M. Tech. Degree Dissertation

On Erlang Capacity of IEEE 802.16e Networks

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by

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Manju Meghwani
June 25, 2009

Abstract

In this thesis, we improve the Erlang capacity of the 802.16 OFDMA based systems. For Erlang capacity calculation, we consider Hard as well as Soft blocking. Hard blocking is due to finite number of subchannels in the cell and Soft blocking is due to interference from nearby cells. Improvement in Erlang capacity is due to:

1. Subchannel permutation schemes: Permutation scheme is proposed for the subchannel formation, i.e., subcarrier to subchannels allocation. We have proposed a method to reduce interference/collision of the subchannels by proposing new permutation schemes. Proposed permutation scheme reduced collision by 200% for Even-Group subchannels and 300% for Odd-Group subchannels.

2. Call Admission Control (CAC) algorithms: We have proposed power reservation based CAC heuristic and optimal CAC algorithms in IEEE 802.16e cellular systems. For handoff calls, we use power reservation based CAC algorithm. Resources are allocated to the user requests and then, subcarrier/subchannel are assigned to the users. The power reservation based CAC heuristic an improvement of 58.64% in Erlang capacity over bandwidth reservation based CAC. By using Optimal CAC, 90% improvement is observed compare to the heuristic CAC algorithm.

Dissertation Approval Sheet

This is to certify that the dissertation entitled

On Erlang Capacity of IEEE 802.16e Networks

by

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is approved for the degree of

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Place: ______________

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Chapter 1

Introduction

1.1 Background

In this chapter, we discuss the need to measure the Erlang capacity of IEEE 802.16e cellular networks. IEEE 802.16e is the emerging technology for the near future due to its capability to support high data rates for various application e.g. multimedia and video conferencing. The evolution of the IEEE 802.16 standard has spurred tremendous interest from the network operators seeking to deploy high performance, cost effective broadband wireless networks. Several commercial implementations of IEEE 802.16e cellular networks have been launched. It has also been considered as a wireless backhaul technology for 2G, 3G, and 4G networks in both developed and developing nations.

WiMAX is a possible replacement for cellular phone technologies such as GSM and CDMA, and can also be used as an overlay to increase capacity. This motivates us to measure the performance of IEEE 802.16e cellular networks. The performance measurement parameters to evaluate the performance of such networks can be divided into User Centric and Network Centric performance measures.

1. User Centric: The performance measures that meet the requirements of the users are called User Centric performance measures. These measure voice as well as data services of a user. They include:

   (a) Outage Probability: It is the probability that the interference seen by a user is above a specified threshold. It measures the quality of voice calls in terms of the interference.

   (b) Delay: Unlike voice calls, data traffic is not blocked, however buffering leads to delay in the data transfer. The performance measure for data services is the mean delay of the data traffic, the probability of the delay exceeding a value (tail probability) and variance of the delay.

2. Network Centric: The measures that characterize the network performance are called Network Centric performance measures. These include:

   (a) Blocking Probability: It is defined as the probability that a user gets blocked (denied services from the base station) due to non-availability of resources. Blocking probability is usually associated with voice calls.

   (b) Throughput: It is the network centric performance for data services, which measures total data transfer in a fixed duration of time.

In this thesis, we use the Erlang capacity as the performance measurement metric for IEEE 802.16e cellular networks. The traditional method of measuring Erlang capacity, in TDMA and FDMA systems is using the hard capacity. In these systems, admitting an incoming call has no impact on bandwidth requirements of the ongoing calls. However, in the interference limited cellular networks, i.e., CDMA and OFDMA systems admitting an incoming call will cause change in resource requirements of the ongoing call. Erlang capacity of interference limited cellular networks is affected by:

1. On-going calls

2. Hand-off calls

In this thesis, we consider both these components to increase the Erlang capacity of IEEE 802.16e cellular networks.

1. Increase in Erlang capacity due to On-going calls: As an interference-limited wireless cellular system, the IEEE 802.16e system should provide adequate signal to interference -plus-noise ratio (SINR) to mobile stations (MSs)throughout the network and at the same time, try to increase the spectrum efficiency. Erlang capacity of the interference limited wireless cellular system is improved by using interference avoidance and interference averaging.

   (a) Interference Avoidance: By utilizing the interference avoidance scheme, the system tries to avoid collisions between the same frequencies used in neighboring cells. This can be done either in a static manner, by allocating different frequencies to neighboring cells (Frequency Reuse Factor (FRF) greater than one) or in a dynamic manner, with an intelligent scheduler taking care of the scheduling. In conventional 2G systems, only a particular set of integer FRFs are adopted, while in IEEE 802.16e systems, fractional frequency factor can be easily implemented in virtue of multi-permutation zone frame structure.

(b) Interference Averaging: In IEEE 802.16 OFDMA systems, interference averaging is realized by employing distributed subcarrier permutation. Two basic modes of distributed subcarrier permutation are defined, i.e., PUSC and FUSC. In the process of subcarrier allocation, subcarriers are selected pesudo-randomly, according to predefined permutation base (PermBase), in order to constitute a logical subchannel. Thus, a frequency subchannel is spread throughout the whole frequency band.

In this section, the Erlang capacity is improved using PUSC permutation schemes for on going calls.

2. Increase in Erlang capacity due to Handoff calls: To improve blocking probability of the handoff calls in the cellular systems, Call Admission Control (CAC) is adopted. The main idea of CAC is to reduce the handoff dropping by limiting the amount of radio resources allocated to active calls and new calls in each cells. Traditional channel reservation scheme is by guard band formation. Bandwidth reservation CAC schemes are not competent in IEEE 802.16e systems. In this thesis, we propose power reservation CAC, this scheme has provided improvement in Erlang capacity.

These two proposed methods to improve Erlang capacity are different from the existing method for Erlang capacity calculation. The difference lies in the PHY layer, which is:

1. IEEE 802.16e systems supports OFDM modulation, which is multicarrier modulation. Each user is allocated multiple subchannel, each subchannel consists of multiple subcarriers. Thus subcarrier to subchannel allocation is called permutation. Permutation scheme causes variation in interference and that affects Erlang capacity.

2. IEEE 802.16e supports Adaptive Coding and Modulation (AMC). AMC results tradeoff between bandwidth and power, i.e., more the power used, lesser is the bandwidth required, and vice-versa.

For permutation as well as CAC schemes, we first need to understand the PHY layer structure of the IEEE 802.16e systems. In the next Chapter, we describe the OFDMA subchannel formation in IEEE 802.16e.

1.2 Contribution of thesis

In this thesis, we propose a permutation scheme for subchannel formation and optimal CAC algorithm to improve the Erlang capacity of IEEE 802.16 cellular networks. Thus, the contribution of thesis is divided into two parts:

1. Part-One: In this part of thesis, we consider the physical layer, subchannel formation of the OFDMA cellular networks:

   (a) We have calculated the Erlang capacity of OFDMA 802.16 systems and observe impact of various permutation schemes. Erlang capacity is improved by using downlink PUSC permutation method by reducing hit-ratio/collision of the subchannel by:

      i. Shuffling Algorithm for outer and inner permutations: In this scheme, we apply shuffling algorithm to the outer PermBase sequence, this variation in the outer PermBase causes, variation in the group formation as well as logical cluster formation from physical cluster. This modification have provided an improvement of 91% for both Odd as well as Even Groups over existing method of subchannelization.

      ii. Subchannel Division: We have reduced the size of a subchannel, i.e., as per standard the subchanel consists of 24 subcarriers. We proposed the subchannel formation of smaller size, i.e., 12 subcarriers. This provides three fold advantage. First as the number of subchannel increases in odd and even group thus, more number of distinct permutation sequence, i.e., IDcell increase fro 8 to 17. Second As the subchannel, i.e., basic unit is reduced. This causes efficient spectral utilization. Third, As the number of subchannel increases causes increase in Hard capacity of the systems. This provides an improvement of 92% over existing permutation method.

   (b) In this section, we redefine the hit-ratio, which as per standard is define as the ratio of subcarrier collision to that of the total subcarrier. Subcarrier collision is measured on same subchannel of neighboring cell. Instead, we measure subcarrier collision in a reference cell sunbchannel with that of all currently used subcarrier of neighbouring cell. It is more practical aspect of the cellular systems. Thus, this causes scheduling (user to subchannel allocation) to consider for measuring hit-Ratio. we calculate Erlang capacity for 1) Sequential scheduling and 2) Random scheduling. There is an improvement of 33.33% on random to that of the Sequential scheduling.

   (c) We have applied the proposed modification on the Erlang capacity calculation of the 802.16 OFDMA based networks. An improvement of 200% on an Odd-group and 300% on an Even-Group Subchannel is observed.

2. Part-Two: In this part of thesis, the Erlang capacity of the IEEE 802.16e cellular networks is improved by reducing blocking probability of the hand off calls. Blocking probability is improved by admitting the handoff calls in the cellular networks, i.e., allocating resources to it. In this section, we calculate the Erlang capacity of the OFDMA 802.16 systems and observe the impact proposed call admission algorithm. The impact of parameters is observed at following level:

   (a) MAC level: At this level, we observe the impact of traditional guard band subchannel allocation to that of proposed power based allocation algorithm, we got improvement of 58%.

   (b) Physical level: At this level the impact of subcarrier allocation to the subchannel causes variation in collision of the subcarrier per subchannel, thus, subchannelization effects blocking probability of the cell. Proposed CAC algorithm is evaluated with and without using permutation scheme. We formulate the problem of power reservation based CAC as an optimization problem.

1.3 Organization of the Thesis

The Thesis consists of 7 Chapters. Chapter 1 is an introduction of IEEE 802.16e cellular networks and performance parameters of the 802.16 OFDMA cellular networks. In Chapter 2, we describe various permutation schemes for subchannel formation. The brief description of related work, and their conclusions. In this Chapter we describe how the Erlang capacity depends upon the permutation methods and its parameters. We have formulated problem by considering all the parameters e.g., permutation sequence, IDcell value pairs and hit-ratio of the subchnannel. Further, the effect of Inner and Outer permutation methods is described, which is followed by solutions to the problems. Each Section has Problem formulation and its solution with simulation results at subchannelization level and scheduling level. In Chapter 3, we calculate the Erlang capacity in the presence of hard as well soft blocking with the suffle (proposed) and existing algorithm for the subchannelization and analysed the improvement due to proposed solution in the

Erlang capacity. In Chapter 4, we discuss CAC in IEEE 802.16e cellular networks. Various CAC strategies and resource allocation, i.e., Fixed channel allocation and dynamic channel allocation scheme are described. In Chapter 5, the problem of CAC strategy in IEEE 802.16e cellular networks system is formulated. We propose a heuristic for the CAC algorithm. Proposed CAC algorithm is based on power reservation scheme for admitting calls in the cellular networks. In this chapter, we use permutation schemes proposed in the previous chapter. In Chapter 6, we calculate the Erlang capacity for the proposed CAC algorithm. Chapter 7 describes, the optimal CAC algorithm. In this chapter, we determine the optimal algorithm for call admission. We have formulated the call admission problem as an optimization problem and have used Lagrangian technique to solve it. The Erlang capacity of optimal CAC is calculated.

Chapter 2

IEEE 802.16e Subchannel Permutation

2.1 Introduction

In this chapter, we describe the existing permutation schemes for subchannel formation and formulated the problem to minimize the hit-ratio. We have propose a permutation scheme called the Shuffle algorithm for subchannel formation. The motivation for considering the permutation algorithm is described as follows. The IEEE 802.16e systems should provide adequate signal to interference -plus-noise ratio (SINR) to mobile stations (MSs)throughout the network and at the same time, try to improve the spectrum efficiency. Erlang capacity of the interference limited wireless cellular systems, is improved by using Interference avoidance and interference averaging.

1. Interference Avoidance: By utilizing the interference avoidance scheme, the system tries to avoid collisions between the same frequencies used in neighboring cells. This can be done either in a static manner, by allocating different frequencies to neighboring cells (FRF greater than one) or in a dynamic manner, with an intelligent scheduler taking care of the scheduling. In conventional 2G systems, only a particular set of integer FRFs are adopted, while in IEEE 802.16e systems, fractional frequency factor can be easily implemented in virtue of multi-permutation zone frame structure.

2. Interference Averaging: In IEEE 802.16 OFDMA systems, interference averaging is realized by employing distributed subcarrier permutation. Two basic modes of distributed subcarrier permutation are defined, i.e., PUSC and FUSC. In the pro-

cess of subcarrier allocation, subcarriers are selected pesudo-randomly, according to predefined permutation base (PermBase), in order to constitute a logical subchannel. Thus, a frequency subchannel is spread throughout the whole frequency band.

In this section, the Erlang capacity is improved using PUSC permutation schemes for on going calls. Effect of permutation schemes are never considered in exsisting literature for measuring Erlang capacity of cellular networks. The reason lies on the fact that existing 2G cellular networks and IEEE 802.16e have different PHY layer. Erlang capacity calculation for the OFDMA cellular systems is different from the FDMA counter part, in terms of permutation method. It is the random selection of the subcarriers to the subchannels, where as in the FDMA systems there is no subchannel formation thus, the collision of the subcarriers is independent of any permutation method. Due to permutation method there is difference in the soft blocking as well as in hard blocking, because permutation method decides number of subchannels in the systems as per the subchannel formation.

To improve the Erlang capacity of the OFDMA 802.16 cellular systems, we need to improve on hard as well as soft blocking.

1. Hard blocking is improved by increasing number of subchannels per group. Number of subchannels can be increased by formation of smaller subchannels, i.e., by reducing number of subcarriers per subchannel in the permutation method. This not only increases number of subchannels in the system but also provides more number of distinct permutation sequence. These permutation sequences reduces inter-cell interference due to collision of common subcarriers per subchannel in the cell.

2. Soft blocking is improved by reducing interference from the neighboring cells. Interference is measured by number of collision of subcarriers per subchannels in the neighboring cell. Thus, the degree of measure of subcarrier collision is hit-ratio as per the standard definition. Designing permutation methods can improve hit-ratio by subcarrier allocation , if the subcarrier allocation is orthogonal in the subchannels of neighboring cell can reduce interference to zero. Inter-cell interference is reduced by reuse factor, i.e., instead of using entire bandwidth in the neighboring cell, orthogonal frequencies are used in neighboring cells. Thus, in the next section, we describe the PHY structure of IEEE 802.16e callular network.

2.2 Orthogonal Frequency Division Multiple Access

In OFDMA systems, multiple signal users are separated in time and/or frequency domain. A burst of OFDMA symbol consists of several OFDM symbols. The subcarriers and the symbol period are the finest allocation units in the frequency and time domain respectovely. Multiple users are allocated different slots in time and frequency domain, i.e., different groups of subcarriers and/or OFDM symbols are used for transmitting the signals to/from multiple users.

2.2.1 OFDMA PHY description

The OFDMA PHY layer description involves time-domain and frequency-domain description. In this thesis, we focus on the frequency domain description of the OFDMA symbol[1]. An OFDMA symbol is made up of subcarriers. The number of subcarriers determines FFT size used. The subcarriers used for the subchannel formation is divided into following types:

(a) Data subcarriers: These are used for the data transmission.

(b) Pilot subcarriers: These are used for the channel parameter estimation.

(c) Null subcarriers: These are used for the guard band and DC carrier.

In [1], subcarriers are grouped into sets known as subchannels. The subcarriers forming one subchannel need not be adjacent. A slot requires both time and subchannel information for completeness and is the smallest unit of data allocation unit.

The resource allocation in the frequency domain is not addressed at the level ofa subcarrier. The smallest granular unit is created by grouping subcarriers into subchannels in an OFDM symbol in various ways. The formation of these subchannels is called subchannelization. The subchannelization is classified into two types:

(a) Adjacent Subcarrier Method (ASM):
In this method, contiguous group of subcarriers are mapped to subchan-

nels. In this subchannel formation, it is expected that the channel frequency response on the subcarrierr in a subchannel will be strongly correlated. Thus, this method is suitable for the use of Adaptive Modulation and Coding (AMC). It requires less overhead as subcarriers are correlated. This method is suitable for fixed, portable and low mobility environments.

(b) Discrete Subcarrier Method (DSM):
In this method, subcarriers from seemingly random position in the frequency domain are grouped into a subchannel. Thus, the subchannel has potential frequency diversity which can be leveraged, when data to be sent on this subchannel is suitably coded and interleaved. This method works very well in the mobile applications. This method is again classified into two types:

    i. Fully Usage Subchannelization Method (FUSC): In this subchannelization method, all subchannels are allocated to the transmitter.
    ii. Partially Usage Subchannelization Method (PUSC): In this subchannelization method, some of the subchannels are allocated to the transmitter.

The transition between modulation and coding takes place on OFDMA symbol boundaries in time domain and on subchannels within an OFDMA symbol in frequency domain. The OFDMA frame includes multiple zones. The transition between zones is indicated in DL-MAP as shown in Fig.2.2.2. In our simulations and analysis, we focus on the PUSC permutation method. This method of subchannelization can be used for the uplink as well as for the downlink transmission.

2.2.2 Symbol Structure for PUSC

The PUSC symbol is constructed using pilots, data and zero subcarrier. The symbol is first divided into basic cluster and zero subcarriers are allocated. Pilot and data subcarriers are allocated within each cluster.

PUSC is structured from two permutations, referred to as “inner” and “outer” permutations. The downlink subcarrier allocation in PUSC is done using the following procedure:

(a) Outer Permutation: The outer permutation is responsible for selecting the clusters to be used by each major group (using the randomization sequence).

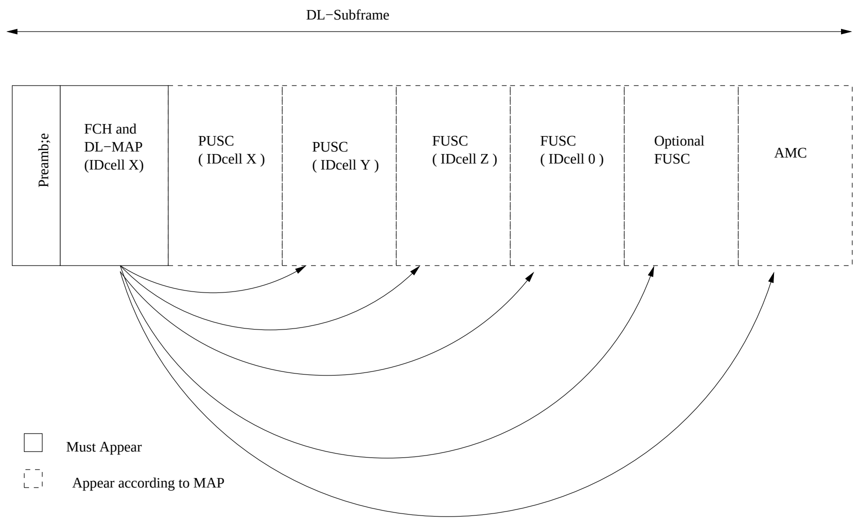


Figure 2.1: OFDMA Frame with Multiple Zones

Each of the 6 major groups holds a continuous group of subchannels (12 or 8 in 2048 FFT case). By default, each pair of groups is allocated to a segment. So, when the outer permutation seed is 0, then segments 0,1,2 (groups (0,1)(2,3)(4,5)) consist of orthogonal set of subcarriers over all cells. When the outer permutation seed is different between cells, the selection of clusters for each major group changes, and we get different (pseudo random) sets in each cell. The following steps are required for the outer permutation:

i. Dividing the subcarriers into 120 physical cluster containing 14 adjansant subcarriers each (starting from subcarrier 0).

ii. Renumbering the physical clusters into logical clusters using the following formula:

$$LogicalCluster = RenumberingSequence((PhysicalCluster + 13 * IDCell) mod 120), \tag{2.1}$$

where, for first PUSC zone of the downlink the default IDcell is 0. The RenumberingSequence is shown in Table-6.1.

iii. Dividing the cluster into 6 major groups. Group 0 includes the clusters 0-23, group 1 includes 24-39, group 2 includes 40-63, group 3 includes 64-79, group 4 includes 80-103, group 5 includes 104-119. These groups are allocated to segments, if the segments is being used, then atleast one

Table 2.1: OFDMA Downlink Carrier allocation-PUSC

Parameters	Values
Number of DC Subcarriers	1
Number of Guard Subcarriers left/right	184/183
Number of used Subcarriers	1681
Number of Subcarrier per cluster	14
Number of Cluster	120
Renumbering Sequence	6, 108, 37, 81, 31, 100, 42, 116, 32, 107, 30, 93, 54, 78, 10, 75, 50, 111, 58, 106, 23, 105, 16, 117, 39, 95, 7, 115, 25, 119, 53, 71, 22, 98, 28, 79, 17, 63, 27, 72, 29, 86, 5, 101, 49, 104, 9, 68, 1, 73, 36, 74, 43, 62, 20, 84, 52, 64, 34, 60, 66, 48, 97, 21, 91, 40, 102, 56, 92, 47, 90, 33, 114, 18, 70, 15, 110, 51, 118, 46, 83, 45, 76, 57, 99, 35, 67, 55, 85, 59, 113, 11, 82, 38, 88, 19, 77, 3, 87, 12, 89, 26, 65, 41, 109, 44, 69, 8, 61, 13, 96, 14, 103, 2, 80, 24, 112, 4, 94, 0
Number of Subchannels	60
PermutationBase12	6,9,4,8,10,11,5,2,7,3,1,0
PermutationBase8	7,4,0,2,1,5,3,6

group should be allocated to it.

(b) Inner Permutation: The inner permutation is responsible for selecting the subcarriers for each subchannel over these clusters. This is performed by first allocating the pilot subcarriers within each cluster, and then taking all remaining data subcarriers within the symbols and using following formula for the subcarrier allocation to the subchannel, IDcell used for the First PUSC zone is 0.

$$subcarrier(k,s) = N_{subchannels}.n_k + \{P_s[n_k mod N_{subchannels}] + IDcell\} mod N_{subchannels} \quad (2.2)$$

where, subcarrier(s,k) is the subcarrier index of the subcarrier n in subchannel s

s is the index number of subchannel, from the set$[0.....N_{subchannels}-1]$ $n_k =$ (k+13.s)mod $N_{subcarrier}$ where, k is the subcarrier -in-subchannel index from th set $[0......N_{subcarriers}-1]$

$N_{subchannels}$ is the number of subchannels

P_s is the series obtained by rotating $PermutationBase_0$ cyclicallyto the left

Table 2.2: AMC levels in IEEE 802.16e

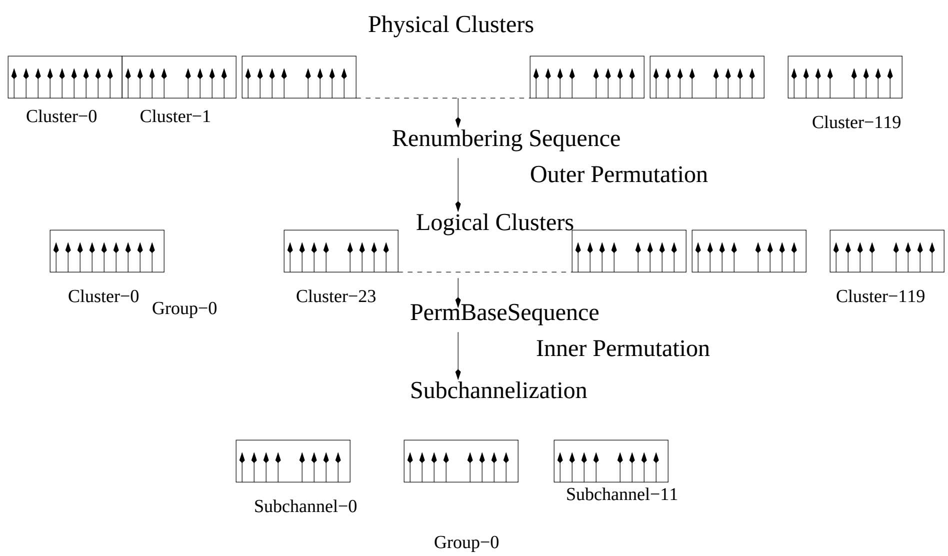
AMC level	Rates/subchannel(kbps)	AMC mode	SINR thrsh.(dB)
1	178.56	QPSK-1/2	7.6
2	256.82	QPSK-3/4	10.3
3	357.82	16 QAM-1/2	14.3
4	535.68	16 QAM-3/4	17.4
5	714.24	64 QAM-2/3	21.0
6	803.52	64 QAM-3/4	22.0

s times

ceil[] is the function that rounds its argument up to the next integer IDcell is an integer ranging from 0 to 31

$X_{mod(k)}$ is the remainder of the quotient X/k, which is at most k-1.

So when the outer IDcell is 0, the segments 0,1,2 (groups (0,1)(2,3)(4,5)) consist of orthogonal set of subcarriers over all cells. When the outer permutation IDcell is different between cells, the selection of the clusters for each major group changes, we get pseudo random set of subcarrier per group in each cell as shown in Fig.2.2.



Subchannel Formation in Wi−MAX Downlink PUSC

Figure 2.2: Downlink PUSC Permutation Method

2.3 Related Work

In this section, we describe summary of related paper, which have calculated performance of IEEE 802.16 based networks using different parameters e.g. throughput, outage probability, Erlang capacity. [2] has measured the performance of the networks using 802.16 standard specifications. On the basis of simulation results, paper have proposed optimal frequency planning strategy, in terms of permutation mode and reuse factor. The conclusion of the paper is as follows :

(a) The reuse factor one is unacceptable for same PermBase PUSC as well as different PermBase PUSC permutation mode.

(b) It was concluded that only same PermBase PUSC permutation mode is feasible for the frequency reuse of 3.

The Assumption and System Model description is as follows:

(a) Homogeneous IEEE 802.16e cellular system of 19 cells are considered. With 6 from the first tier and 12 from the second tier.

(b) Each cell is three 120-degree sectors.

(c) The technique of AMC is utilized.

(d) The reuse factor of 1,1 and 1,3 defined in standard is used.

(e) Performance evaluation criterion adopted is outage probability and throughput of the system.

In this paper the Erlang capacity is not considered for the performance analysis and as per the conclusion reuse factor 1 is unsuitable for the deployment of the IEEE 802.16e with acceptable outage probability.

On the other hand, [3] authors have calculated the performance of an OFDMA 802.16 systems using Erlang Capacity. The Erlang capacity is calculated, when the blocking probability is above certain threshold (.02%). The blocking probability, i.e., an incoming call will be blocked depends upon interference. Interference in the cellular system is calculated by mean number of the symbol collision in the multi-cellular systems. By applying this model authors have determine the way to choose the modulation scheme within Erlang capacity region so as to reduce the symbol loss rate. Following are the assumptions and system model specification :

(a) Homogeneous IEEE 802.16e system, where each cell is divided into 3 sectors by means of directional antenna.

(b) IEEE 802.16e systems with $1X3$ PUSC permutation mode and three orthogonal set of subchannels so as to reduce the interference from the nearby cell.

(c) FFT used for the OFDMA systems is 2048 each segment having 40 subchannels and total of 120 subchannels, where each subchannel have 12 subcarriers.

(d) Traffic model considered is with Poisson arrival rate and service time as Adaptive (i.e., holding time donot depends upon transmission rate) and Elastic service time (holding time depends upon bit transmission rate).

[3] results, were based on [4] conclusion, Authors concluded that mean number of collision per subchannel is independent of subchannelization method, i.e., the formation of subchannel using subcarriers. Authors concluded that if the subchannels are formed by set of contiguous subcarriers than mean collision among subchannels is same as that of the mean collision, if subchannels were formed by random selection of subcarriers in the subchannels. Subchannelization method donot effect the mean collision rate. This conclusion is due to two reasons, First is that, each arrival call have independent set of subchannels but in practice the traffic model is Markov chain in which current subchannel allocation depends upon previous state or the subchannel allocation. Second, is that the subchannel is assumed to be collided if atleast one of the subcarrier is collided,so it is as good as that the subchannel with single subcarriers. Hence, due to both reasons the subchannelization seems to be not effecting the collision of the subchannel.

This motivates our problem to consider the permutation methods and its parameter for the collision of the symbols which i turn implies interference among the subchannels and SIR ratio of the subchannel. Thus, will effect not only soft blocking but also hard blocking because number of subchannels in the systems depends upon the permutation method used for the subchannel formation.

[5] authors measured the performance of the cellular network by calculating reverse link Erlang capacity of an OFDMA wireless system by considering various resource allocation scheme. Following are the assumptions and system model specification:

(a) Hexagonal 7-cell cellular systems with reuse factor one .

(b) Intra-cell interference is zero and inter-cell interference causes reduction in the SIR of the subchannel in the cellular systems.

(c) Traffic model considered is M/M/m Queuing Markov Model.

Authors concluded that adaptive resource allocation schemes improves Erlang capacity of the celluar systems. *This motivates us to consider effect of various scheduling scheme along with permutation methods for Erlang capacity calculation.*

From above, the problem is divide into two sections.

2.4 Problem-I

The permutations mitigate cross-interference between neighboring cells by minimizing the number of hits that any subchannel of one cell observes from any single subchannel of the neighbor cell. Thus permutation method should be designed as follows:

(a) Maximal hit-ratio between any two subchannels should be minimized. It is defined as the minimizing hit ratio over all possible combination of the IDcell outer as well as inner permutation.

(b) Maximizing number of different permutation sequences.

In this problem formulation, we consider the standard method of permutation for the hit-ratio calculation and propose a method to improve the hit-ratio over existing permutation method. PUSC method is used for both downlink as well as uplink, in our simulation and analysis we calculate hit ratio for the downlink PUSC permutation method of 802.16 OFDMA systems. As per the standard the downlink and uplink permutation methods are different. Uplink considers 3 OFDM symbols for permutation. Even though, the method for the inner and outer permutation for uplink and downlink is different, still the maximum number of collisions per subchannel is same for the Erlang capacity calculation.

As mentioned in Section-2.2.2 that in 802.16 standard reuse 1 and reuse 3 both are supported. Reuse 1 has advantage that it do not require frequency planning but the interference can be reduced over subchannels by randomization. The randomization is done using PUSC and FUSC methods. PUSC method has two modes one suitable for reuse 1 and other for reuse 3. PUSC first zone can only be activated in reuse 3 mode, because IDcell =0 for outer permutation for all the neighboring cells thus, group formation in all the cells is same and orthogonality is due to inner-permutation of IDcell value. Only disadvantage of this permutation method is requires frequency planning. Since FCH (frame) maps are in PUSC first zone, this force frequency planning in the systems. Thus, for first few OFDMA symbols it is not possible to deploy frequency planning for reuse factor of 3.

Problem Statement

As discussed in Section-2.2.2, FCH maps are in First zone outer IDcell=0, this forces frequency planning in the systems in order for subscriber station to be able to register and obtain map information, thus, it is impossible to deploy reuse 3. *Thus if reuse 1 is used than, first major group will always collide with first major group of any other segment with the same number, thus, first slot FCH suffers from low SIR. Thus, we need to design the permutation method to minimize the reduction in SIR for first slot FCH.*

2.5 Solution

2.5.1 Existing Solution

In the existing solution [6] [7], instead of using IDcell equal to 0, for the outer permutation for First PUSC zone, set the outer permutation IDcell any value greater than 0. Thus, subscriber station should blindly find the correct value by scanning. The difference between two for the reuse-1 is shown in Fig.2.3, where, maximal collision over all IDcell values from 1 to 32 is measured for subchannels of group-0 (even group) and group-1 (odd group). Fig.2.4 for the reuse-3, i.e., if the IDcell is zero than subchannels for all the segments are orthogonal, but we are unable to take this advantage till the FCH information is send to the subscriber. If we apply reuse-1 than the collision is maximum and by applying existing solution, hit-ratio is reduced to 16.67%, thus, improvment of 83.33%.

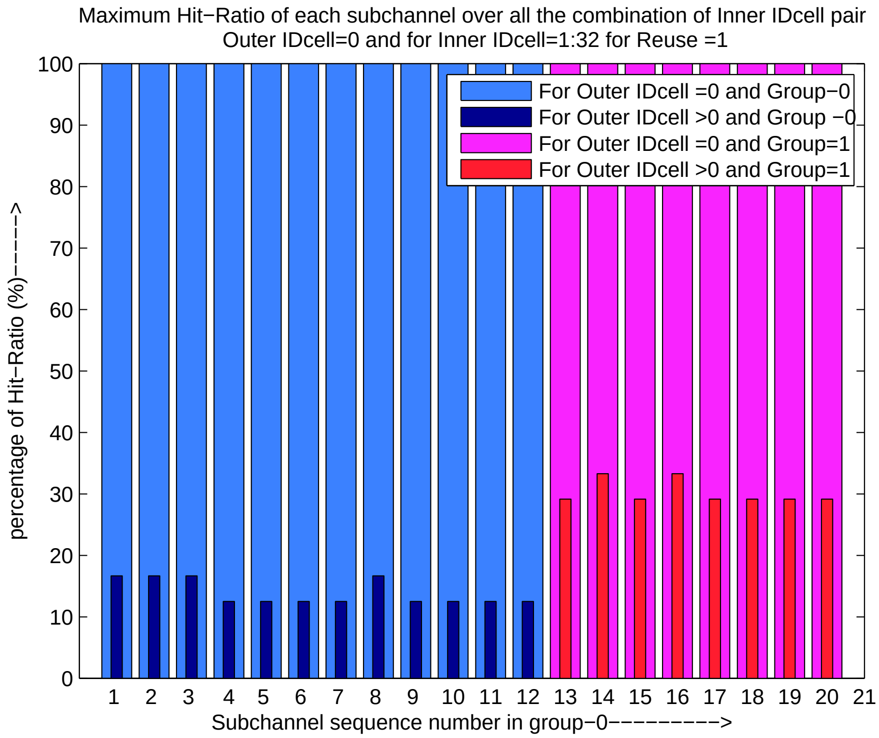


Figure 2.3: Comparison of Existing permutation with Outer IDcell=0 and with variable Outer IDcell for reuse-1

2.5.2 Proposed Solution-I

From the permutation formula used, as shown in Section-2.2.2, i.e.,

$$LogicalCluster = RenumberingSequence((PhysicalCluster + 13 * IDCell) mod 120) \tag{2.3}$$

where, for First PUSC zone of the downlink the default used IDcell is 0. Thus, the Group formation in all the cell is same because of same outer PermBase sequence being used for the physical to logical cluster mapping. Thus, subcarriers for the subchannel formation in the group is same for all the cells. Then, we apply inner permutation for the subcarrier to subchannel allocation in all the cell which is done by following formula:

$$subcarrier(k,s) = N_{subchannels}.n_k + P_s[n_k mod N_{subchannels}] + IDcell mod N_{subchannels} \tag{2.4}$$

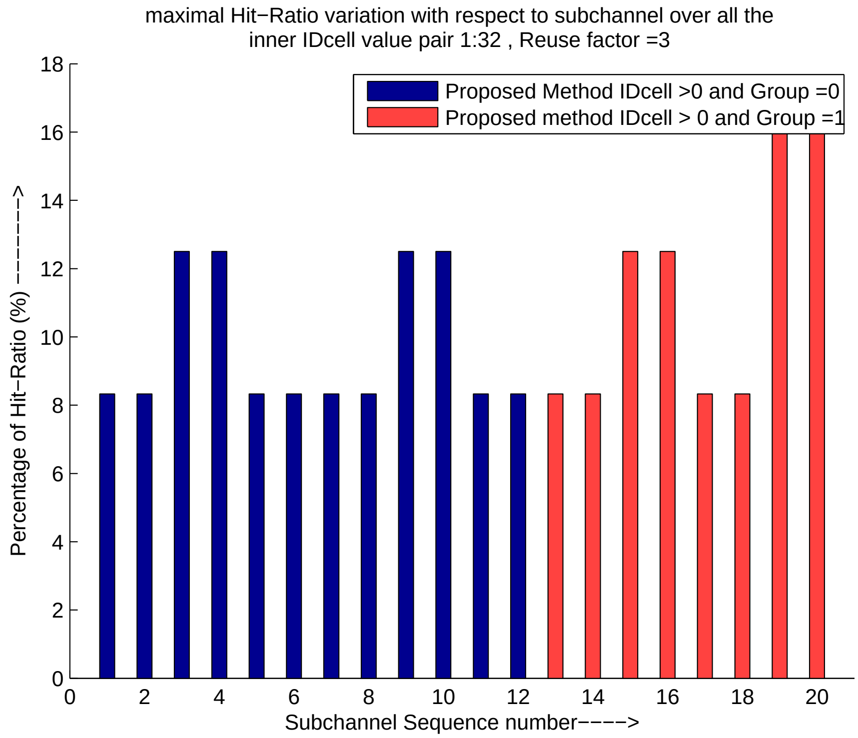


Figure 2.4: Comparison of Existing permutation with Outer IDcell=0 and with variable Outer IDcell for reuse-3

where, subcarrier(s,k) is the subcarrier index of the subcarrier n in subchannel s
s is the index number of subchannel, from the set$[0.....N_{subchannels} - 1]$
n_k = (k+13.s)mod $N_{subcarrier}$
where, k is the subcarrier -in-subchannel index from th set $[0......N_{subcarriers} - 1]$
$N_{subchannels}$ is the number of subchannels
P_s is the series obtained by rotating $PermutationBase_0$ cyclicallyto the left s times
ceil[] is the function that rounds its argument up to the next integer
IDcell is an integer ranging from 0 to 31, which identifies the particular BS segment and is specified by MAC layer
$X_{mod(k)}$ is the remainder of the quotient X/k, which is at most k-1.

Modification-I

From the formula, and simulation we found that for the same n_k, i.e., in two different cells for same subchannel and subcarrier e.g., k=1 and s=1 , i.e., for subchannel formation using subcarriers, the cells with inner IDcell value to be multiple of $N_{subchannel}$ causes, similar group formation. Thus, even though the outer IDcell =0, but for the reuse=1 and for all the possible inner IDcell 1 to 32

, we found that the subchannels are same for the 1,12,25 and 2,13,26 and so on. This causes 100% hit-Ratio for theses inner IDcell pairs. Thus, we can make it orthogonal if we will allow only $N_{subchannel}$ IDcell value pairs. For the even IDcell value 1:12 and for odd IDcell value 1:8, but this causes reduction in the distinct permutation sequence to $N_{subchannels}$ only.

Modification-II

For this, we apply Fisher and Yates' Shuffle method. The basic method given for generating a random permutation of the numbers 1N goes as follows:

Algorithm 1 Shuffle Method

1: Let **A1** = 1, **A2** = 2 and so on up to **AN**=N and let := N.
2: Pick a random number **k** between 1 and n inclusive.
3: **if** k ! = n **then**
4: Swap **Ak** and **An**;
5: **end if**
6: Decrease **n** by 1.
7: Repeat from step 2 untill n is less than 2.

We use the shuffliing algorithm to generate distinct sequence of PermBase sequence for the outer permutation instead of using standard sequence for the outer permutation, this causes distinct group formation, i.e., different physical to logical cluster mapping, thus, even if the inner permutation IDcell value pair is multiple of $N_{subchannels}$, still due to distinct outer PrmBase sequence causes reduction in hit-Ratio. Simulation result as shown in Fig.2.5 for reuse 1 and Fig.2.6 for reuse 3, provides an improvement of 91% for group 0 and group-1, i.e., even and odd group.

From above Shuffling method, we got the improvement on hit-ratio of the subcarriers per subchannels by factor of 91%.

2.5.3 Proposed Solution-II

In this section, we propose the permutation method on the same lines as specified by the standard with the following difference of following points:

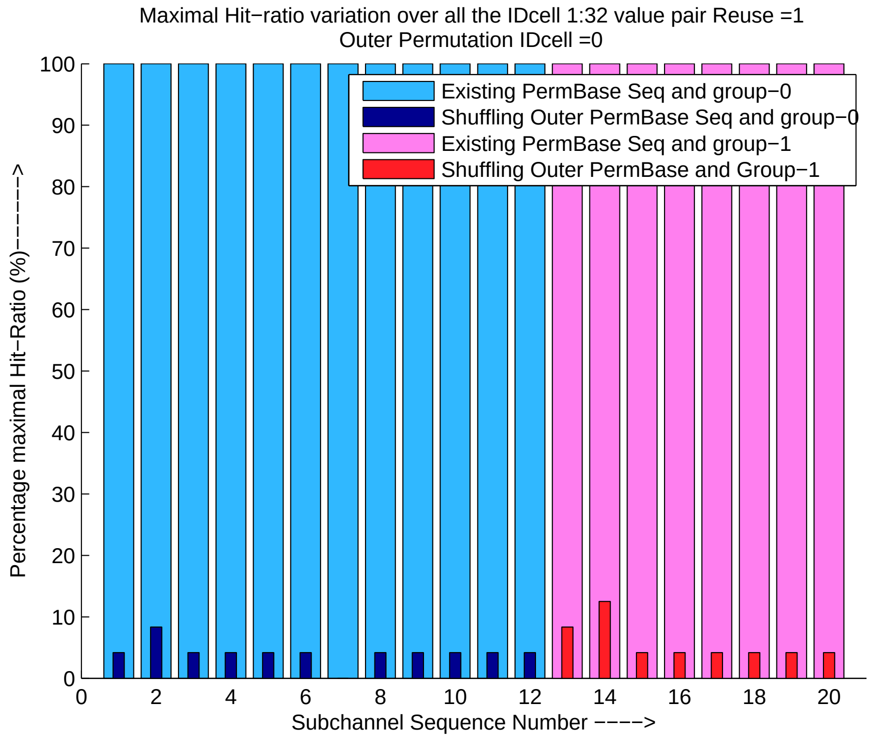


Figure 2.5: Comparison of existing permutation method with shuffling algorithm for the Outer PermBase for reuse-1

(a) The number of subcarriers per subchannels is 12, instead of 24 as per standard specified PUSC permutation method.

(b) The number of subchannels per even group is 24, and for odd groups its 16, whereas as per standard PUSC method its 12 and 8 respectively.

(c) In the proposed method, the Outer PermBase sequence is generated by the shuffling method mentioned in Algorithm-1 and is different for the different inner IDcell value pair, instead standard specified permutation method uses same inner PermBase for the outer permutation.

(d) As the even group have 24 instead of 12 , the standard has specified even group inner PermBase sequence for 12 subchannel, the sequence is generated using shuffling method for 24 subchannels in an even group as well as for the odd group.

The proposed algorithm for the permutation is as follows :

Thus, by applying proposed algorithm we got the three fold improvement.

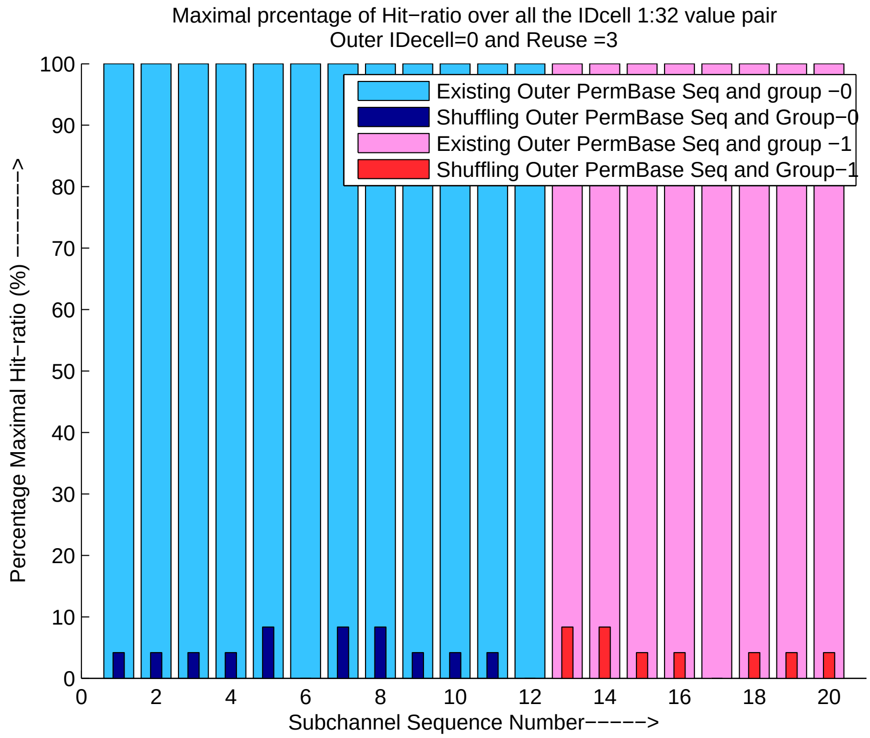


Figure 2.6: Comparison of existing permutation method with shuffling algorithm for the Outer PermBase for reuse-3

(a) As the size of the subchannel is reduced from 24 subcarriers to 12 subcarriers per subchannel, i.e., basic allocation unit get smaller thus, more efficient utilization of the spectrum.

(b) As the number of subcarriers is reduced per subchannels thus, number of subchannels in the group is increased. For the even group its 24 and for odd its 16. Hence, increases the distinct IDcell values pair for the inner permutation, that further reduced the hit-ratio problem and reduces the interference per subchannel.

(c) As the number of subchannel is increased from the above two there is reduction in the collision, thus, reduces interference and consequently improves soft capacity of the system. Whereas, due to increase in the subchannel Hard capacity of the cell is also increased.

Simulation results of the proposed algorithm is shown in Fig.-2.7 from the figure its is shown that, there is am improvement of 92% over existing permutation method for both reuse 1 and reuse 3 over even as well as odd groups and instead of apply-

Algorithm 2 Outer Permutation for each cell

1: Divide the subcarriers into 120 **PhysicalCluster** containing 14 adjunct subcarrier each.
2: Generate **RenumberingSequence** using Algorithm1.
3: LogicalCluster Formation from PhysicalCluster using following formula with IDcell -0 for Firt PUSC:

$$LogicalCluster = RenumberingSequence((PhysicalCluster + 13 * IDCell) mod 120) \tag{2.5}$$

4: Dividing Clusters into 6 major groups. **Group-even** having 24 clusters and **Group-odd** having 16 clusters.
5: Apply above to all the cells in order to perform outer permutation.

Algorithm 3 Inner Permutation for each cell

1: Allocate pilot carrier in each cluster formed by Algorithm-5. For **Group-even** pilot is at 5th and 9th position and for **Group-odd** pilot is at 1st and 13th position.
2: For subchannel formation from each group remove all the pilot subcarriers from the cluster.
3: Generate P_s by applying shuffling Algorithm-1.
4: Subchannel formation using subcarriers per group is by applying following with $N_{subchannel}$ is 24 for **Group-even** and 16 for **Group-odd**, with $N_{subcarrier}$ is 24.

$$subcarrier(k, s) = N_{subchannels}.n_k + P_s[n_k mod N_{subchannels}] + IDcell mod N_{subchannels} i \tag{2.6}$$

5: Apply above to group of each cell.

ing Algorithm-6 using exiting outer permutation method, we got improvement of 75.75% .

2.6 Problem-II

Problem statement

As per the the standard definition of the hit-ratio, is define as the number of collisions or the hits that any subchannel of one cell observe from any single subchannel of the neighboring cell. And the difference in the permutation method causes difference in hit-Ratio per subchannel. In practical scenario, if the call is entered into the cell, the number of hits in the allocated subchannel to the call is not because of a single sunchannel but because of all the subchannel currently being used in the neighbor cell. Thus, we redefine the Hit-Ratio definition as the number of hits

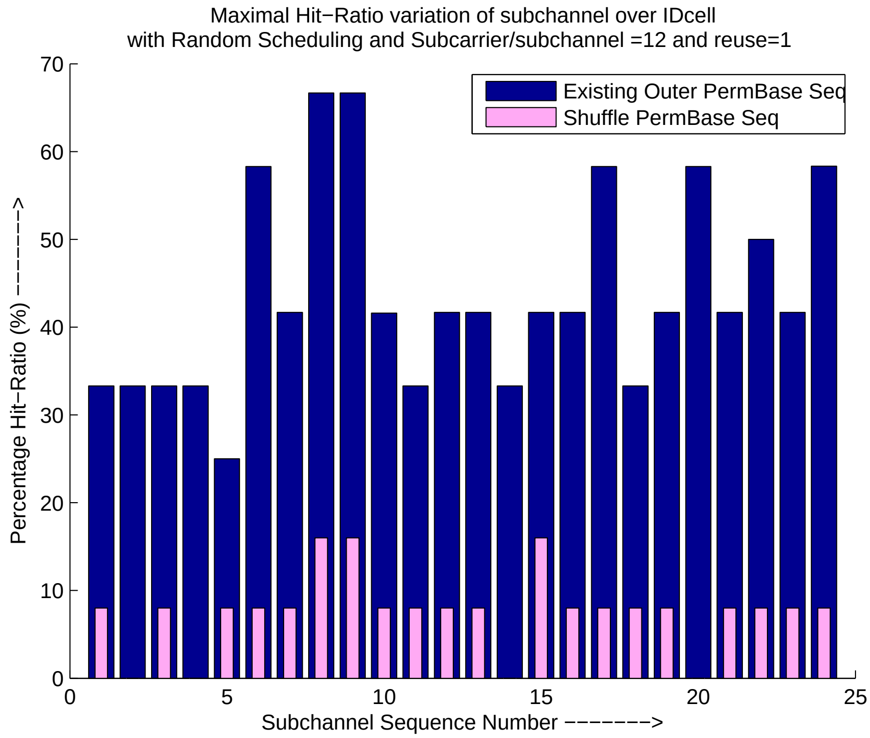


Figure 2.7: Comparison of Existing permutation method and proposed permutation method

that an allocated subchannel will face from the currently used subchannels of the nearby cells. As the call arrival process is Poisson for all the cells with different mean call arrival rate, thus, at any instant the maximum number of subchannel currently being used from a single group is equal to the number of subchannels in the group. For the call service in the nearby cell which subchannel is currently serving call will decides the number of collisions per subchannel. Thus, subchannel allocation to the call impacts collision rate. This provides one more dimension to the Erlang capacity calculation considering scheduling in the nearby cell. From this we need to minimize the new Hit-Ratio by considering different scheduling schemes in the near by cells.

2.6.1 Solution

Paper [5] has considered the effect of the various resource allocation, i.e., scheduling schemes on the Erlang capacity of the 802.16 OFDMA based cellular systems. Here, authors have considered three scheduling schemes Random allocation, Adaptive with SIR measurement on each of the subchannel before allocating it to the call and Adaptive allocation by knowing the use factor of the subchannels. In this, authors have not considered the impact of the permutation method on the Hit-ratio. Thus, there simulation are independent of the subcarriers allocation to the subchannels, whereas authors assumed that blocking probability will be function of only number of suchannels. From our findings we can say that blocking probability (Hard) depends upon the number of subchannels but the number of subchannels in the cell is decided by permutation method used for the subchannelization. And the blocking probability (Soft) is decided by the subcarrier allocation in the nearby cell e.g., if the used subchannels are orthogonal to the allocated subchannels than the collision is 0. Hence, Erlang Capacity depends upon following parameters:

(a) At System level- Scheduling used in the nearby cell for the subchannel allocation for the on-going calls.

(b) At Cell level- Permutation method used for the subcarrier to subchannel allocation per cell.

Fig.-2.8 shows the maximal percentage of Hit-ratio variation for all the subchannels over all possible IDcell value pair. Thus, different scheduling collision for the sequential scheduling is 100%, because in the nearby cell due to variation of the inner IDcell causes subcarrier to subchannel allocation, i.e., subcarrier in the subchannels are different. But at any instant if the maximum number of subchannel used in the nearby cell is 12 than from the modified definition of the Hit-Ratio, for sequential scheduling every subcarrier of the subchannel gets collided becuase due to outer IDcell=0 the subcarrier allocated to the groups, i.e., the subcarrier in the current subchannel will have the subcarrier from the used subcarriers of nearby cell. Thus, from the random scheduling the Hit-ratio get reduced by on an average of 50%. Fig.2.9, the modified Hit-ratio is applied on the proposed permutation Algorithm-1,5,6. From the figure we found on an average an improvement of 33.33%.

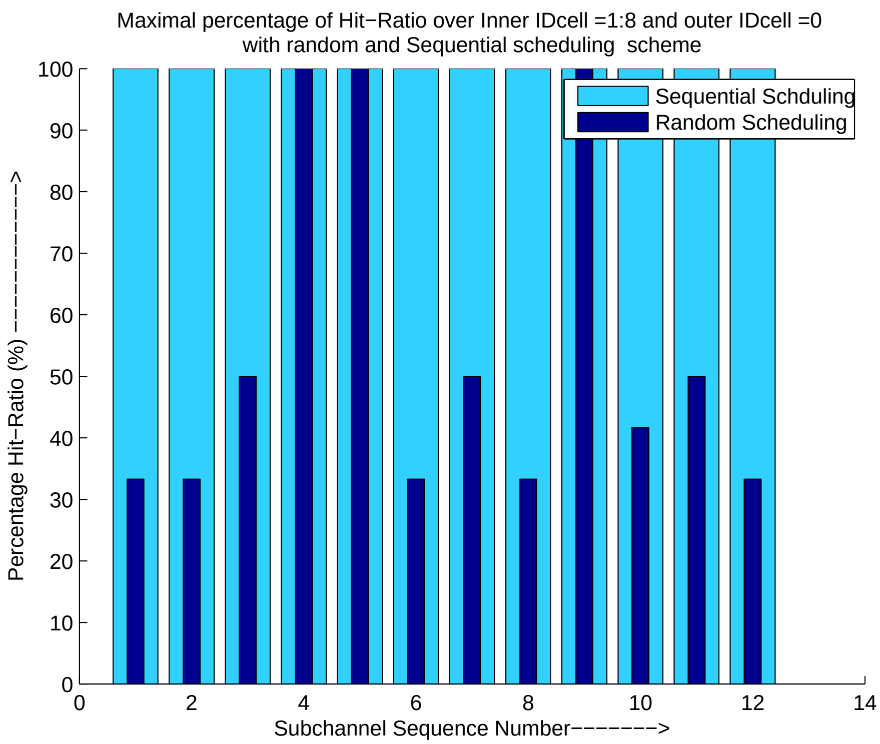


Figure 2.8: Comparison of Existing permutation method with Sequential and random scheduling

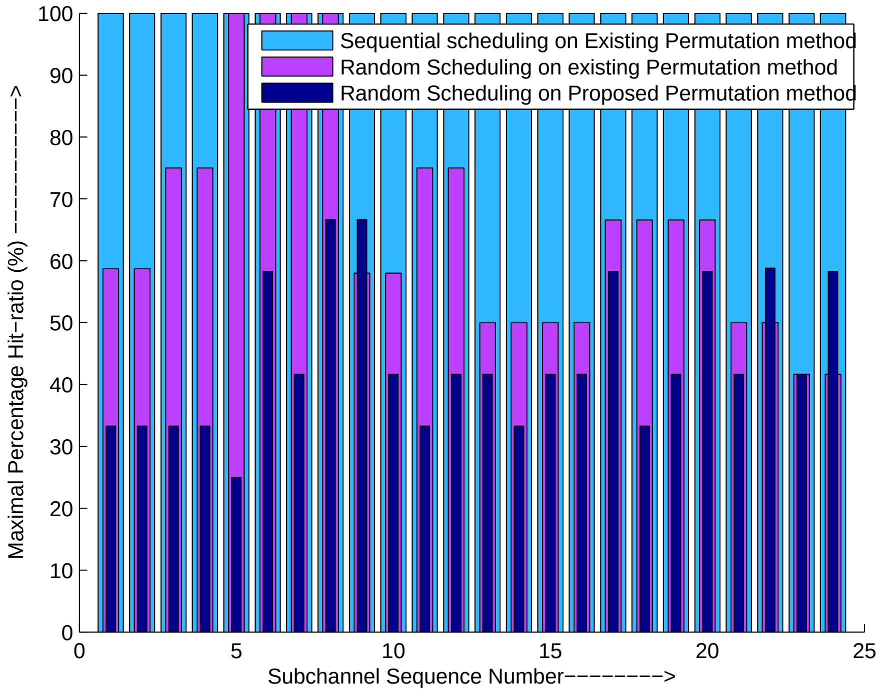


Figure 2.9: Comparison of Proposed and Existing permutation method with Sequential and Random scheduling

Chapter 3

Erlang Capacity with Shuffle Permutation Scheme

3.1 Introduction

In this chapter, we calculate the Erlang capacity of 802.16 OFDMA based cellular networks. The Erlang B formula has been widely used for modeling and evaluation of the Erlang capacity using blocking probabilities. Thus, call blocking is considered to be most important parameter in evaluating performance of the network. Here, we assume two types of blocking system models for evaluation:

(a) Hard blocking: This is due to insufficient number of subchannels in the cell.
System Model:
It assumes a fixed capacity system with Poisson arrivals. The holding time is independently and identically distributed exponential variable, therefore the call departure process is also a Poisson process. The rejected and blocked calls disappear and never come back. The number of subchannels occupied fluctuates as calls arrive and depart. A call is blocked if all suchannels are occupied when the call arrives. This type blocking is due to finite number of subchannels in the cell. This system can be modeled as a M/M/m/m queue as shown in Fig.3.1, it is identical to the M/M/m queue except that if an arrival finds all m servers busy, it does not enter the system and is lost. The last m indicates a limit on the number of the customer in the system. This model is used for telephonic systems. The performnce measure of such system

is the blocking probability, i.e., steady state probability that all subchannels are busy. By the Erlang B formula, the probability is given by:

$$B = B(A, N) = \frac{\frac{A^N}{N!}}{\sum_{n=0}^{N} \frac{A^n}{n!}} \tag{3.1}$$

where, N are the number of subchannels in the system and $A = \frac{\lambda}{\mu}$ is called offered load and is measured in Erlang. At most N channels can carry N erlangs of traffic, thus, one Erlang corresponds to continuous use of a single subchannel. Fig.3.2 corresponds to the hard Erlang capacity of the system. Whereas, Fig.3.3 is comparison of the Practical and theoretical Hard Erlang capacity of the system. For AMPS N =19 subchannels available per cell for 2% blocking probability occurs for A=12.4 Erlangs of offered traffic. That is when average number of ongoing calls is 12.4, there is a 2% chance that an incoming call will be blocked at any particular time.

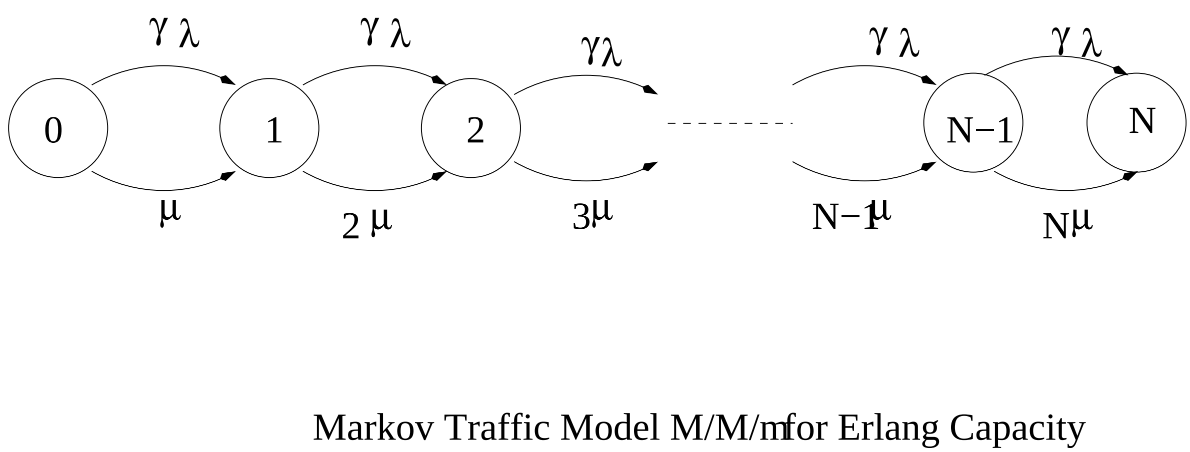


Figure 3.1: Markov Queuing Model M/M/m/m

(b) Soft blocking: This occurs when the number of active users in the system exceeds the maximum number of subchannels in the cell. Thus, though subchannels are available, due to interference from the users of the neighboring cells, SIR goes below the threshold and hence calls are blocked. This is called Soft Blocking. It is due to reuse 1 in the 802.16 OFDMA cellular systems.

Interference Model: This is the factor due to which the Erlang capacity of the 802.16 OFDMA cellular system is different from the other cellular systems. Following are the system parameters for the Interference Model:

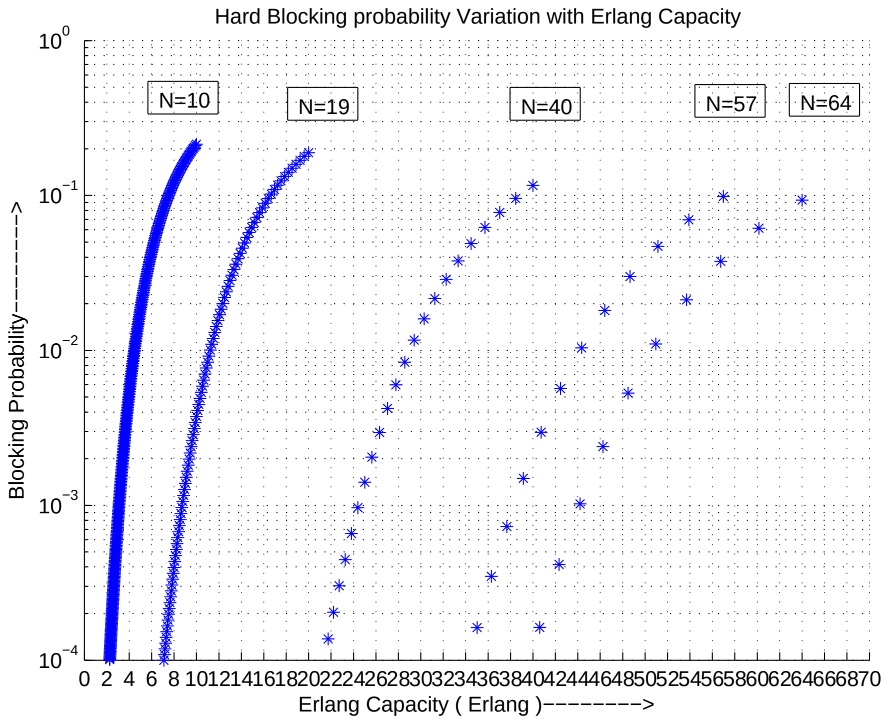


Figure 3.2: The Hard Blocking Probability

i. Homogeneous IEEE 802.16e system with interference from the 1st tier of the cellular systems.

ii. Reuse factor is 1 as well as 3 as supported by the 802.16 OFDMA standard.

iii. Each subchannel consists of multiple subcarriers. Therefore, subcarrier to subchannel formation is also an improtant parameter in determining the Erlang capacity. Therefore, the effect of permutation also needs to be considered.

iv. Collision of the subcarriers depends upon the scheduling as decided in the previous chapters thus, Soft Erlang capacity also depends upon the scheduling mechanisms used.

The Erlang capacity variation with the SIR threshold is shown in Fig.-**??**.

Thus, combining the effect of Hard and Soft blocking, the system blocking probability is calculated as follows :

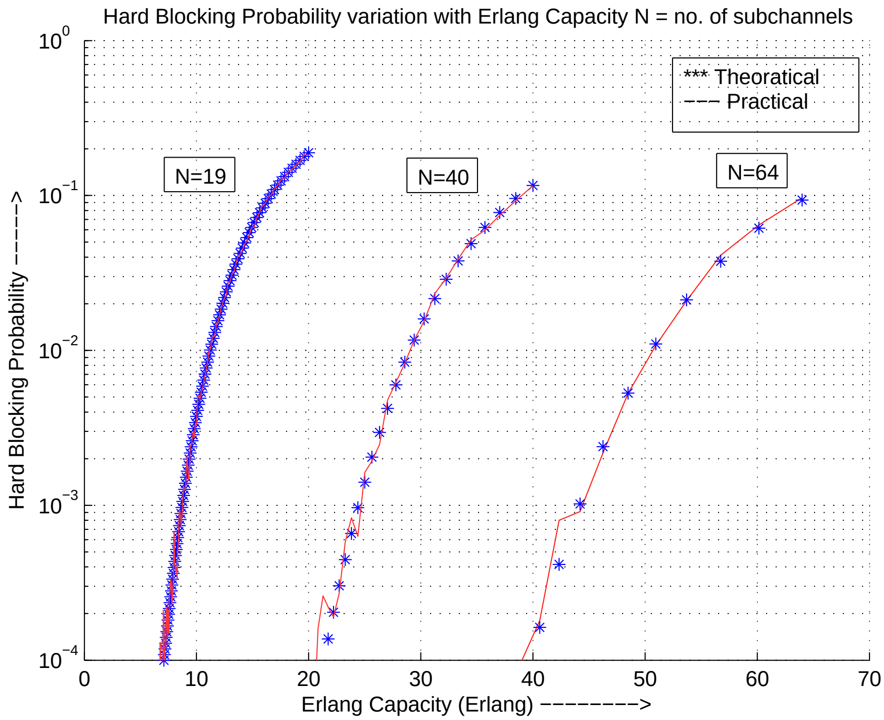


Figure 3.3: The Hard Blocking Probability theoretical and Practical

$$P_{blocking} = 1 - (1 - P_{soft})(1 - P_{hard}), \tag{3.2}$$

$$P_{blocking} = P_{hard} + (1 - P_{hard})P_{soft}, \tag{3.3}$$

$$P_{soft} = P_{collision}(Hit - Ratio > thresh) * P_{interference}(SIR < SIR_{thresh}), \tag{3.4}$$

$$P_{hard} = B = B(A, N) = \frac{\frac{A^N}{N!}}{\sum_{n=0}^{N} \frac{A^n}{n!}}, \tag{3.5}$$

$$A = \frac{\lambda}{\mu}, \tag{3.6}$$

It can be inferred that

(a) If we apply the Existing Algorithm for the PUSC permutation with Squential scheduling, $P_{collision}(Hit - Ratio > thresh) = 1$, hence the blocking probability of the OFDMA cellular system is same as that of the FDMA/CDMA system.

(b) Using the Proposed algorithm, we are improving Erlang Capacity by reducing the subcarrier collision, i.e., $P_{collision}(Hit - Ratio > thresh) < 1$. By using Proposed Solution-II, we have $P_{collision}(Hit - Ratio > thresh) = 0$, thus, mitigating interference completely.

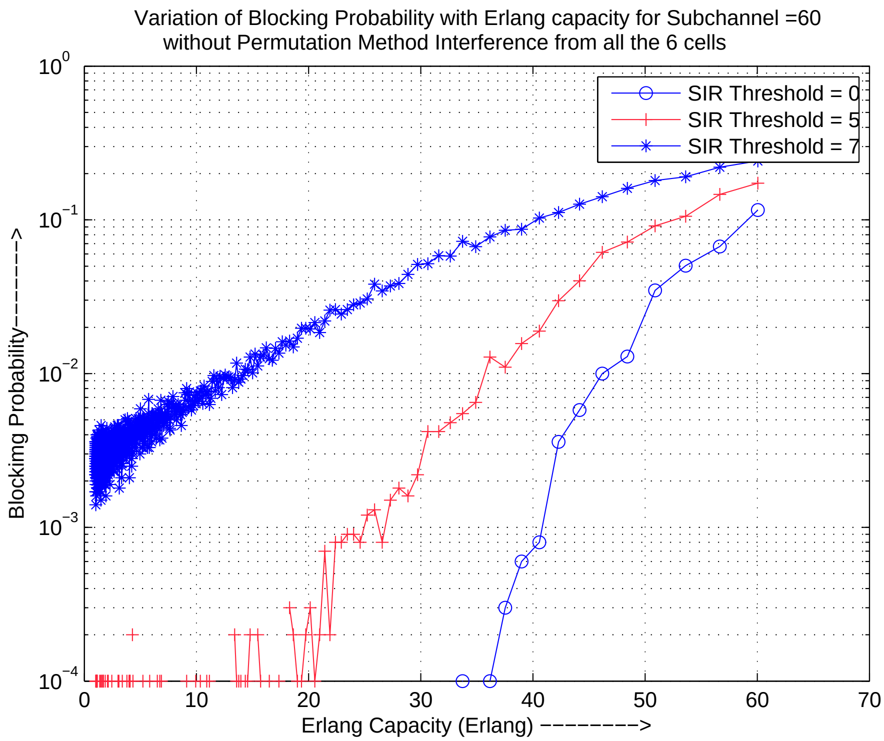


Figure 3.4: Erlang Capacity variation with SIR threshold

3.2 Algorithm

In Section-3.1 we discussed that Erlang capacity depends on soft blocking as well as hard blocking. For the Erlang capacity calculation, we apply the following Algorithm-4:

3.2.1 Simulation Parameters

Applying 802.16 OFDMA standard specified algorithm for the Erlang capacity. During simulation, We have calculated Hit-Ratio per Group Applying following setting to the Algorithm-7:

(a) Inner IDcell value pair - 2:7 and Outer = 0.

(b) Permutation Method, Outer PermBaseSeq = Standard specific and Proposed Shuffle method.

(c) Scheduling FCFS and Random.

(d) For Even-Group (12 subchannels) and Odd-Group (8 subchannels) subchannels.

Table 3.1: Cell Configuration

Parameters	Values
Cell Structure	6 cell 1-tier
Cell Radius	1Km
User Distribution	Random
Propogation Model	PathLoss
Multiple Access	OFDMA
Effective Bandwidth	20 MHz
FFT Size	2048
Power Distribution	Equal over all subcarriers in subchannel
Scheduling Type	Sequential and Random
Number of data Subcarriers	1680
Number of groups in cell	6
Number of subchannels in group	12/8
Number of subcarriers in a subchannel	24
Subchannel Mode	Downlink PUSC

3.3 Simulation Results

Applying proposed modification to improve Hit-Ratio in the subchannels per group. Fig.3.5, shows an improvement of applying Shuffling Algorithm on the existing permutation method with the sequential algorithm, which is about 150%. and is observed for the Even-Group for 10 subchannels. Whereas, when we apply scheduling as well as modified permutation method on the Even-Group subchannels as shown in Fig.3.6, provides an improvement of 200%, which is as good as saying that there is no soft blocking due to subchannel reuse. This is because as shown in Algorithm-7 the SIR is reduction is significant if the Hit-ratio is more than 50%, i.e., if more than half of the subcarriers in the subchannels are collided than the SIR reduction can cause the blocking again depends upon the pathloss factor of the user in the cell. By applying proposed method, we found that Hit-ratio for the subchannels in Odd as well as Even Groups are becomes less than 50%, hence, causes no SIR reduction and no soft blocking which is reflected in the simulation results. As shown in Fig.3.7 the Erlang capacity for the Odd-Groups provides an improvement of 200% because of same reason. Further, Erlang capacity can be improved mentioned in the next chapter. Fig.3.8, shows the improvement of 400% on Even-Group subchannels using Proposed method over existing method for the calculation of Erlang capacity.

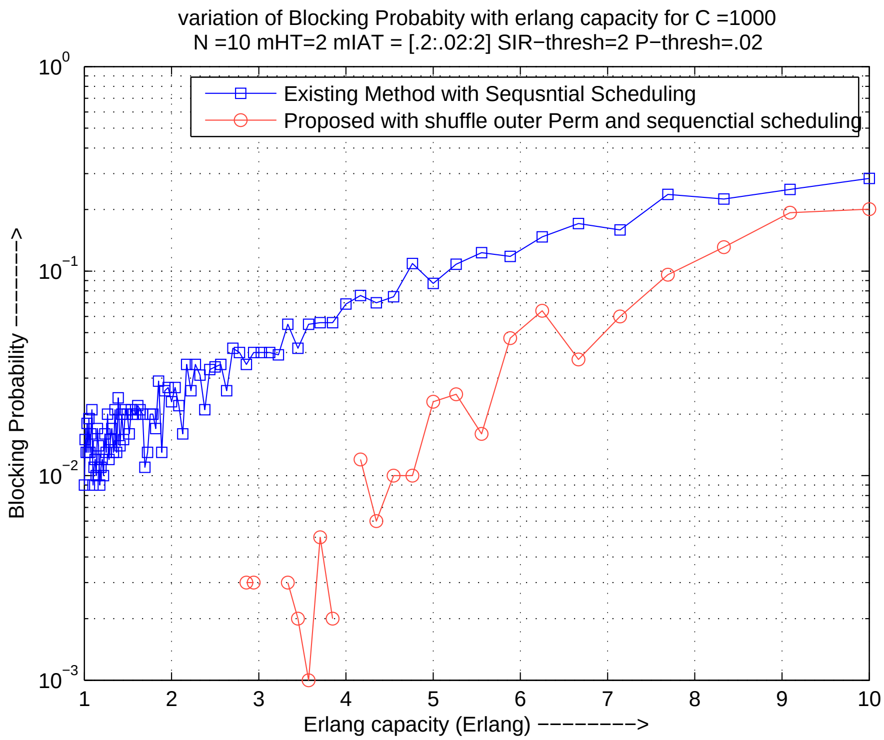


Figure 3.5: Erlang Capacity for Existing and Proposed Method with Shuffled Outer PermBase

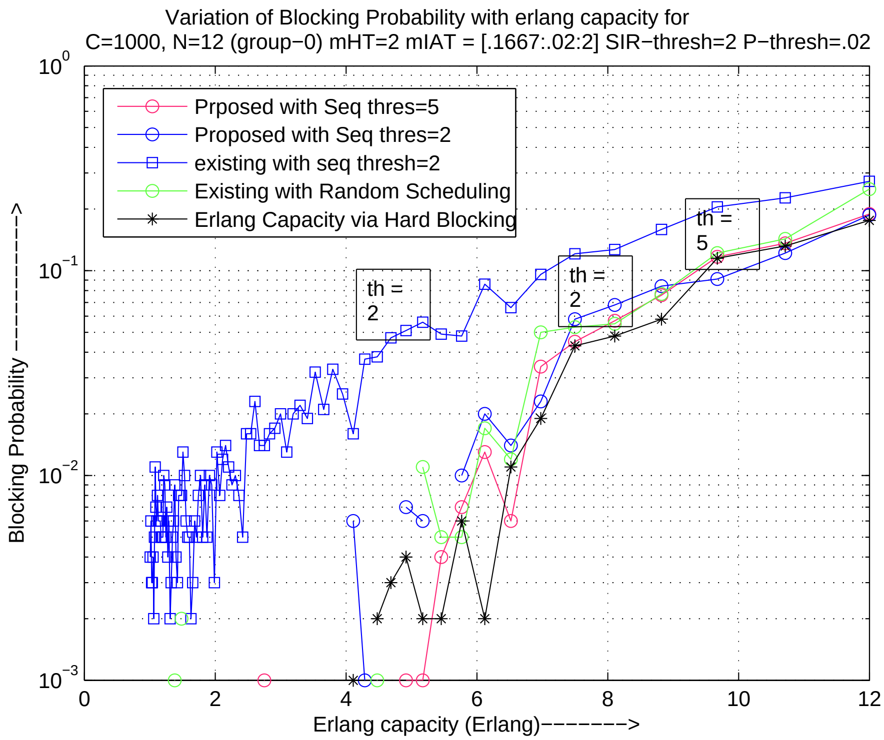


Figure 3.6: Erlang Capacity for Existing and Proposed Method with Even Group

Algorithm 4 Erlang Capacity of OFDMA 802.16 Systems

For each cell in the system;
DSM Subchannelization
Apply **Outer** and**Inner** permutation for subchannel using Algorithm-1.
Calculate Maximal Hit-Ratio **MaxHitRatio** for each subchannel of the cell using scheduling -*Sequential* and *Random*.
Hit-Ratio is calculated assuming all the subchannels in the cell, for even group 12 and for odd group 8 subchannels and is maximized over all the inner IDcell value pair.
Erlang Capacity of the Reference Cell
Set **N** number of subchannel, for each call service time is **mHT** mean Holding Time and **mIAT** is the mean Inter Arrival time are exponentially distributed, because calls are with poisson arrival.
Set the **arrInst** each call and **termInst** of each call. Following is the check for whether the subchannel is engaged or not
For each subchannel **N**
if arrInst $<$ **SubchannTime then**
    Hard Blocking: current subchannel is servicing call, go to the next subchannel **N** = **N+1**.
else
    Soft Blocking: check for the Interference from the near by cell for **Soft Blocking**
    if MaxHitRatio $>$ **.5**, Due to permutation method **then**
        calculate **SIR** using Pathloss Model for interference calculation
        if SIR $> SIR_{thresh}$ **then**
            Call is **Served SubchannTime** = **TermInst** of a call.
        end if
    else
        SIR reduction is not significant and call is **Served** by subchannel.
    end if
end if
To Check the call blocked
if Call is **NotServed then**
    Blocked = **Blocked +1**;
end if
To calculate Erlang Capacity **ErC**
if Blocked == .02 **then**
    Erlang Capacity **ErC** = $\lambda\mu$
end if

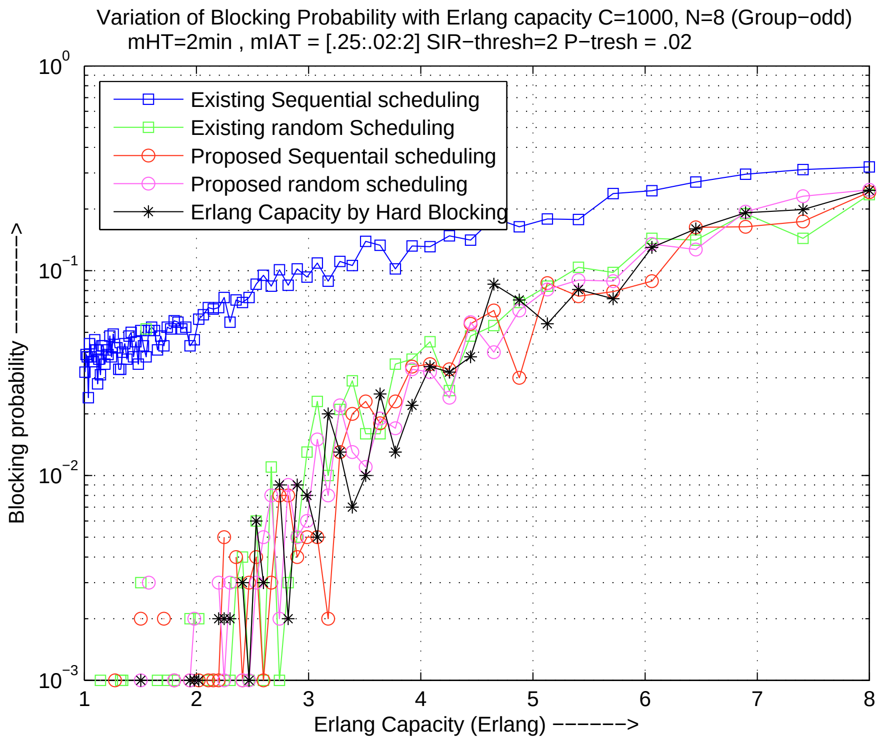


Figure 3.7: Erlang Capacity for Existing and Proposed Method with Odd Group

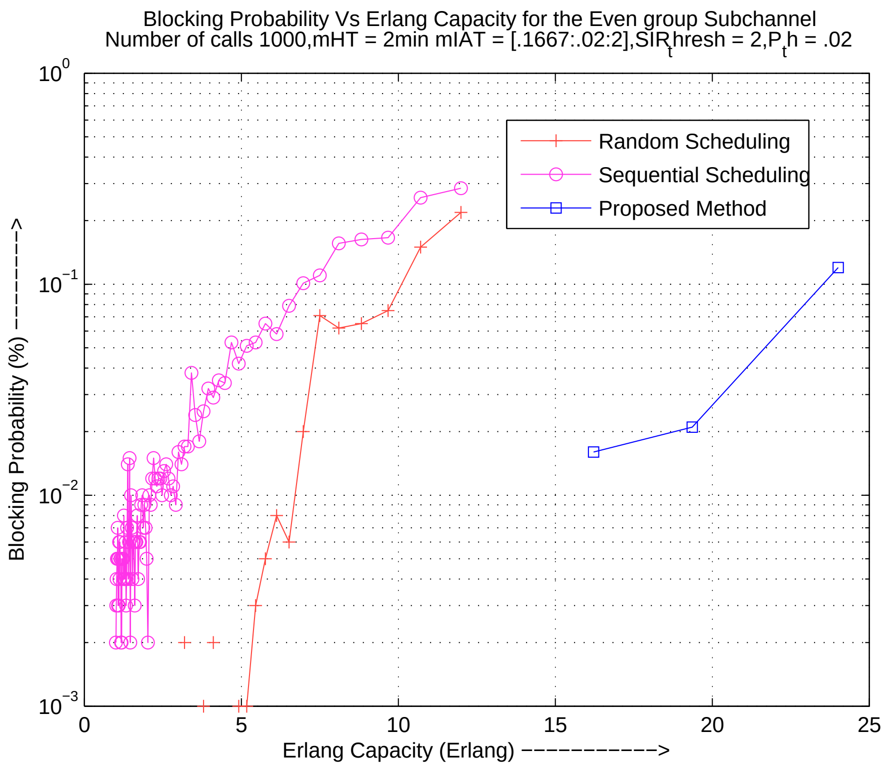


Figure 3.8: Comparison of the Erlang capacity of Existing Algorithm and Proposed Algorithm

Chapter 4

Call Admission Control

4.1 Introduction

In this chapter, we describe the existing Call Admission Control in cellular systems. In cellular systems, user mobility results in handoff calls. In order to use limited radio resources to accomodate an increasing the number of users for services, one approach is to deploy cells of smaller size for more frequency use. A consequence of this is more frequent handoffs. It is better to be blocked in the beggining of a call, than to be dropped during the connection. Thus, handoff calls should be given higher priority then new calls by reserving some resources exclusively for the handoff calls. In [8] and [9], bandwidth is reserved as a guard band for handoff calls.

The mechanism to handle handoff calls is called Call Admission Control (CAC). CAC is a concept applied to real time media traffic and not to a data traffic. CAC mechanisms compliments the capabilities of QoS tools to protect voice traffic from the negative effects of other voice traffic and to keep excess voice traffic of the network.

CAC in cellular system are of various kinds like code availability, or setting a threshold on the number of users, or based on SIR measurement. In admission control based on code availability, calls are admitted as long as there are codes available for allocation. Calls do not find codes for transmision are blocked. Admission control based on SIR used threshold which is enough to maintain the bit error rate (BER) of a user below a specified value.

CAC is used to prevent congestion in voice traffic. The design of CAC algorithm for mobile cellular networks is especially challenging given the limited and highly variable resources, and the mobility of users encountered in such networks. Hand off prioritization is a common characteristic of these schemes. In this thesis users generate traffic of different bit rate and quality of service requirements. The admission control policy admits new and handoff calls. We have examined the different method for the CAC, depends on bandwidth reservation and power reservation.

4.2 Admission control strategy

In addition to these OFDMA-specific resource allocation consideration, one must also take into account the admission and rate control using AMC for the different kinds of traffic. In general, CAC strategies can be classified into two strategies:

3. Non-Adaptive admission control: In this, calls are given fixed amount of resource, independent of the actual load. In IEEE 802.16e, this corresponds to a call being allocated to a certain number of time/frequency resources depending upon its class of traffic, in a circuit switched way. A new arrival is then blocked if there are no available resources to serve it.

4. Adaptive admission control: Elastic calls ma tolerate lower throughputs, thus, one may free resources to accept more users.

4.3 Resource Allocation and Scheduling

In the thesis, the CAC algorithm consists of Resource allocation and Subcarrier assignment.

(a) Resource Allocation: We decide number of subcarriers each user gets, i.e., its bandwidth allotment depending upon its rate requirements and the users' average channels gain.

(b) Subcarrier Assignment: We have use inter base station communication for subcarrier assignment, to reduce the interference on a particular subchannel by utilizing information of the subchannels used in neighboring cell.

4.3.1 Resources Allocation

In IEEE 802.16, the BS (Base station)centrally allocates the channels in different SSs(subscriber stations) for uplink and downlink which in turn allocates these resources. In IEEE 802.16e 802.16 system, frequency is allocated on the basis of subchannels, each consisting of several subcarriers. Resources are allocated in the IEEE 802.16e on both time and frequency bases. a call may share a subchannel with the other user.
The users in cellular system need to share the available resources in the system. The resources in a cellular system could be the available bandwidth, the transmit/receive power, the rate of transmission and so on. These resources are limited and hence have to be manged efficiently to achieve good system performance.The system performance is measured on which resources are allocated depend upon type of services the system offers and the requirement of the users in the system. In cellular system with voice only traffic, the transmission rate on different carrier frequencies or time slots are equal. Hence, resource allocation is essentially the allocation of time slots or carrier frequency to different user.

4.3.2 Channelized cellular system

Channelized cellular systems work on the principle of interference avoidance. Therefore, no two users in the same cell can use the same channel (time slot and carrier frequency). channels can be allocated to the user on the fixed basis or on a dynamic basis. Fixed channel allocation (FCA) and dynamic channel allocation (DCA) are as follows:

(a) Fixed Channel Allocation: In channelized cellular systems with fixed channel allocation (FCA), the reuse distance is the distance between the base station of the cell-of-interest and that of the nearest cell in which a channel can be reused. This reuse distance is obtain by calculating the maximum possible interference at the base station or user on the uplink/downlink. The total number of available channels is divided into subsets and each subset of a channels is allocated to cell. It is taken care that if te two subsets that have the common element, then they are allocated to cell that are reuse distance apart. A new call in the cell that finds all the channels in the subset of channels allocated to a cell, busy are blocked. Such systems are relatively easier to design and system performance analysis is also simple and accurate. the blocking probability is determine by applying Erlang-B loss formula. FCA donot take into account the exact position of the users. FCA is static and donot adjust to varying traffic condition.

(b) Dynamic Channel Allocation: The dynamic channel allocation allows adaptation to spatial and temporal traffic variation. The dynamic nature is allowed to use any channels as long as the interference measured by the base station or user on downlink or uplink is below a specified threshold. Performance in terms of blocking probability in comparison to FCA is better, but is computationally complex.

4.3.3 Subcarrier Assignment

In this section, we solve the problem of subcarrier assignment by scheduling algorithm for interference management in broadband wireless access network. The algorithm aims to minimize the co-channel interference using base station co-ordination, while still maintaining QoS requirement. The interference reduction is achieved by avoiding concurrent transmission on same frequency in the two neighboring cells. In order to implement the algorithm in a distributed manner, base stations have to exchange traffic information.

Numerous scheduling algorithm have been proposed for multimedia scheduling over wireless links. Most of these algorithm are in essence modified versions of some scheduling algorithm employed in wireline networks. Several algorithms have proposed the concept of user diversity by making use of the channel variations and allocate a lot of for users with good channel condition and less for the users with bad channel condition. These scheduling algorithms have been studied either in isolated cells or in multiple cells but without considering the scheduling techniques in the interference management.

In this thesis, we implemente resource allocation and subcarrier assignment i.e., scheduling scheme for the broadband wireless system.

4.3.4 Inter Basestation Communication

Broadband wireless access networks are for multimedia services including real-time traffic (voice and vedio) and non-real time traffic(http and ftp data) are to be supported. In this thesis, a transmission scheduling algorithm is used by taking interference information from the neighboring cell using inter base station communication. Through interbase station communication the traffic information is conveyed to the reference cell for making decision for the communication. Dynamic frequency allocation is used by using interference information by inter base station co-ordination for the communication.

In this report, we are measuring performance of the IEEE 802.16e system using Erlang capacity. There are range of different Erlang formula, to calculate these, including Erlang B, Erlang C and the related Engset formula. As per the system requirement of OFDMA cellular system, we use Erlang B formula. Erlang capacity as per [10] [11] can be divided as

(a) Hard Blocking:
It is the call blocking in cellular system due to limitation of physical slots either time or frequency. The incoming call will be blocked if all the servers or subchannels are engaged. The Erlang capacity is calculated at the blocking probability of greater than certain threshold usually .02%.

(b) Soft Blocking:
It is call blocking in case of interference limited networks e.g. CDMA systems, where physical slots are available, blocking is due to SIR reduction below than certain threshold.

In the OFDMA, the Hard Blocking is due to limited number of the physical channels and Soft Blocking is due to inter cell interference caused because of reuse factor one. For finding the interference or collision of the subchannels in the OFDMA systems.

Chapter 5

Power Reservation Scheme for Call Admission Control

5.1 Introduction

In this chapter, we motivate the need for power reservation based CAC instead of reserving bandwidth for admitting calls in the system.
At a high speeds, MSs may change their serving cell several times during the lifetime of their conversation. Handoff dropping will occur when the available resources in the target cell cannot meet the requirement of the handoff call. In order to keep the handoff dropping rate at an acceptable level, call admision control is widely adopted in mobile communication systems. The main idea of which is to reduce handoff drppings by limiting the amount of radio resources allocated to active calls and new calls in each cell. A number of significant CAC schemes have been proposed during the last 2 decades. These schemes are classified into static and dynamic control schemes. Traditional static schemes reserve a fixed number of channels exclusively for handoff calls, which do not adapt to changes in the traffic pattern. The dynamic control schemes make the admission decisions in a distributed manner, relying on status information exchange between cells.

These channel reservation schemes are not competent in IEEE 802.16e systems, as mentioned in the previous chapters. Therefore, in this chapter, we use power reservation based CAC schemes. For this, we minimized the power used by ongoing calls, so that the handoff calls dropping probability is reduced. The problem is formulated and a heuristic is proposed for the CAC scheme.

5.2 Problem-I

We consider the problem of resource allocation in the downlink of cellular OFDMA systems. In principle, performing resource allocation for cellular OFDMA systems requires the solution of power and subcarrier allocation jointly in all cells, taking into consideration the interaction between users of different cells via multicell interference. Unfortunately in most of the practical cases, this global optimization problem is not convex and therefore, does not have a simple analytical solution. Therefore, we propose a practical method for the subchannel and power allocation. The proposed allocation schemes for the subcarrier and power for the user request is as shown below [12] :

$$min(\sum_{i=0}^{M} P_i) \tag{5.1}$$

subject to

$$P_i = N_i * F(MC_i) \tag{5.2}$$

where,

$$N_i = R_i/DR(MC_i) * B_0, \forall\ i(5.3)$$

$$\sum_{i=0}^{M} N_i \leq N \tag{5.4}$$

In the above problem formulation, we minimize the power allocated to i^{th} user P_i, the, total power transmitted by base station is summation of all the active users' power. Power allocated to a user is product of number of subchannels N_i allocated to the user as per assigned AMC, and power allocated per subchannel $F(MC_i)$, as show in Table-2.2, where MC_i, is the modulation level assigned to a particular user, B_0, is the bandwidth per subchannel, i.e., product is the data rate per subchannel of cellular system. In the fomulation, the total number of subchannels in the system is a constraint.

Thus, for the efficient allocation of resources in 802.16e cellular systems, instead of reserving subchannels for the handoff calls, power is reserved and all the subchannels are used for on going calls. Thus, we need to minimize the power for the handoff calls. The performance measure used for evaluation of the proposed algorithm are blocking probability and Erlang capacity of system.
The PUSC permutation scheme is applied for the subchannel formation. Here, the

resource allocation is used for the request to be satisfied. Resource for the allocation is orthogonal subchannels(which is formed using PUSC), and power used for the transmission of the user data. Thus, we are using same scheme mentioned in the paper for the resource allocation. Subcarrier assignment is the type of subchannel to be allocated to the incoming or handoff call, it is allocated dynamically using inter basestation co-ordination information. Thus, subcarrier assignment problem is solved by assigning subcarriers/subchannels to the users, according to traffic information in the neighboring cells

5.3 Proposed Solution-I

The proposed solution for the above problem involves power reservation for the handoff calls and CAC is based on the availability of the power instead of subchannel availability. Once the resources are allocated, exactly which subchannel/subcarriers are to be assigned to the user request is decided by the inter base station co-ordination traffic information. The proposed solution is implemented using the following steps:

(a) Subchannel Formation: Using PUSC method for the subchannel formation as per the standard 802.16 specifications.

(b) Resource Allocation: Allocating resources, such that minimum power is required for the ongoing calls and maximum power is reserved. This is done using Adaptive Coding and Modulation. The on-going calls are allocated with the minimum power and more subchannels.

(c) Subcarrier Assignment: Once resources are allocated to the ongoing calls, how to allocate the subchannels/subcarriers to the users is decided by the scheduling algorithm, this in greedy sense can be done by choosing a user, which currently requires more power for transmission. Thus, by allocating subchannel with minimum power more power can be reserved for the handoff calls.

Performance of the proposed algorithm is measured using blocking probability or Erlang capacity of the cellular system. Erlang capacity is discussed in the next section.

5.3.1 Algorithms

Subchannel formation algorithm is as per the 802.16 standard divided into outer and inner permutation schemes.

Algorithm for the Inner permutation is as follows:

Algorithm 5 Outer Permutation for each cell

1: Divide the subcarriers into 120 **PhysicalCluster** containing 14 adjunct subcarrier each.
2: Generate **RenumberingSequence** using Algorithm1.
3: LogicalCluster Formation from PhysicalCluster using following formula with IDcell -0 for Firt PUSC:

$$LogicalCluster = RenumberingSequence((PhysicalCluster + 13 * IDCell) mod 120) \tag{5.5}$$

4: Dividing Clusters into 6 major groups. **Group-even** having 24 clusters and **Group-odd** having 16 clusters.
5: Apply above to all the cells in order to perform outer permutation.

Algorithm 6 Inner Permutation for each cell

1: Allocate pilot carrier in each cluster formed by Algorithm-5. For **Group-even** pilot is at 5th and 9th position and for **Group-odd** pilot is at 1st and 13th position.
2: For subchannel formation from each group remove all the pilot subcarriers from the cluster.
3: Generate P_s by applying shuffling Algorithm-1.
4: Subchannel formation using subcarriers per group is by applying following with $N_{subchannel}$ is 24 for **Group-even** and 16 for **Group-odd**, with $N_{subcarrier}$ is 24.

$$subcarrier(k, s) = N_{subchannels}.n_k + P_s[n_k mod N_{subchannels}] + IDcell mod N_{subchannels} i \tag{5.6}$$

5: Apply above to group of each cell.

Chapter 6

Erlang Capacity with Power Reservation based Call Admission Control

6.1 Introduction

In this chapter, we calculate the Erlang capacity of 802.16 OFDMA based cellular networks. The Erlang B formula has been widely used for modeling and evaluation of the Erlang capacity using blocking probabilities. Thus, call blocking is considered to be most important parameter in evaluating performance of the network. Here, we assume two types of blocking system models for evaluation:

1. Hard blocking: This is due to insufficient number of subchannels in the cell.
   System Model:
   It assumes a fixed capacity system with Poisson arrivals. The holding time is independently and identically distributed exponential variable, therefore the call departure process is also a Poisson process. The rejected and blocked calls disappear and never come back. The number of subchannels occupied fluctuates as calls arrive and depart. A call is blocked if all suchannels are occupied when the call arrives. This type blocking is due to finite number of subchannels in the cell. This system can be modeled as a M/M/m/m queue as shown in Fig.6.1, it is identical to the M/M/m queue except that if an arrival finds all m servers busy, it does not enter the system and is lost. The last m indicates a limit on the number of the customer in the system. This model is used for telephonic systems. The performnce

measure of such system is the blocking probability, i.e., steady state probability that all subchannels are busy. By the Erlang B formula, the probability is given by:

$$B = B(A, N) = \frac{\frac{A^N}{N!}}{\sum_{n=0}^{N} \frac{A^n}{n!}} \tag{6.1}$$

where, N are the number of subchannels in the system and $A = \frac{\lambda}{\mu}$ is called offered load and is measured in Erlang. At most N channels can carry N erlangs of traffic, thus, one Erlang corresponds to continuous use of a single subchannel. Fig.6.2 corresponds to the hard Erlang capacity of the system. Whereas, Fig.6.3 is comparison of the Practical and theoretical Hard Erlang capacity of the system. For AMPS N =19 subchannels available per cell for 2% blocking probability occurs for A=12.4 Erlangs of offered traffic. That is when average number of ongoing calls is 12.4, there is a 2% chance that an incoming call will be blocked at any particular time.

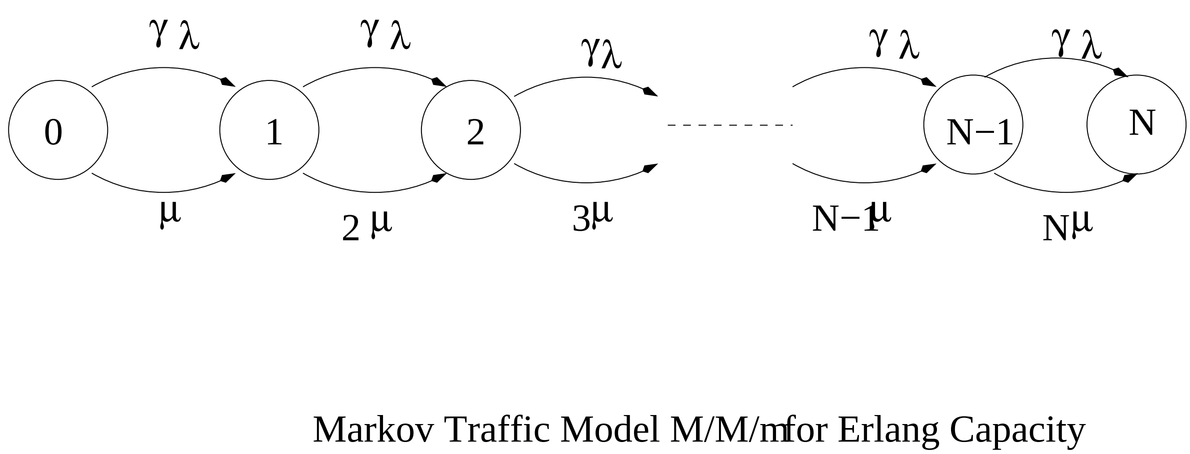


Figure 6.1: Markov Queuing Model M/M/m/m

2. Soft blocking: This occurs when the number of active users in the system exceeds the maximum number of subchannels in the cell. Thus, though subchannels are available, due to interference from the users of the neighboring cells, SIR goes below the threshold and hence calls are blocked. This is called Soft Blocking. It is due to reuse 1 in the 802.16 OFDMA cellular systems.

   Interference Model: This is the factor due to which the Erlang capacity of the 802.16 OFDMA cellular system is different from the other cellular systems. Fol-

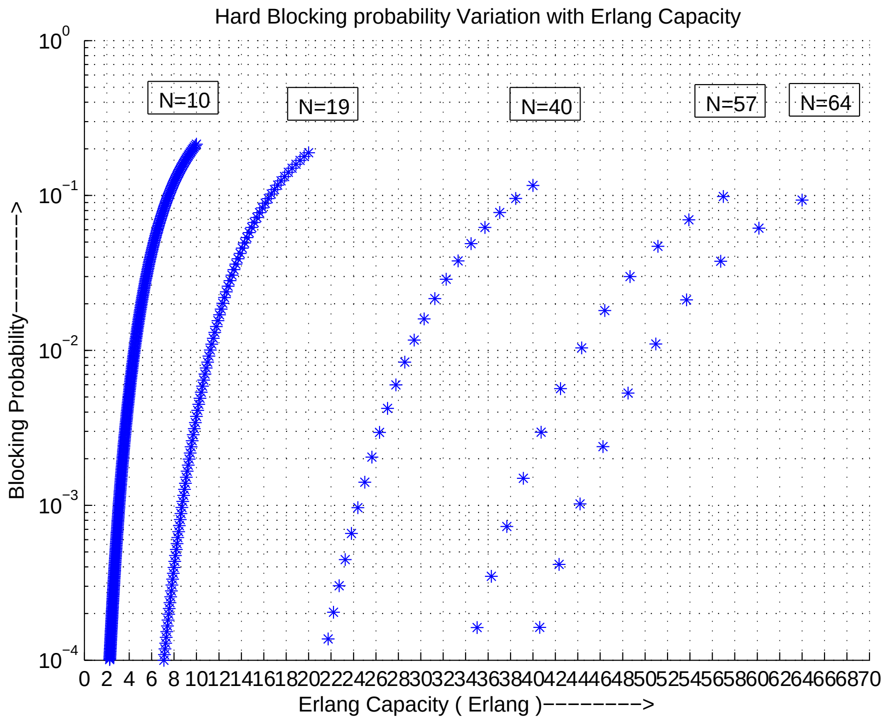


Figure 6.2: The Hard Blocking Probability

lowing are the system parameters for the Interference Model:

(a) Homogeneous IEEE 802.16e system with interference from the 1st tier of the cellular systems.

(b) Reuse factor is 1 as well as 3 as supported by the 802.16 OFDMA standard.

(c) Each subchannel consists of multiple subcarriers. Therefore, subcarrier to subchannel formation is also an improtant parameter in determining the Erlang capacity. Therefore, the effect of permutation also needs to be considered.

(d) Collision of the subcarriers depends upon the scheduling as decided in the previous chapters thus, Soft Erlang capacity also depends upon the scheduling mechanisms used.

The Erlang capacity variation with the SIR threshold is shown in Fig.-??.

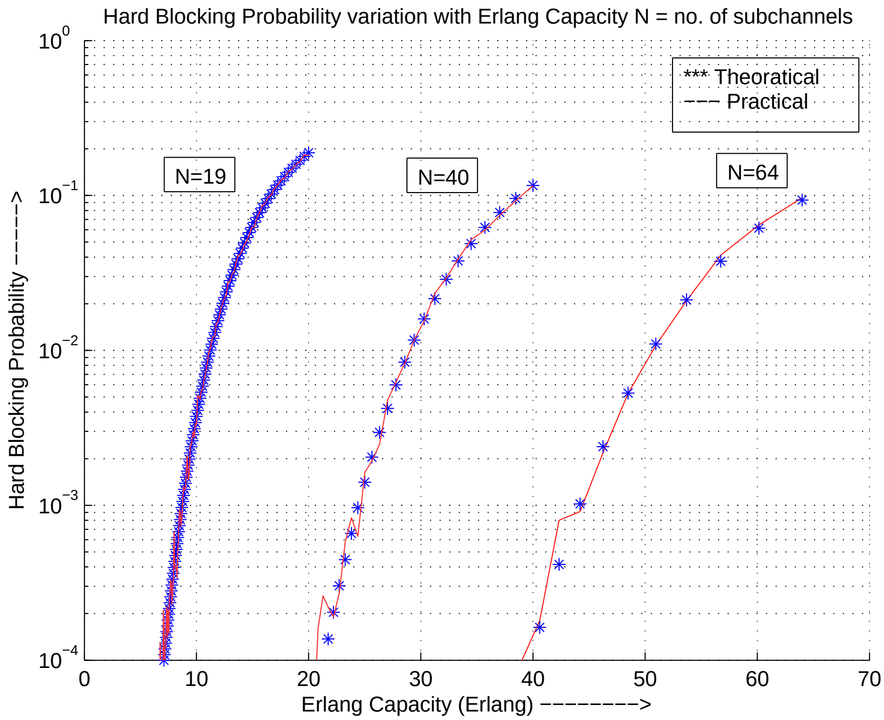


Figure 6.3: The Hard Blocking Probability theoretical and Practical

Thus, combining the effect of Hard and Soft blocking, the system blocking probability is calculated as follows :

$$P_{blocking} = 1 - (1 - P_{soft})(1 - P_{hard}), \tag{6.2}$$

$$P_{blocking} = P_{hard} + (1 - P_{hard})P_{soft}, \tag{6.3}$$

$$P_{soft} = P_{collision}(Hit - Ratio > thresh) * P_{interference}(SIR < SIR_{thresh}), \tag{6.4}$$

$$P_{hard} = B = B(A, N) = \frac{\frac{A^N}{N!}}{\sum_{n=0}^{N} \frac{A^n}{n!}}, \tag{6.5}$$

$$A = \frac{\lambda}{\mu}, \tag{6.6}$$

It can be inferred that

1. If we apply the Existing Algorithm for the PUSC permutation with Squential scheduling, $P_{collision}(Hit - Ratio > thresh) = 1$, hence the blocking probability of

the OFDMA cellular system is same as that of the FDMA/CDMA system.

2. Using the Proposed algorithm, we are improving Erlang Capacity by reducing the subcarrier collision, i.e., $P_{collision}(Hit - Ratio > thresh) < 1$. By using Proposed Solution-II, we have $P_{collision}(Hit - Ratio > thresh) = 0$, thus, mitigating interference completely.

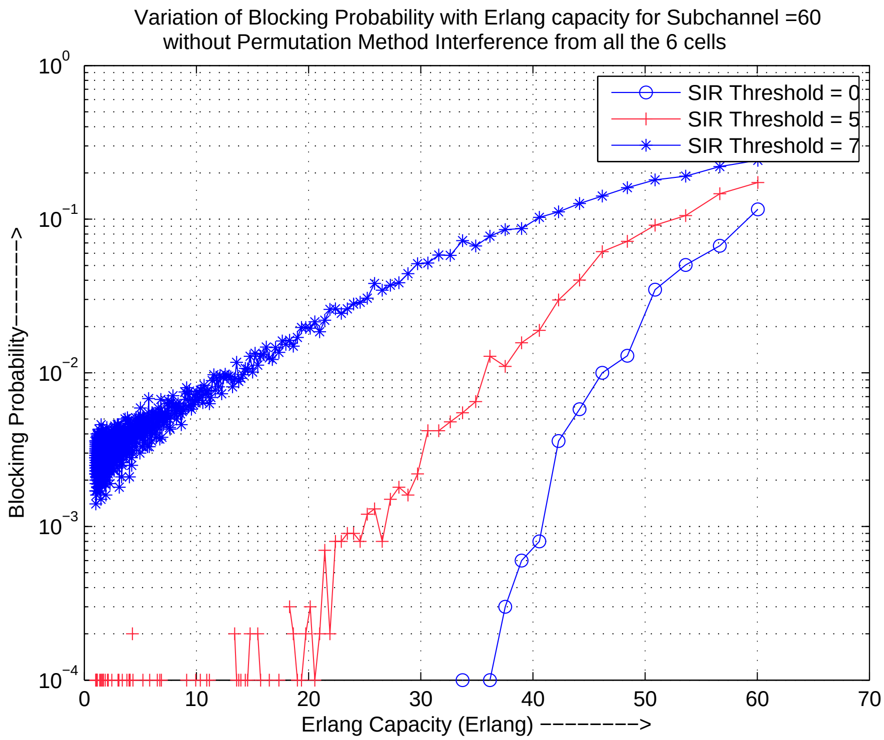


Figure 6.4: Erlang Capacity variation with SIR threshold

6.2 Algorithm

In Section-6.1 we discussed that Erlang capacity depends on soft blocking as well as hard blocking. For the Erlang capacity calculation, we apply the following Algorithm-7:

6.2.1 Simulation Parameters

Applying 802.16 OFDMA standard specified algorithm for the Erlang capacity. During simulation, We have calculated Hit-Ratio per Group Applying following setting to the Algorithm-7:

1. Inner IDcell value pair - 2:7 and Outer = 0.
2. Permutation Method, Outer PermBaseSeq = Standard specific and Proposed Shuffle method.
3. Scheduling FCFS and Random.
4. For Even-Group (12 subchannels) and Odd-Group (8 subchannels) subchannels.

Table 6.1: Cell Configuration

Parameters	Values
Cell Structure	6 cell 1-tier
Cell Radius	1Km
User Distribution	Random
Propogation Model	PathLoss
Multiple Access	OFDMA
Effective Bandwidth	20 MHz
FFT Size	2048
Power Distribution	Equal over all subcarriers in subchannel
Scheduling Type	Sequential and Random
Number of data Subcarriers	1680
Number of groups in cell	6
Number of subchannels in group	12/8
Number of subcarriers in a subchannel	24
Subchannel Mode	Downlink PUSC

6.3 Simulation Results and Observations

As shown in Fig.6.5, blue is for the AMC level $M = 1$, thus, more blocking is due to unavailability of the subchannel, as the power transmitted per subchannel is less, thus to satisfy the user's QoS requirement more subchannels will be required. Whereas, for $M = 6$, the blocking is due to more power transmission, which increases blocking due to power constraint and due to interference on subchannels. Allocating smaller AMC level at cost of allocating more sbchannels to the users currently using maximum power for transmission, results into more power saving.

There is more blocking in case if, we choose user randomly for the AMC, i.e., allocating less power and providing more subchannels. But random selection of user for power conservation to handle calls provides less blocking then blocking without using AMC.

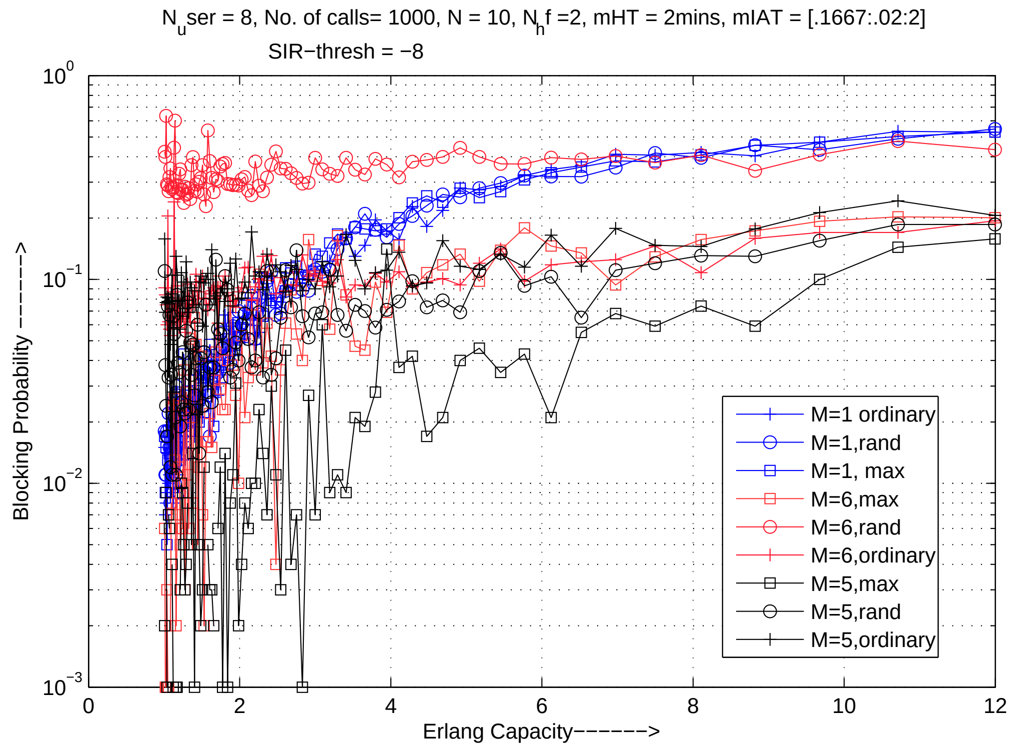


Figure 6.5: Blocking Probability variation with Erlang capacity using power reservation CAC schemes

Thus, AMC provides one more dimension to improve the network performance in terms of call blocking or Erlang capacity. As shown, in the Fig.6.5, its not true in all the cases, that random selection may or may not provide good performance measure as compare to performance measure without using AMC. Which is shown for $M = 1$, as maximum and minimum power required for the users in the cell is same.

As shown in Fig.6.6, that inter base station co-ordination provides traffic information for the interference management in the cell, so as to reduce, the inter cell interference. Thus, interbase station scheduling is combined with the power reservation for CAC.

Fig.**??**, shows the variation of blocking probability with respect to Erlang capacity three different curves corresponds to different number of subchannels, i.e., N=6,8,12, in the presence of inter base station co-odination scheduling and power reservetion for the CAC. We observes that as the number of subchannels increases blocking reduces.

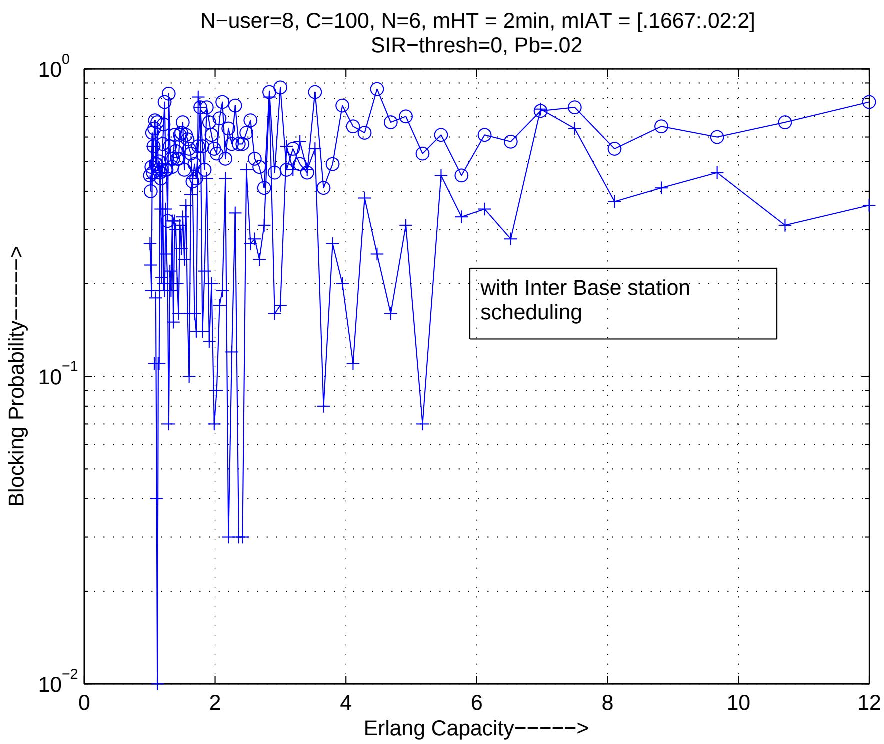


Figure 6.6: Blocking probability variation with respect to Erlang capacity using with or without inter base station co-ordination for scheduling

Algorithm 7 Erlang Capacity of OFDMA 802.16 Systems

For each cell in the system;
DSM Subchannelization
Apply **Outer** and **Inner** permutation for subchannel using above algorithm.
Apply Traffic model Poisson arrival process and exponentially distributed service time for each of the request in the cell.
Communicated the arrival instants, call duration and subchannel allocation of each of the request to the neighboring cell for interbase station co-ordination scheduling in order to reduce the impact of inter cell interference.
Erlang Capacity of the Reference Cell
Set **N** number of subchannel, for each call service time is **mHT** mean Holding Time and **mIAT** is the mean Inter Arrival time are exponentially distributed, because calls are with poisson arrival.
Set the **arrInst** each call and **termInst** of each call. Following is the check for whether the subchannel is engaged or not
For each user request calculate the number of subchannel required by $N_i = R_i/(DR(MC_i) * B_0)$, **N**
if arrInst $<$ **SubchannTime then**
  Subchannel is currently in use either by the reference cell or by neighboring cell
  if the subchannel used in the neighboring cell **then**
    then calculated SIR on it, and if SIR is more then threshold, call is served.
  else
    Hard Blocking: if the subchannel is used in the reference cell, then call will be blocked. (all the sbchannels are in use)
  end if
  Hard Blocking: current subchannel is servicing call, go to the next subchannel **N** = **N+1**.
else
  Soft Blocking: check for the Interference from the near by cell for **Soft Blocking**
  if subchannel then
    == **0**, as per the scheduling i.e., if the current channel is not used for the reference cellthen interference , on that subchannel will be less and SIR, calculated will be maximum.
  else
    Interference is measured on the subchannel, thus SIR, is calculated on it.
    calculate **SIR** using Pathloss Model for interference calculation
    if SIR $> SIR_{thresh}$ **then**
      Call is **Served SubchannTime** = **TermInst** of a call.
    end if
  end if
end if
To Check the call blocked
if Call is **NotServed then**
  Blocked = **Blocked** **+1**;
end if
To calculate Erlang Capacity **ErC**
if Blocked == .02 **then**
  Erlang Capacity **ErC** = $\lambda\mu$
end if

Chapter 7

Optimal Power Reservation based Call Admission Control

7.1 Introduction

In the previous chapter, we have proposed a heuristic to minimize the power at the base station in order to reserve it for the handoff calls. Power reserved for handoff calls is used to admit hand off calls using AMC. In this chapter, we formulate and solve the optimization problem, to maximize the Erlang capacity using power reservation. In the next section, we formulate the problem and solve it using optimization techniques.

7.2 Problem formulation

We consider the problem of resource allocation in the downlink of cellular OFDMA systems. In principle, performing resource allocation for cellular OFDMA systems requires solving the problem of power and subcarrier allocation jointly in all the considered cells, taking into consideration the interaction between users of different cells via multicell interference. In this chapter, we determine the optimal algorithm, using the lagrangian optimization technique. Following is the optimization problem:

$$min(\sum_{i=0}^{M} P_i) \tag{7.1}$$

subject to

$$P_i = N_i * F(MC_i), \tag{7.2}$$

where,

$$N_i = R_i/DR(MC_i) * B_0, \forall\ i(7.3)$$

$$\sum_{i=0}^{M} N_i \leq N. \tag{7.4}$$

In the above problem formulation, we minimize power allocated to the i^{th}, user denoted by P_i. Total power transmitted by the base station is the summation of all the active users' power. Power allocated to the user is the product of the number of subchannels N_i allocated to the user as per the assigned AMC. The power allocated per subchannel is $F(MC_i)$, as shown in Table-2.2. Here MC_i is the modulation level assigned to a particular user. B_0 is the bandwidth per subchannel. In the fomulation, we put a constraint on the total number of subchannel in the system.

Thus, for the efficient resource allocation in 802.16e cellular systems, instead of reserving subchannels for the handoff calls, power is reserved and all the subchannels are used for the ongoing calls. Thus, we need to minimize the power for ongoing calls in order to reserve it for the handoff calls. The performance measure used to evaluate of the proposed algorithm is the blocking probability and the Erlang capacity.

Interference on all the subchannels is the same, $f(MC_i)$ is the threshold to maintain BER. From [13], for any modulation the transmit power and constellation size are adapted to maintain a given

1. Instantaneous BER or

2. Average BER

1. Instantaneous BER

The bit error rate is approximated as[2][3]

$$P_b(\gamma) \approx c_1 exp[\frac{-c_2\gamma\frac{S(\gamma)}{S}}{2^{c_3 k(\gamma)} - c_4}] \tag{7.5}$$

where c_1, c_2, and c_3 are positive fixed constants, and c_4 is a real constant.

Therefore $k(\gamma)$ is given as follows:

$$k(\gamma) = \log_2 M(\gamma) = \left\{ \begin{array}{cc} \frac{1}{c_3}\log_2\left[c_4 - \frac{c_2\gamma}{\ln\frac{P_b}{c_1}}\frac{S(\gamma)}{S}\right], & S(\gamma) \geq 0, k(\gamma_0) \geq 0 \\ 0, & otherwise \end{array} , \right\} \tag{7.6}$$

2. Average BER

In this section, instead of fixing the instantaneous BER, we will fix average BER. In addition to adapting rate and power, we can also adapt the instantaneous P_b subject to the average constraint P_b.

Spectral efficiency $DR(MC_i)$, for multi-level modulation is given by:

$$\frac{R}{B} = k(\gamma) = \log_2 M(\gamma) \tag{7.7}$$

For continuous rate adaptation the spectral efficiency is given by:

$$\frac{R}{B} = \int_0^\infty k(\gamma)p(\gamma)d\gamma \quad bits/s/Hz \tag{7.8}$$

For discrete rate adaptation the spectral efficiency is given by:

$$\frac{R}{B} = \sum_{i=0}^{N-1} k_i \int_{\gamma_i}^{\gamma_{i+1}} p(\gamma)d\gamma \quad bits/s/Hz \tag{7.9}$$

where N is number of fading regions. In this thesis, we consider instantaneous $f(MC_i) = \gamma\frac{S(\gamma)}{S}$ SNR threshold to maintain instantaneous BER, It is given as follows:

$$P_b(MC_i) \approx c_1 exp[\frac{-c_2 f(MC_i)}{2^{c_3 k(MC_i)} - c_4}], \tag{7.10}$$

where, $c_1, 0 \leq c_2 \leq 1, 1 \leq c_3 \leq 2$ and $-1 \leq c_4 \leq 1$, all depend on the modulation index.

$$f(MC_i) = -\frac{1}{c_2} ln(\frac{P_b}{c_1})(2^{c_3 k(MC_i)} - c_4), \tag{7.11}$$

In our case,

$$\frac{R}{B} = k(MC_i) = \log_2 M(MC_i) \tag{7.12}$$

7.3 Optimal solution

For each user i, the optimization function to minimize power is given as:

$$min(\sum_{i=0}^{M} P_i). \tag{7.13}$$

Thus, by applying eqn. 7.11, the objective function can be written as:

$$min(\sum_{i=0}^{M} N_i * F(MC_i)) = \sum_{i=0}^{M} N_i * \frac{f(MC_i) * (\eta + I_i)}{G_i} = \sum_{i=0}^{M} -\frac{(\eta + I_i)}{G_i} \frac{1}{c_2} ln \frac{P_b}{c_1} (N_i (2^{k_{1i}/N_i} - C_4)), \tag{7.14}$$

where, $k_{1i} = c3 * R_i/B_0$, $P_b = 10^{-6}$, is to be maintained for each user i. The minimization problem with inequality constraint can be modelled as a nonlinear programming problem. This can be solved by using the lagrangian optimization method. For an optimal solution to exist, we apply the following KKT conditions:

Necessary conditions

Suppose that the objective function, i.e., the function to be minimized, is f : $\mathbb{R}^n \rightarrow \mathbb{R}$ and the constraint functions are$g_i : \mathbb{R}^n \rightarrow \mathbb{R}$ and $h_j : \mathbb{R}^n \rightarrow \mathbb{R}$. Further, suppose they are continuously differentiable at a point x^* . If x^* is a local minimum that satisfies some regularity conditions, then there exist constants μ_i $(i = 1, \ldots, m)$ and λ_j $(j = 1, \ldots, l)$ such that

1. Stationarity:
   $\nabla f(x^*) + \sum_{i=1}^{m} \mu_i \nabla g_i(x^*) + \sum_{j=1}^{l} \lambda_j \nabla h_j(x^*) = 0,$

2. Primal feasibility:
   $g_i(x^*) \leq 0,$ for all $i = 1, \ldots, m.$
   $h_j(x^*) = 0,$ for all $j = 1, \ldots, l$

3. Dual feasibility:
   $\mu_i \geq 0$ $(i = 1, \ldots, m)$

4. Complementary slackness:
   $\mu_i g_i(x^*) = 0$ for all $i = 1, \ldots, m.$

Applying above KKT conditions on proposed nonlinear problem having:

1. Objective Function: In case of non linear objective functions, the lagrangian method is applied. A solution exist if and only if the function is convex, i.e., first derivative is zero at optimal point and the double derivative is positive. Thus, for the above given objective function optimal solution exists.

2. Constraint: For the inequality constraint in the optimization problem, there is an associated lagrange multiplier λ, which should be positive.

By applying above conditions:

$$\frac{(\eta + I_i)}{G_i}\frac{1}{c_2}ln\frac{P_b}{c_1}((1 - \frac{k_{1i} * ln2}{N_i}) * 2^{\frac{k_{1i}}{N_i}} - c_4) = \lambda \tag{7.15}$$

Where,$P_b = 10^{-6}$, and $k_{2i} = -\frac{(\eta+I_i)}{G_i}\frac{1}{c_2}ln\frac{P_b}{c_1}$, thus,

$$k_2((1 - \frac{k_{1i} * ln2}{N_i}) * 2^{\frac{k_{1i}}{N_i}} - c_4) = \lambda \tag{7.16}$$

$$(1 - \frac{k_{1i} * ln2}{N_i}) * 2^{\frac{k_{1i}}{N_i}} = \frac{\lambda}{k_{2i}} + c_4, \tag{7.17}$$

applying, $N_i = \frac{R_i}{B_0 * log2(MC_i)}$

$$(\frac{6 * ln(c_1)}{\lambda * c_2})((1 - c_3 * ln(MC_i)) * (MC_i)^{c_3} - c_4) = \frac{G_i}{\eta + I_i}, \tag{7.18}$$

First derivative of the lagrangian does not have a closed form solution. The values of the constants are not known, thus, to determine their values, we plot the above result. As shown in Fig.7.1, the modulation index variation is plotted as a function of the ratio of pathloss gain to that of noise and interference. In this plot, we assume $K = \frac{6*ln(c_1)}{\lambda*c_2} = 10$. We plot the modulation index variation is plotted as a function of the ratio of pathloss gain to that of noise and interference for different values of k, as shown in Fig.7.2. From this, we can conclude that greater the value of k, higher is the scaling of the modultaion index and pathloss gain to noise to interference ratio.

As shown in Fig.7.1 and Fig.7.2, we observe that the modulation index varies inversely with respect to pathloss gain and noise to interference ratio. As the ratio of pathloss gain to noise and interference increases, the modulation index decreases. This is similar to Channel Inversion. Therefore, smaller modulation index is allocated to the users who are nearer to the base station. Thus, by using this alogrithm, with the adaptive modulation, we allocate more number of subchannels and less power per subchannel to maintain BER (10^{-6}) and QoS (user data rate), requirement of a user.

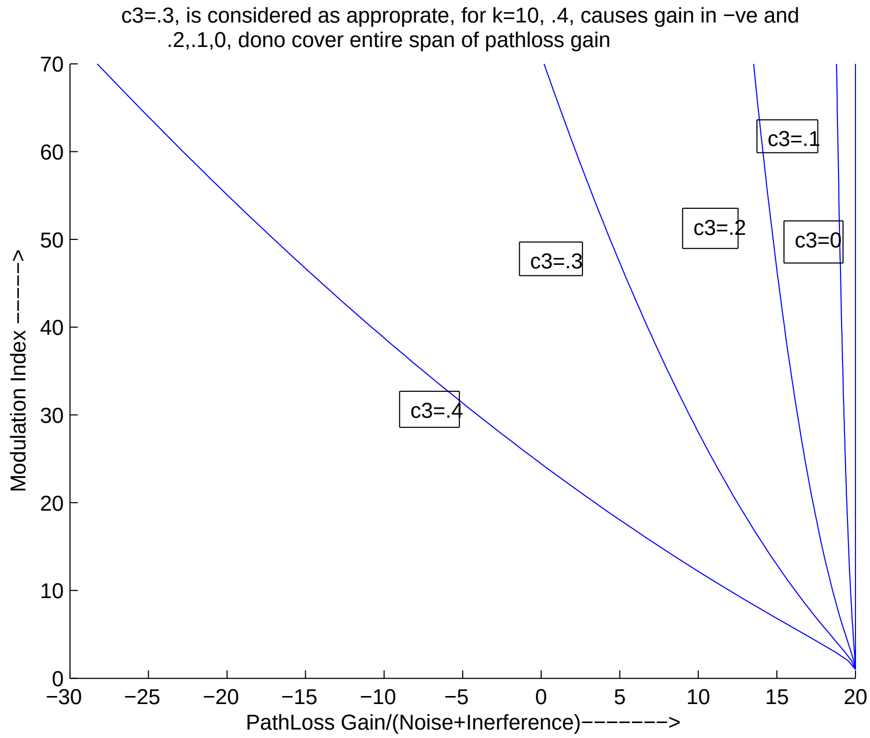


Figure 7.1: Variation of modulation index with ratio of pathLos gain to that of noise and interference

7.4 Erlang Capacity calculation using Optimal Call Admission Control

In this section, we evaluate the optimal power reservation based CAC algorithm by calculating Erlang capacity. As shown in Fig.7.3, Erlang capacity is calculated using blocking probability $P_b = .1$. We observe an improvement of 25%, for the optimal algorithm as compare to the heuristic CAC algorithm for $AMC = 3$. As shown in Fig.7.4, we observe an improvement of 90%, for $AMC = 5$. Therefore, the optimal CAC is better than the heuristic in the previous chapter.

7.5 Conclusion

The optimal power reservation based CAC provides 90% improvement over the heuristic power reservation based CAC with AMC level 5. With AMC level 3 an improvement of 25% is observed. The result of the optimal power reservation CAC is similar to Channel Inversion. In Channel Inversion, more power (higher level modulation index) is allocated

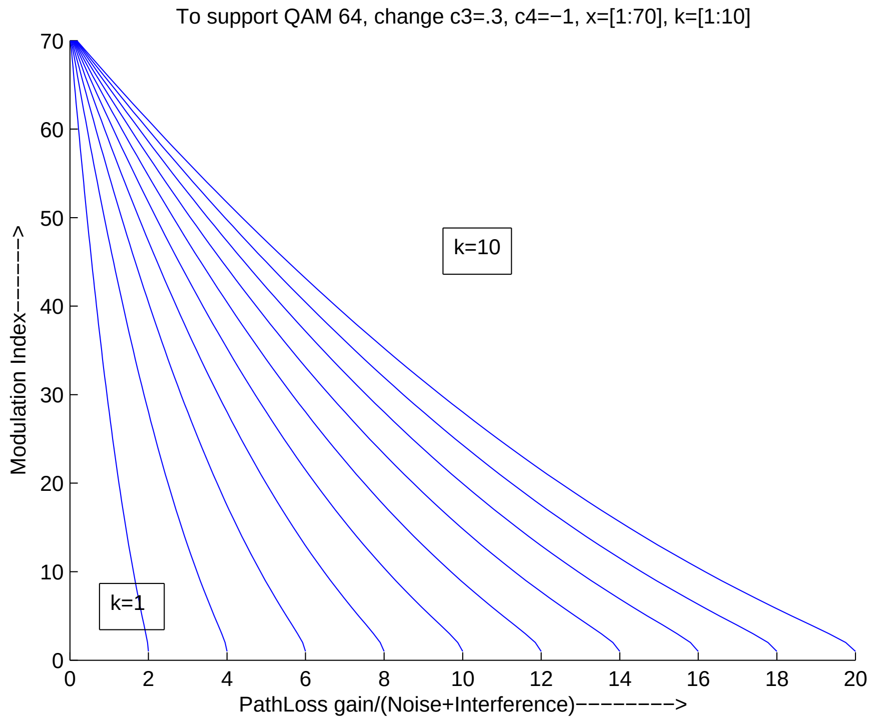


Figure 7.2: Variation of Modulation Index, with respect to pathloss and noise interference ratio, by varying k value

to the user who is far from the base station and vice versa. When a call is admitted in the reference cell, the base station checks for the availability of power reserved for handoff calls. If power is available, then, additional power is allocated to distant users in exchange of some subchannels, which are now allocated to the admitted handoff call. If the power is not sufficient to admit the call, then it is blocked. From the observations we conclude that, Erlang capacity of the IEEE 802.16e cellular networks is improved by using optimal power reservation CAC.

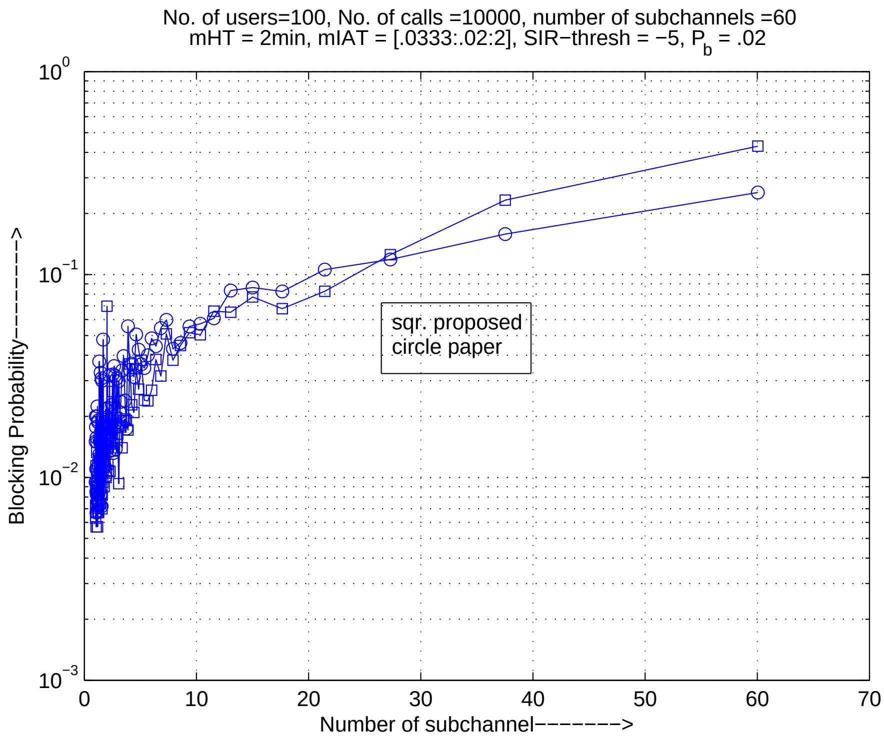


Figure 7.3: Variation of Blocking probability with number of subchannels for AMC=3

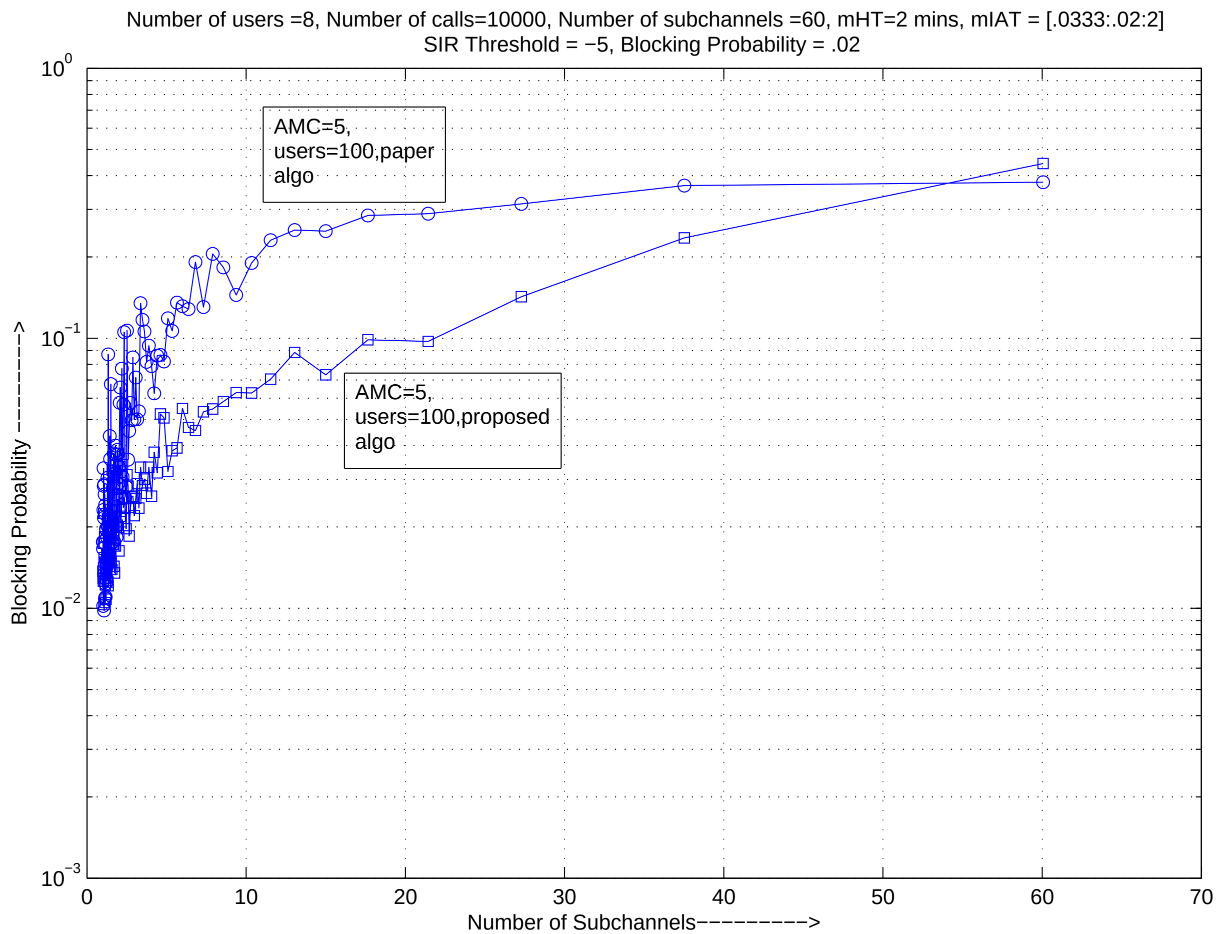


Figure 7.4: Variation of Blocking probability with number of subchannels for AMC=5

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