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Erlang Capacity Evaluation Procedure for 4G Cellular Communication Systems under Co-Channel Interference

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

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

Abstract — *Long Term Evolution (LTE) is one of the standards in 4G cellular technologies which offers different peak data rates for voice, video, messaging traffic and other services. The Orthogonal Frequency Division Multiple Access (OFDMA) is a well applicable multiple access scheme of 4G-LTE cellular technology for supporting variable bit rate services. OFDMA-based cellular communication network faces challenges in providing excellent Quality of Service (QoS) to the users. In order to provide good QoS, network operators have to make effective use of their available resources, which leads to effective network design and planning. Capacity is one of the significant parameters in determining the performance of any cellular communication system and it is also used for effective network design and planning. However, the interference limits the capacity of cellular systems. Co-Channel Interference (CCI) is the major source of interference which is an important limiting factor for estimating the Erlang capacity in cellular systems . In this paper, an analytical method is proposed to evaluate the Erlang capacity of 4G-LTE cellular systems under CCI. Here the probability of CCI is considered for capacity determination. Erlang capacity results are evaluated for a different number of co-channel interferers, various spectral efficiencies, voice activity factors and various data rates.*

Keywords- *LTE; OFDMA; CCI; Probability of CCI; Erlang capacity*.

I. INTRODUCTION

In the field of communication the term multiple access allows multiple users to simultaneously share the finite bandwidth with least degradation in the performance of the system[3]. There are several ways to access the communication channel. The basic possible access techniques are: FDMA, TDMA, CDMA, WCDMA and OFDMA.

Orthogonal Frequency Division Multiple Access (OFDMA) technique plays a vital role in 4G (Fourth Generation) Long Term Evolution(LTE) standard. LTE uses OFDMA as its downlink air interface. To satisfy the demand for higher band width offering multiple services with better quality of service (QoS) to the users it is required to design different cellular architectures deploying various wireless technologies. The multiple access schemes like OFDMA and MC-CDMA provides good system performance in 4G LTE systems. The performance of this multiple access techniques mainly depends on the capacity and spectral efficiency. To use spectrum efficiently, most of the cellular systems employ a frequency reuse factor close to 1. From [1]-[2], it is noted that frequency reuse factor is 1 for implementing OFDMA, WCDMA and CDMA cellular systems . [5]-[7] shows the effect of Co-Channel interference(CCI) obtained by using the frequency reuse factor as 1. To use available spectrum in an efficient way the frequency reuse factor is set to one ,which leads to CCI and by using different multiple access techniques we can reduce , and the one among the access techniques which can cope with the CCI environment is OFDMA. In this paper, the estimation of Erlang capacity for 4G- LTE based cellular systems is done under CCI .

Area of coverage and capacity of the system are the factors that indicate the system performance and number of users a system can accommodate. But practically interference, an inherent characteristic of the system which may be adjacent channel interference (ACI) / co-channel interference (CCI) severely affects the performance of the system. The CCI is the major contributor in interference of cellular systems [8].The cells which are adjacent to each other lead to ACI ,the CCI results from reused cells which are at a distance in the cluster. In FDMA and TDMA , the frequency reuse factor was usually greater than 1, the interferes are less and the effect of interference on system capacity is less. [7] indicates that by using frequency reuse factor less than 1 in OFDMA the effect of CCI is more and can result from (intra-cell interference) and the surrounding cells (inter-cell interference).

In this paper, an evaluation procedure under CCI is proposed to determine the capacity in Erlangs per cell of an OFDMA cellular system for a particular geographical area and the analysis is described with the implementation of channel overhead power. Here, in a widely used quality of service criterion, the probability of CCI [10] is considered for the capacity evaluation. Rayleigh distribution is considered for the analysis of conditional probability of CCI in a given cellular network. The capacity results are evaluated and compared with various data rates. The capacity of a OFDMA system can be improved with the low data rates , voice activity factor and less number of co-channel interferers.

In section II, the probability of co-channel interference for OFDMA-based cellular system is analysed. In section III, the Erlang capacity of OFDMA under Co-Channel Interference (CCI) is evaluated. In section IV, the results have been shown and the conclusion is given in section V.

II. PROBABILITY OF CO-CHANNEL INTERFERENCE

2.1 Probability of co-channel interference

The CCI is the crosstalk from two different radio transmitters using the same frequency. The CCI arises in the cellular mobile networks owing to the phenomenon of frequency reuse. Thus, besides the intended signal from within the cell, signals at the same frequencies arrive at the receiver from the undesired transmitters located in some other cells and lead to deterioration in the receiver performance.

In this paper, the probability of CCI is considered for the evaluation of OFDMA capacity under CCI.
The co-channel interference probability is defined as[10]

$$P(CCI) = \sum_{n} P(CCI|n)\, P(n) \qquad (1)$$

where, $P(CCI|n)$ is the corresponding conditional CCI probability and $P(n)$ is the probability of n co-channel interferers being active.
$P(n)$ can be modeled with the binomial distribution and represented in terms of carried traffic per channel as

$$P(n) = \binom{K}{n} A_c^n (1 - A_c)^{K-n} \qquad (2)$$

where, K is the maximum number of effective co-channel interferers and A_c is carried traffic per channel (Erlangs/channel).
P(CCI) for OFDMA system for 5 co-channel interferers from equation(1) can be expressed as

$$P(CCI) = P(CCI|1)P(1) + P(CCI|2)P(2) + P(CCI|3)P(3) + P(CCI|4)P(4) + P(CCI|5)P(5) \qquad (3)$$

2.2 Conditional probability of CCI

The conditional probability is defined as the probability of an instantaneous (S/I) ratio below the required threshold at the receiver [11]. It can be formulated as

$$P(CCI|n) = P(P_d/P_n < \alpha) \qquad (4)$$

where, P_d is the desired signal power, P_n is the total interference power from n active channels and α is the required threshold at the receiver.

Small-scale or short-term fluctuations (few tens of wavelengths) of the received signal envelope in a multipath channel are commonly illustrated by a Rayleigh distribution. The probability density function for the signal amplitude a_i of the i^{th} interferer, conditional on its local mean power P_{0i} , is given by

$$P_{a_i}(a_i|P_{0i}) = \frac{a_i}{P_{0i}} exp\left(-\frac{a_i^2}{2P_{0i}}\right), \quad a_i \geq 0 \qquad (5)$$

This significant small-scale variation is called fast fading.

The corresponding probability density function for the instantaneous power P_i is exponentially distributed as

$$P_{p_i}(P_i|P_{0i}) = \frac{1}{P_{0i}} exp\left(-\frac{P_i}{P_{0i}}\right) \qquad (6)$$

The local mean power P_{oi} reflects large-scale or long-term variations in the received signal level and it is usually modeled as a log-normal random variable with probability density function

$$P_{p_{0i}}(P_{0i}) = \frac{1}{\sqrt{2\pi}\sigma_i P_{0i}} exp\left(-\frac{(ln\, P_{0i} - m_i)^2}{2\sigma_i^2}\right) \quad (7)$$

Equations. (5) to (7) are valid for the amplitude, instantaneous and local mean power of the desired signal by substituting the index *i* with *d* in corresponding variables (a_i , P_i , P_{0i} , s_i , m_i *and* x_i).

All interference components are assumed to be identically distributed random variables. Rayleigh distributed components are assumed to be independent and thus uncorrelated. Log-normal components may be correlated or uncorrelated. Furthermore, it is presumed that co-channel interference adds non-coherently.

If it is assumed that the total interference from different sources is the result of non-coherent addition with equal local mean powers, i.e.; $P_{0i} = P_0$ the probability density function for the joint interference power P_n is obtained by convolving equation (4) *n* times. The result is the gamma distribution

$$P_{p_i}(P_n) = \frac{1}{P_0}\frac{(P_n/P_0)^{n-1}}{(n-1)!} exp\left(-\frac{P_n}{P_0}\right) \quad (8)$$

The conditional co-channel interference probability can be derived from equations (4), (6) and (8) as

$$P(CCI|n) = \int_0^{\infty} dP_n \int_0^{\alpha P_n} \frac{1}{P_0 P_{0d}}\frac{(P_n/P_0)^{n-1}}{(n-1)!} exp\left(-\frac{P_d}{P_{0d}} - \frac{P_n}{P_0}\right) dP_d \quad (9)$$

Finally, after integrating equation (9) the probability of CCI for *n* interferers can be obtained (when only Rayleigh fading is considered) as

$$P(CCI|n) = 1 - \left(\frac{1}{\alpha.P_{0i}/P_{0d} + 1}\right)^n \quad (10)$$

where, P_{0i} is the local mean power of the interference and P_{0d} is the mean power of the desired signal.

III. ERLANG CAPACITY OF OFDMA

3.1 Radio capacity of OFDMA cellular communication system

The air interface capacity of an OFDMA system is expressed in terms of number of subscribers [13]. The total cell site capacity (total number of subscribers in a cell) with Quality of Service (QoS) data rate can be expressed as

$$C_{subs} = \frac{K * N_s * S_e * B * L_{bh}}{R} \quad (11)$$

where K is over subscribe factor, N_s is number of sectors in a cell, S_e is average downlink spectral efficiency, B is bandwidth of the system, L_{bh} is busy hour loading and R is QoS data rate.

In order to provide a more practical point of view for the number of subscribers, the above equation can be modified for the downlink OFDMA in 4G-LTE cellular system to provide the impact of interference on the number of subscribers. Hence, the above equation can be modified as

$$C_{DL,subs} = \frac{(1 - P_{co})K * N_s * S_e * B * L_{bh}}{\nu * R * \gamma * I} \quad (12)$$

where P_{co} is percentage of channel overhead power, γ is signal-to-noise ratio, ν is voice activity factor and I is the interference factor.

3.2 Evaluation procedure for calculation of Erlang Capacity under CCI

1. Calculate the value of Radio capacity based on equation (12) by selecting the parameters of OFDMA (number of Interferers active, mean power of the received interference, mean power of the desired signal, Spectral efficiency, voice activity factor and other transmission parameters).
2. Analyze the CCI, Rayleigh distribution function is applied on the signals.
3. Calculate the conditional probability for number of active interferes P(CCI/│n)
4. Compose polynomial function according to equation (1) and make it equal to the desired CCI Probability.
5. Solve roots (A_c, carried traffic with CCI in a cellular system) of the polynomial and pick up the smallest real root which is $A_c < 1$.
6. Calculate the Erlang capacity under Co-channel interference(CCI)

$$M = C_{DL} * A_c \tag{13}$$

IV. RESULTS AND DISCUSSION

The evaluation of Erlang capacity of OFDMA system under CCI has been done from the basic procedure described in the above section for OFDMA(4G-LTE) cellular system under various co-channel interferers with the following assumptions.

- The Erlang capacity evaluated in this paper is limited by co-channel interference only.
- Rayleigh distribution is considered with co-channel interference threshold,α= 0dB, mean power of the interference signal, P_{0i}=1mW and mean power of the desired signal P_{0d} = 4mW.
- Number of co-channel interferers, K= 3, 5, 7, 8 and 10 are considered for Erlang capacity evaluation
- The other parameters such as voice activity factor (ν = 0.5 and 0.6), data rates (R = 128Kbps ,256Kbps and 512Kbps) and link spectral efficiency (S_{eff} = 0.5, 0.8, 1.4b/Hz/sec) are considered in the Erlang capacity evaluation procedure.

The conditional CCI probability, $P(CCI|n)$ for OFDMA system for 5 co-channel interferers from equation (10) can be evaluated as

$$P(CCI|1) = 1 - \left(\frac{1}{1.(1/4) + 1}\right)^1 = 0.200$$

$$P(CCI|2) = 1 - \left(\frac{1}{1.(1/4) + 1}\right)^2 = 0.360$$

$$P(CCI|3) = 1 - \left(\frac{1}{1.(1/4) + 1}\right)^3 = 0.490$$

$$P(CCI|4) = 1 - \left(\frac{1}{1.(1/4) + 1}\right)^4 = 0.590$$

$$P(CCI|5) = 1 - \left(\frac{1}{1.(1/4) + 1}\right)^5 = 0.627$$

From equation (2), the P(n) of OFDMA cellular system for 5 co-channel interferers can be written as

$$P(1) = 5A^5 - 20A^4 + 30A^3 - 20A^2 + 15A^1$$

$$P(2) = -10A^5 + 30A^4 - 30A^3 + 10A^2$$

$$P(3) = 10A^5 - 20A^4 + 10A^3$$

$$P(4) = -5A^5 + 5A^4$$

$$P(5) = A^5$$

Substituting the values of $P(CCI|n)$ and P(n) for 5 co-channel interferers in equation (3), P(CCI) becomes,

$$P(CCI) = 0.002A^5 - 0.01A^4 - 0.4A^2 + A \tag{14}$$

The variation of Erlang capacity of OFDMA-based cellular system under CCI with P(CCI) for various co-channel interferers has shown in Fig.1.

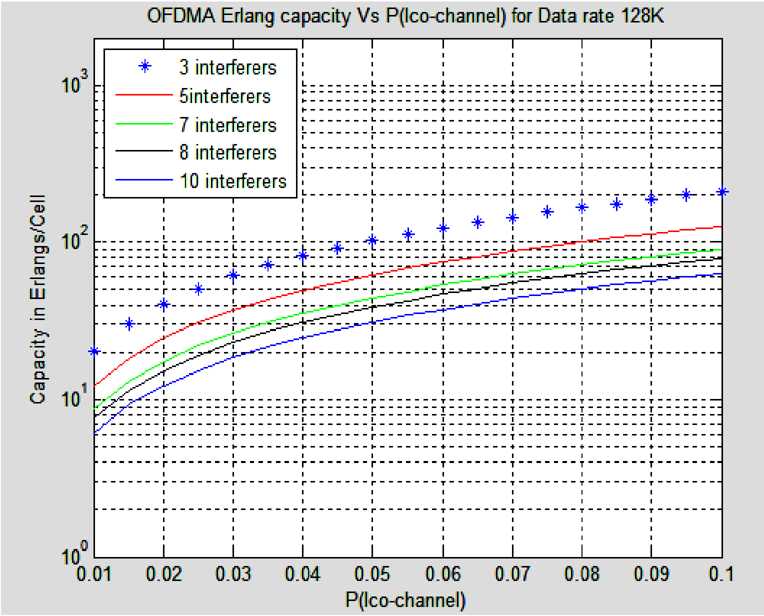

Fig. 1 Variation of Erlang capacity with CCI for different interferers

OFDMA system capacity increases as the number of co-channel interferers decreases for a given probability of CCI. For a 0.1 CCI probability, the Erlang capacity increases from 63.666 Erlangs/cell to209.709 Erlangs/cell as the number of co-channel interferers decreases from 10 to 3 ,that is, the number of interferers decreases then the capacity of OFDMA increases. The simulated values are shown in Table 1.

Table 1. OFDMA Erlang capacity for K= 3, 5, 7, 8 &10

P(CCI)	**Erlang Capacity M for different interferers(K)**				
	K= 3	**K=5**	**K=7**	**K= 8**	**K= 10**
0.010	20.291	12.150	8.748	7.655	6.075
0.015	30.497	18.347	13.122	11.421	9.234
0.020	40.824	24.543	17.496	15.309	12.272
0.025	51.030	30.740	21.992	19.197	15.309
0.030	61.358	36.936	26.366	23.085	18.468
0.035	71.685	43.133	30.861	26.973	21.627
0.040	82.134	49.451	35.357	30.861	24.786
0.045	92.583	55.647	39.852	34.871	27.945
0.050	103.032	61.965	44.348	38.880	31.104
0.055	113.481	68.405	48.843	42.768	34.263
0.060	124.052	74.723	53.460	46.778	37.422
0.065	134.622	81.162	58.077	50.787	40.703
0.070	145.193	87.480	62.694	54.918	43.983
0.075	155.885	94.041	67.311	58.928	47.142
0.080	166.577	100.481	71.928	62.937	50.423
0.085	177.269	106.920	76.667	67.068	53.703
0.090	187.961	113.481	81.284	71.199	56.984
0.095	198.774	120.042	86.022	75.330	60.386
0.100	209.709	126.725	90.761	79.461	63.666

The variation of Erlang capacity of OFDMA cellular system under CCI for different voice activity factors with 5 co-channel interferers is shown in Fig.2.

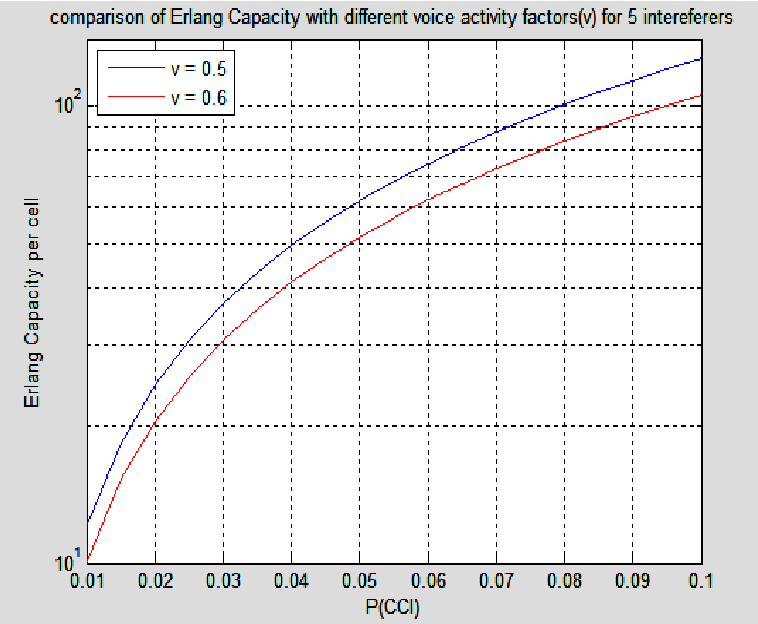

Fig. 2 Variation of Erlang capacity with CCI for v = 0.5 and 0.6

From Figure 2, it is observed that the Erlang capacity of OFDMA cellular system increases low voice activity factor for a given probability CCI. For 0.1 CCI probability the Erlang capacity increases from 105.604725Erlangs/cell to 126.725Erlangs/cell as the voice activity factor decreases from 0.6 to 0.5

Table 2. OFDMA Erlang capacity under CCI for v= 0.5 & 0.6

Erlang Capacity, M for 5 interferers		
P(CCI)	**v=0.5**	**v =0.6**
0.010	12.150	10.125
0.015	18.347	15.289
0.020	24.543	20.453
0.025	30.740	25.616
0.030	36.936	30.780
0.035	43.133	35.944
0.040	49.451	41.209
0.045	55.647	46.373
0.050	61.965	51.638
0.055	68.405	57.004
0.060	74.723	62.269
0.065	81.162	67.635
0.070	87.480	72.900
0.075	94.041	78.368
0.080	100.481	83.734
0.085	106.920	89.100
0.090	113.481	94.568
0.095	120.042	100.035
0.100	126.725	105.604

The variation of Erlang capacity of OFDMA based cellular system under co- channel interference for different data rates has been shown in Fig.3.

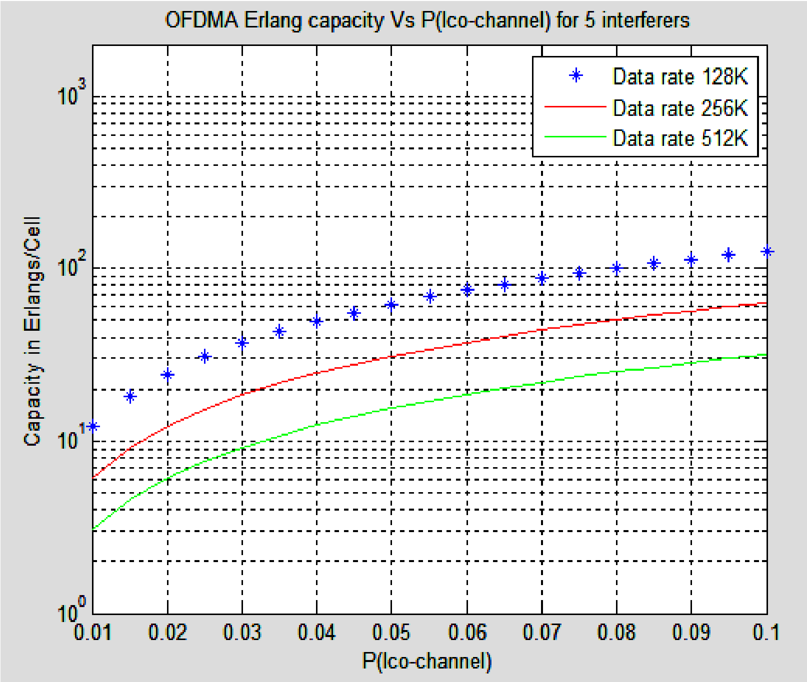

Fig. 3 Variation of Erlang capacity with CCI for different data rates

From Figure 3. OFDMA Erlang capacity increases as the information data rate decreases under CCI probability. For 0.05 probability CCI, the Erlang capacity increases from 15.501Erlangs/cell to 62.003Erlangs/cell as the data rate decreases from 512Kbps to 128Kbps as shown in Table 3.

Table 3. OFDMA Erlang capacity under CCI for different data rates

Erlang Capacity M for 5 interferers			
P(CCI)	**R=128Kbps**	**R =256Kbps**	**R =512Kbps**
0.010	12.199	6.099	3.050
0.015	18.335	9.168	4.584
0.020	24.497	12.248	6.124
0.025	30.683	15.342	7.671
0.030	36.895	18.448	9.224
0.035	43.133	21.567	10.783
0.040	49.397	24.698	12.349
0.045	55.687	27.843	13.922
0.050	62.003	31.001	15.501
0.055	68.346	34.173	17.086
0.060	74.715	37.358	18.679
0.065	81.112	40.556	20.278
0.070	87.537	43.768	21.884
0.075	93.989	46.994	23.497
0.080	100.469	50.234	25.117
0.085	106.977	53.488	26.744
0.090	113.514	56.757	28.378
0.095	120.079	60.040	30.020
0.100	126.674	63.337	31.668

V. CONCLUSION

The Co- channel interference is one of the important limiting factors which limits the capacity of cellular systems. The Erlang Capacity of OFDMA (4G-LTE)-based cellular system under CCI is estimated. A new analytical method is proposed in this paper to evaluate the capacity in Erlangs/cell of OFDMA-based cellular systems under CCI. Here the probability of CCI is considered for the Erlang capacity estimation. The Erlang capacity results are evaluated and analyzed for OFDMA cellular systems with different co-channel interferers, voice activity and data rates. The Erlang capacity of a OFDMA-based cellular system increases with the less number of co-channel interferers. For the probability of CCI the Erlang capacity of OFDMA system increases for low information data rates. The estimated Erlang capacity under CCI is useful for the accurate estimation of blocking probability of OFDMA(4G-LTE)based cellular systems. These estimated values are useful to provide inherent protection from co-channel interference (CCI) in OFDMA-based cellular systems.

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