) are considered for erlang capacity comparison for GSM (TDMA) and CDMA.

Table1. GSM (TDMA) Erlang capacity for N=3, 5, 7 and 10

S.No	**P(Ic)**	**N=3**		**N=5**		**N=7**		**N=10**	
		ac	**m1**	**ac**	**m1**	**ac**	**M1**	**ac**	**m1**
1	0.01	0.004	1.149	0.002	0.690	0.002	0.493	0.001	0.344
2	0.02	0.009	2.307	0.005	1.386	0.004	0.990	0.002	0.691
3	0.03	0.013	3.472	0.008	2.087	0.006	1.492	0.004	1.041
4	0.04	0.018	4.645	0.011	2.795	0.008	1.998	0.005	1.395
5	0.05	0.023	5.827	0.014	3.508	0.010	2.509	0.007	1.751
6	0.06	0.028	7.017	0.016	4.227	0.012	3.025	0.008	2.112
7	0.07	0.032	8.215	0.019	4.953	0.014	3.545	0.009	2.475
8	0.08	0.037	9.422	0.022	5.684	0.016	4.070	0.011	2.843
9	0.09	0.042	10.630	0.025	6.422	0.018	4.600	0.012	3.213
10	0.1	0.047	11.866	0.028	7.167	0.020	5.135	0.014	3.588

Table: 1 shows carried traffic and erlang capacity for GSM with a cluster size of 4 for different interfering sources N=3, 5,7,10. It is observed that erlang capacity per cell in a GSM network increases as the number of co-channel interferers decreases for a given probability of co-channel interference.

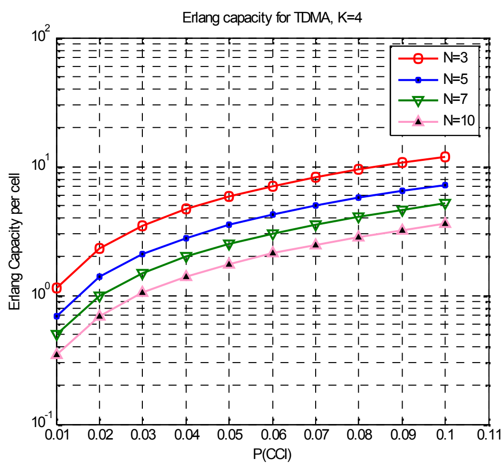

Figure 1. GSM (TDMA) Erlang capacities

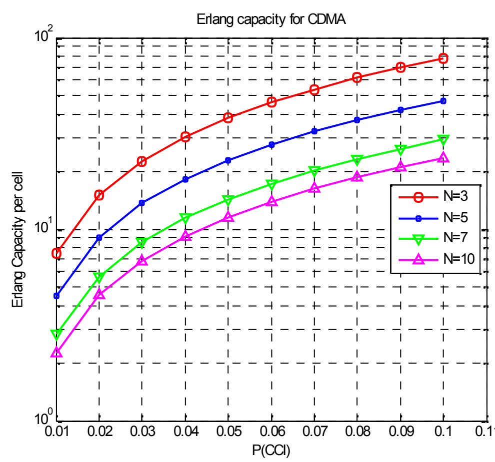

Figure 2. CDMA Erlang capacities

For a 0.1 CCI probability, the Erlang capacity per cell increases from 3.588 erlangs/cell to 11.866 erlangs/cell as the number of interferers decreases from 10 to 3. The variation of TDMA erlang capacity for cluster size of 4 with probability of CCI for different number of co-channel interferers is shown in Figure 1.

Erlang Capacity per cell for CDMA also increases as the number of co-channel interferers decreases for a given probability of CCI. For a 0.1 CCI probability, the Erlang capacity per cell increases from 23.58 erlangs/cell to 77.64 erlangs/cell as the number of interferers decreases from 10 to 3. The variation of CDMA erlang capacity with probability of CCI for different number of co-channel interferers is shown in figure 2.

Table 2: CDMA Erlang capacity for N=3, 5, 7 and 10

S.No	P(Ic)	N=3		N=5		N=7		N=10	
		ac	m1	ac	m1	ac	m1	ac	m1
1	0.01	0.016	7.525	0.010	4.518	0.006	2.824	0.005	2.260
2	0.02	0.033	15.101	0.020	9.073	0.012	5.674	0.010	4.541
3	0.03	0.050	22.728	0.030	13.666	0.019	8.550	0.015	6.842
4	0.04	0.067	30.409	0.040	18.297	0.025	11.450	0.020	9.166
5	0.05	0.084	38.143	0.051	22.969	0.031	14.377	0.025	11.511
6	0.06	0.102	45.931	0.061	27.681	0.038	17.328	0.030	13.879
7	0.07	0.119	53.775	0.072	32.435	0.045	20.305	0.036	16.269
8	0.08	0.137	61.675	0.082	37.232	0.051	23.307	0.041	18.682
9	0.09	0.154	69.632	0.093	42.073	0.058	26.333	0.046	21.120
10	0.1	0.172	77.648	0.104	46.960	0.065	29.382	0.052	23.581

Table 2 shows carried traffic and erlang capacity for CDMA for different interfering sources N=3, 5, 7, 10. It is observed that erlang capacity per cell in a CDMA network also increases as the number of co-channel interferers decreases for a given probability of co-channel interference.

5. CONCLUSIONS

Co-channel interference (CCI) is the major source of noise which limits capacity of wireless networks. In this paper an analytical method is presented for the evaluation of erlang capacity of GSM and CDMA systems due to the CCI. This method is suitable for the cellular network where the number of active interferes is low. The probability of CCI is assumed to follow a Rayleigh distribution. The erlang capacity is evaluated and compared for both GSM and CDMA systems with different number of active interferers. It is observed that the Erlang capacity per cell increases as the number of co-channel interferes decreases for a given CCI probability. In GSM, it is observed that for 0.1 CCI probability, erlang capacity increases from 4 erlangs/cell to 12erlangs/cell as the number of interferers decreases from 10 to 3 and in CDMA erlang capacity increases from 24 erlangs/cell to 78 erlangs/cell. The results showed that best erlang capacity is achieved by reducing number of active interferers

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