Inter-cell Interference Coordination in Indoor LTE Systems

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Master thesis

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Abstract

Inter-cell interference coordination in 3GPP Long Term Evolution system received much attention in recent years. However, most of the studies are based on ideal system with regular hexagon-shaped cell. The indoor environment has special characteristics that the building shape and BS locations are irregular; the traffic load has great variation compared to urban and rural area. So, conventional ICIC scheme may not be used in indoor situation directly. In this thesis, ICIC scheme is employed for indoor environment. Based on different quality of backhaul, static and dynamic schemes will be proposed. The performances of proposed schemes and the performance of system without ICIC will be simulated and compared. At last, how much the improvement of the system can acquire after applying ICIC schemes will be analyzed, and the question about whether it is good to apply ICIC scheme in indoor environment will be answered.

Keywords: Inter-cell interference coordination, LTE, SFR, indoor environment, traffic load, dynamic, throughput, OFDMA, edge user.

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Terminology

Abbreviations

3GPP	3rd Generation Partnership Project
AFR	Adaptive frequency reuse
BS	Base Station
DL	Downlink
EDGE	Enhanced Data rates for GSM Evolution
eNB	evolved Node B (eNode B)
FFR	Fractional frequency reuse
GSM	Global System for Mobile Communications
ICIC	Inter-Cell Interference Coordination
LTE	Long Term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PFR	Partial frequency reuse
SINR	Signal to Interference plus Noise Ratio
SISO	Single Input and Single Output
SFR	Soft Frequency Reuse
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System

1. Introduction

3GPP Long Term Evolution (LTE) is the latest standard in the mobile network technology tree that produced the GSM/EDGE and UMTS/HSxPA network technologies.[1] The target of LTE includes peak data rate in excess of 100Mbps for DL with 20MHz, improved spectral efficiency and the improved cell edge performance.[1]

LTE uses orthogonal frequency division multiplexing (OFDM) as modulation scheme and orthogonal frequency division multiple access (OFDMA) as multiple access scheme.[2] In OFDMA system, the spectrum is divided to a large number of sub carriers. Since those sub-carriers are orthogonal with each other, there is no intra cell interference. The inter cell interference is particularly detrimental for mobiles located at cell boundaries.

There are many ways to decrease the inter-cell interference and improve the system performance especially the cell edge performance, such as ICI coordination, ICI cancellation, and ICI randomization. Since ICI coordination scheme has been widely used in LTE system and has a good development, it is studied in this thesis to find out whether it is suitable to be employed in indoor environment. First, existing ICIC schemes will be reviewed. Then, one or several schemes will be chosen and modified to allow an irregular cell deployment in the indoor scenario. The performance of the proposed schemes will be examined by simulation experiments. At last, the performance of the system with the proposed schemes and without using ICIC scheme will be compared and how much improvement can be expected after operating ICIC scheme in indoor environment will be find out.

1.1. Background

There are already many researches in ICIC. The basic idea is Fractional frequency reuse (FFR) which offers a simpler alternative to the frequency reuse problem in multi-cell OFDMA networks. The user is divided into two group, center group or edge group. Often, FFR is thought to be static, which means the boundary between center and edge is statically set on the SINR threshold or the distance between the serving BS and UE. To adopt with new systems with high requirement, some variations of FFR are proposed. One is called SFR (soft frequency reuse) scheme, which is proposed in [3]. In this scheme, sub-carriers are divided into two groups in every cell. “One group is called major sub-carriers group, and the other one is called minor sub-carriers group.”[3] The major sub-carrier is allowed to cover the whole area, while the minor one can only be used in the inner part of the cell area. Different from the conventional FFR, SFR can adapt the variation of the service distribution in each cell by adjusting the power ratio. It gives better performance than purely static coordination because of the changing UE traffic and throughput requirements characteristics. There are many other schemes proposed such as adaptive frequency reuse schemes [4, 5], dynamic ICIC schemes [6] and graph-based approach. In [7, 8, 9, 10], they give a good collection and conclusion.

However, all previous studies of ICIC schemes are based on the assumption of regular hexagon-shaped cells or stable traffic load. In realistic radio environment, the perfect cell shape and distribution almost cannot exist. Especially in indoor situation, the cells often have their own sizes and shapes which may be quite different from each other according to the architecture structure and the stop of walls. The existing ICIC schemes may not get expected performance; some even cannot be utilized. Under the circumstances, more complicated assumption was considered when study the ICIC scheme.

In [11, 12, 13], the performance of SFR and FFR in urban area with irregular shape is analyzed. It makes further step of studying ICIC but there are still obvious limitation. The result they got is based on stable traffic load.

So, a study about ICIC scheme focus on indoor environment is studied in this thesis.

1.2. Problem formulation

The indoor situation has two main characteristics. The first one is the irregular cell shape and BS locations. The second one is the huge variation and asymmetry in traffic load. These two characteristics increase the requirement and complexity when operating ICIC scheme in the system. Meanwhile, the performance of indoor system after employing ICIC scheme is an unknown value.

Backhaul capability may affect the ICIC also. To propose ICIC schemes considering different connection situations between BSs, the schemes can be modified in variations of ways.

If there is an existing scheme, or the existing scheme with a little modification which can be used in indoor environment simply, it is called static scheme for the moment. The proposed scheme considering different backhaul capability and with better expected performance called dynamic scheme. The research questions are as following.

- Whether static scheme is good to be used in indoor environment with irregular cell shape and asymmetry traffic load?
- If better performance is expected when operating dynamic scheme, how much improvement the dynamic scheme can achieve?

The concrete processing steps are as follows: First of all, existing ICIC schemes will be reviewed to find out whether there is an existing scheme can be used in indoor situation directly. Second, ICIC scheme for indoor environment is developed, to employ existing scheme or with modification if possible. Then, the proposed scheme will be examined by simulation tool. The performances of proposed schemes and the performance of system without ICIC will be compared. How much improvement the system can acquired after using ICIC will be analyzed at last.

The performance metrics are the average throughput of total users and the average throughput of user with bad communication quality.

1.3. Overall aim and contribution

The overall aim of this project is to find out whether it is good to operating ICIC scheme in the indoor environment and how much the system performance can be improved after using ICIC scheme compared to without using ICIC scheme. If there is a proposed scheme, it should have a complete model and have reasonable parameter settings so that it can achieve higher total throughput, better fairness and an acceptable payload for the server. The scheme will be simulated in dissimilar environments with different traffic load to give a final conclusion.

The novelty of this thesis is that this is the first time to study the ICIC scheme in indoor environment and there is no such research yet. The contribution of this thesis is to find different ways to achieve ICIC in indoor environment and estimated each performance. Since the study emphasis is the ICIC in indoor LTE system, performances of different schemes in indoor system will be compared. There is no comparison between ICIC in indoor system and ICIC in outdoor system.

1.4. Scope

This study focuses on the indoor situation. It is assumed that no interference coming from outside of the building. The number of cells and shape of cover area may quite different with each other because of given building structure. Since the performance depends on geometry parameters, different kinds of situation should be considered to give out an objective conclusion. There are two different building structures with limited number of BSs be simulated. The emphasis is the frequency scheduling.

Also, only downlink is considered in this thesis. The uplink is not talked about and it is assumed that each user occupies the sub-band with same bandwidth no matter how many users there are in a cell.

At last, snapshot-based Monte Carlo simulation is adopted which means the performance in one frame is considered, and it is system level simulation.

1.5. Outline

Chapter 1 describes the background, aim, scope, goals and problem motivation. Chapter 2 contains the related work, which includes the theoretical basis, the contrast of different existing ICIC schemes and so on. Chapter 3 proposes several ICIC schemes and Chapter 4 shows the design of the simulation model. It includes the system assumptions, the model, the calculation process and the parameters and so on. In chapter 5 results are presented. Chapter 6 is the discussion about the project as well as the conclusions and possible future work.

2. Related work

2.1. Existing basic ICIC schemes

Full frequency reuse

Full Frequency Reuse is the conventional way of operating an LTE network. There is no frequency partitioning in wireless network. The sub-channel is randomly distributed to users with uniform power over the entire system bandwidth. The users at cell-edge experience heavy interference from neighboring cells. [8]

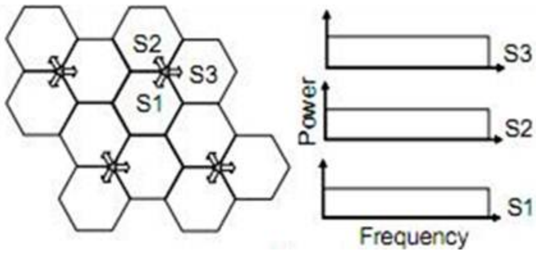

Figure1. Full frequency reuse scheme [14]

Hard frequency reuse

HFR is a way of frequency distribution. Often sub-carriers are divided into disjoint sets, for example three sets as shown in figure2. "These sets of subcarriers are assigned to the individual eNBs in such a way that neighboring cells don't use the same set of frequencies."[8] Since there is no interference from neighbor cell, the total interference of the user at cell edge is maximally reduced. However the spectrum efficiency drops heavily which equals to the reuse factor.

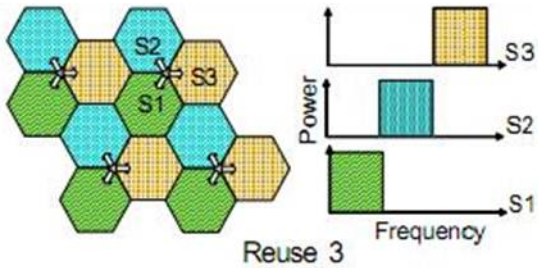

Figure2. Hard frequency reuse scheme with reuse 3 [14]

Partial frequency reuse

Partial frequency reuse is also named as FFR in some papers, for instance in [8]. As mentioned in section1.1, the users are divided into two group, center group and edge group. The center group is distributed by a frequency band and uses PFR, while the edge groups in each cell use the remaining frequency band and adopted HFR. Figure3 gives an intuition view. Often, it is used in uplink situation.

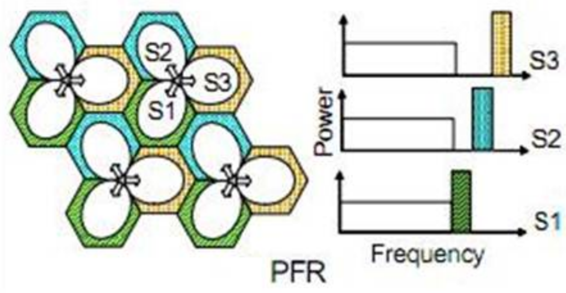

Figure3. Partial frequency reuse scheme [14]

Soft frequency reuse

The traditional SFR scheme is shown in the figure4. Since the cell is symmetric, the cells are often set in three groups. The cell edge users in each group have corresponding frequency band. The cell center users use the remaining frequency bands. It is a variation of FFR and often used for DL. [3]

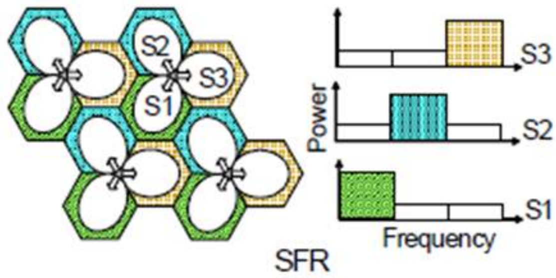

Figure4. Soft frequency reuse scheme [14]

Fractional frequency reuse

FFR is defined as PFR in some papers. In some other papers such as [14], FFR is defined as all the schemes with frequency reuse for cell-edge UEs. Then, SFR and PFR are thought to be two variations of FFR.

Figure5 is the frequency distribution with omnidirectional antenna.

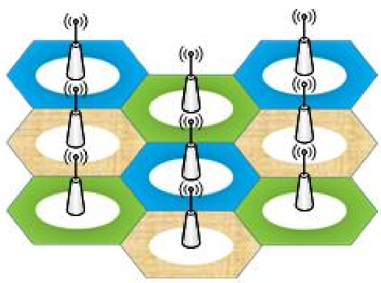

Figure5. Frequency distribution with omnidirectional antenna

2.2. Existing modified ICIC scheme

Adaptive frequency reuse scheme

"One of the main assumptions behind the FFR and SFR schemes is that the traffic load within each cell remains stable throughout the life-time of the deployment."[7] In AFR, the allocation of the frequency is more flexible. For example, if heavy traffic presenting at the cell edge is detected by a cell, more frequency resource can be allocated to the edge clients if it is not for the neighboring cell. For this scheme, some forms of communications are needed. [7]

Two methods for interference avoidance near the cell edge are proposed in [4]. One considers only frequency scheduling coordination and one considers time scheduling coordination combined with frequency scheduling coordination. These two can be thought as an adaptive frequency reuse schemes based on semi-static resource allocation to address the varying traffic loads near the edge of each cell. The simulation result is given in [5].

There are also many other modified schemes proposed in conferences or journals and analyzing ICIC from varied points of view. For example in [15] an adaptive FFR method is proposed. There are fixed number of modes operations; different sectors can obtain different desired coverage gains by using different modes. Figure6 express four modes used in [15].

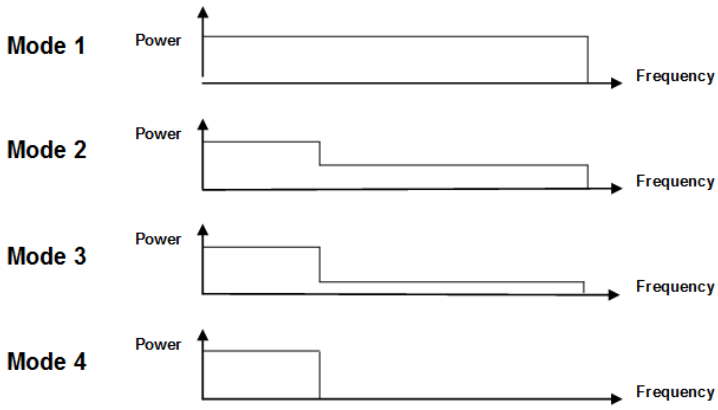

Figure6. Adaptive FFR modes[15]

In [16], the UE traffic is thought to be low enough and the transmission requires a portion of the total system bandwidth. In [17], two algorithms are proposed at base station level and controller level respectively to analyze the co-channel interference.

There are also dynamic ICIC schemes such as [6] and [14] which can achieve higher interference avoidance gain. However, all above schemes are based on the ideal hexagon-shaped cell.

ICIC in system with irregular shape

Very limited studies about ICIC based on irregular shape can be found in the literature. In [11], SFR is employed in urban area with irregular shape. It provides a feasible way about the frequency distribution in the urban area with a large quantity of BSs and cells. [12] analyzes FFR and [13] gives the comparison of the results of [11] and [12]. However, the traffic load is stable in urban area. The way they used in [11] does not consider the variations of traffic load, so it is not applicable for indoor scenario either.

3. ICIC methods for indoor environment

3.1. Without ICIC scheme

“Without ICIC” refers to the conventional way of operating an LTE network. It adopts full frequency reuse which has simple characteristic and is easy to operate. As introduced in the related work, there is no frequency partitioning in wireless network and the sub frequency is distributed to users with uniform power over the entire system bandwidth randomly. This way is simulated in this thesis as a basic comparison to judge whether it is necessary to employ ICIC in indoor situation.

3.2. Static scheme

The static scheme used in indoor situation is almost the same as it is employed in ideal communication environment with symmetric cell shape. Since DL is considered in this thesis, SFR is chosen. The difference is that in irregular system, since the cells are no longer symmetric, existing ICIC cannot be used directly. So, the way to allocate the sub-frequency to edge user and how to ensure the sub-band number become a problem.

As introduced in chapter 1, [11] proposed a way of frequency scheduling. However, that method sometimes is not efficient in indoor situation since the cell quantity is rather small. The coverage of each server is also small and servers are close to each other. Thus, a little difference such as the change of the client’s position or the variation of the traffic load may lead to a quite different result.

So, the first step of applying static scheme is trying to find the assignment of frequency band and other parameters so that the throughput is maximized. Since sub-band number with three (three groups) are often used, and the total amount of cells is rather small, two situations with three sub bands and two sub bands are chosen. Take three sub-bands as an example, each cell will be labeled as one, two, or three. The edge users in cell one can only use the special part of frequency with labeled number one. The center user in cell one will use the remaining frequency. The interference is caused by the users using same sub-band. The total cell quantity is limited, so that the permutation and combination of the frequency allocation can be tried. Several power ratios (power for edge user divided by power for center user) is also considered in. At last, all the possible value of parameters can be simulated to find a so called best combination or best set which gives best result.

The parameters have to be confirmed in static scheme are

- Power ratio
- Sub band number

- Frequency allocation in each cell

A best set of above parameters can be acquired after simulation. However, the best set for system may not always have a single choice, for instance with different traffic load.

It is well known that the interference is growing with the traffic load increasing, so the interference has maximum affection when there is full traffic load. The parameters used in static scheme are fixed as the best set with full traffic load. This time, the best set has a unique value.

A best set is used in a system after the building shape and BS locations are fixed, and these parameters are no longer changed. That is why it is called static scheme in this thesis. The best set for static scheme is given at chapter 5.1.

Static scheme can save the system runtime. It has no requirement of advanced data such as UE's quantity in the system, so the capability of connection between BSs has no affection of this scheme. These are advantages of static scheme.

However, as analyzed before, there may be several choices of best set for different traffic load and varied distribution of UEs, using the best set with full traffic load may not give optimal result. Aim at this problem, a low dynamic scheme is proposed.

3.3. Low level dynamic scheme

The static scheme means that the scheme is only based on geometry. If the server supposes to know the total number of user, a low level dynamic scheme is proposed. It requires the connection between BSs to be reliable and efficient. The low level dynamic scheme is as shown in figure7.

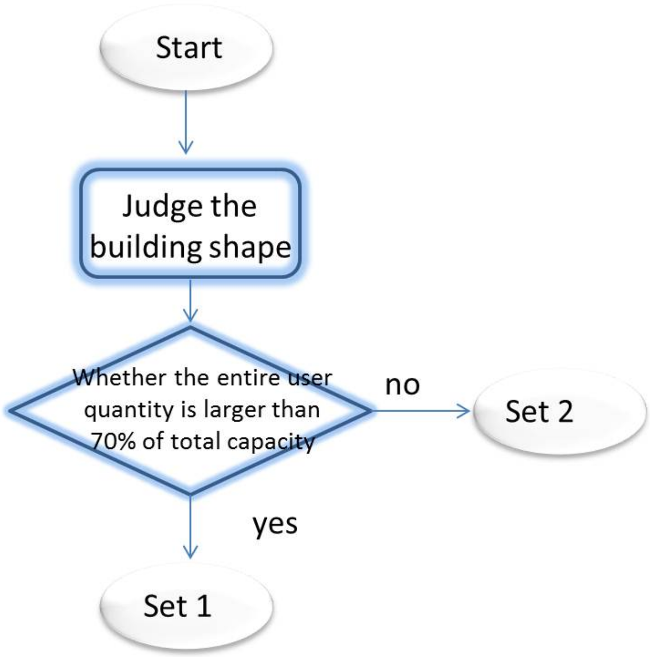

Figure7. Diagram of low level dynamic scheme only based on total user number

If there are two best sets in a system, for example set 1 and set 2, these two sets corresponding to two situations of traffic load, for instance more than 70% of system capacity and lower than 70%. The system can use either set 1 or set 2 as long as the total user quantity is known. Since the best set can changed, it is called low level dynamic scheme. The judge number 70% in the standard can be got according to the simulation result. Other value may chose in different indoor environment. In a same principle, if there are three best sets for one system, the system can use set1, set 2 or set3 according to its own standard of traffic load.

The low level dynamic scheme has a modified edition if the shape of building are absolute symmetric and every cell have fair locations. In this scheme, the servers are supposed to know the total number of users in the system and serving user quantity in each cell. Then, there may be more choices of best set and more judgment condition are existed. As shown in figure8.

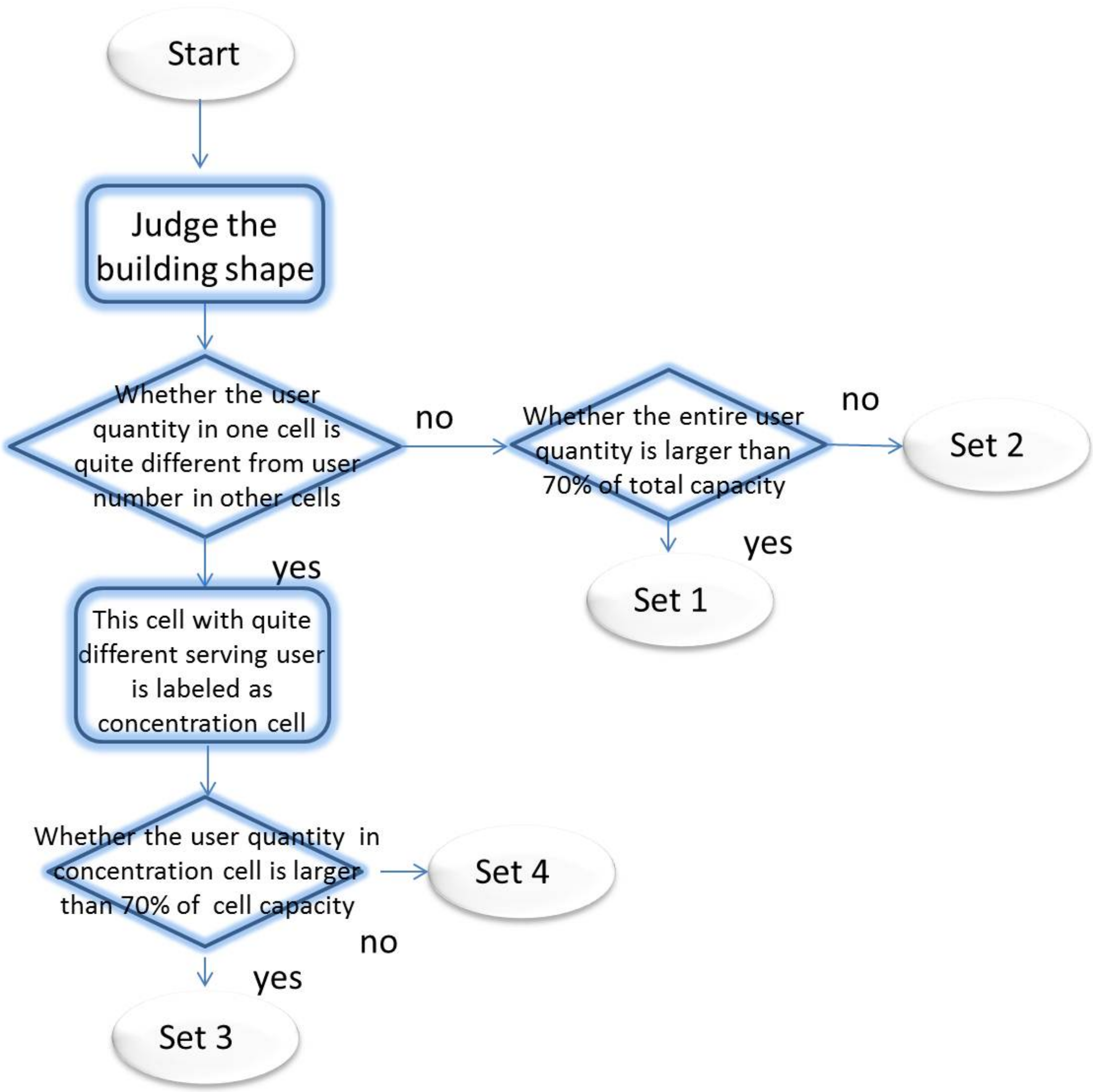

Figure8. Diagram of low level dynamic scheme for symmetric building cell

A judgment of UE distribution is added in figure8. This time, the best sets increases from two to four. More choices of best sets indicate more accurate expression of system. The judgment number 70% and best sets from set1 to set4 should be calculated by simulation tool in advance too.

The limitation of this edition of low level dynamic scheme is the fair location of cell. For example, figure10 in chapter4 is qualified, while figure9 is not. That is because the server in center location in figure9 produces larger interference to other cells than the servers in wing positions. Under this circumstance, the judgment of concentration cell cannot be used.

So, the low level dynamic scheme has a basic edition that only the total traffic load is used and a modified edition that for symmetric building cell with fair location. The low level dynamic scheme based on long term channel condition and instantaneous traffic load. It can be finished in an absolute limited time at the start of any frame.

3.4. Intermediate level dynamic scheme

Low level dynamic scheme bases on geometry and UE quantity. If the building has complicated shape or the distribution of users is quite a chaos, there maybe not a best set existing any more. Or the best set can be got under some special cases, such as homogeneous traffic load. Then, even if the server gets the information of all serving-user's quantity in other cell, the low level dynamic scheme cannot work perfect without a best set or with a best set under special cases.

To have a complete resolution, an intermediate level dynamic scheme is proposed.

In intermediate level dynamic scheme, the backhaul connection is still supposed to be reliable and efficient. Except for this, the server is assumed to have strong calculation ability. The locations of all BSs should be known in advance. All the requiring data to support intermediate dynamic scheme include the serving-user's quantity in each cell and locations of users in its own cell. The last condition can be easily achieved as long as some location bits added in the packet.

After the server gets this information, it analyzes the data at the server termination. The serving user is given sub channel then several typical combination of set is attempted. It can calculate suitable parameters by itself and escape the limitation of using the known best set in low level dynamic scheme. It can also solve the problem in case there is no best set for some special cases. The parameters that intermediate level dynamic scheme has to decide are still power ratio, sub band number and frequency allocation in each cell. Since the optimal values of parameter are assured to be decided, much better throughput is expected.

It is same with low level dynamic scheme; it is also based on long term channel condition and instantaneous traffic load.

3.5. High level dynamic scheme

All the schemes above do not consider the channel condition. A high level dynamic scheme is proposed under the circumstance that the condition of channel can be detected.

Considering there is Rayleigh fading, the channel condition may change a lot over time. If a pilot packet is send to the system and the real time channel condition can be detected, an even better performance can be expected. Because not only the parameters in best set (power ratio, the sub band number and allocation of frequency) but also the number of sub channel for each user can be modified. For example if the user with low SINR can get twice or even wider frequency band than normal user, quite large improvement can be expected. This part exceeds the coverage of this thesis and will be discussed in the future work.

4. Simulation model

4.1. Indoor environment

The main characteristic of indoor situation is irregularity. The irregularity here has the following meanings. First, since the indoor situation is considered, due to the architecture of the building and the obstacle of wall, the deployment of base stations is always irregular. Accordingly, the shapes of service area are different with each other. The location of the BS is another significant deciding factor in the system model. Second, the personnel fluidity is relatively bigger in indoor situation than in other situations. The dynamic of traffic load must be considered. Both homogeneous and heterogeneous traffic load and different spectrum occupancy probability all has to be considered.

To simulate the indoor situation, a corridor with special shape is assumed. A cross corridor as shown in following is used as an example.

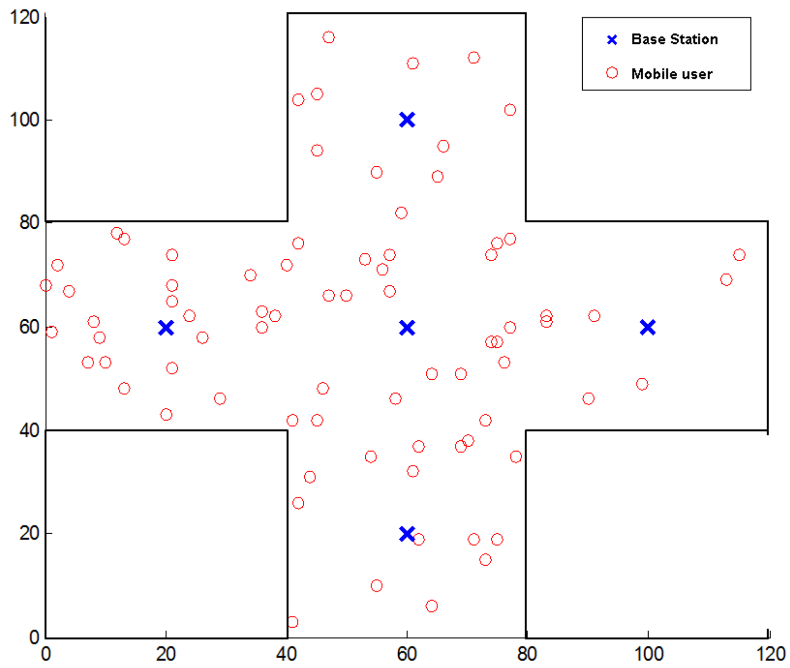

Figure9. First map of BSs and UEs

As shown in figure9, the blue x represents the base station. The red circles represent the mobile users which are distributed randomly. In realistic situation, the base station is often set in the center of an area to guarantee better coverage. If there are walls in the transmission path, different equations will be used. Since the walls lead to significant fading of the signal, the affection of the walls cannot be omitted. Also, different shapes of corridor and different distribution of base stations will be employed when verifying the ICIC scheme to give an overall result. As shown in figure10.

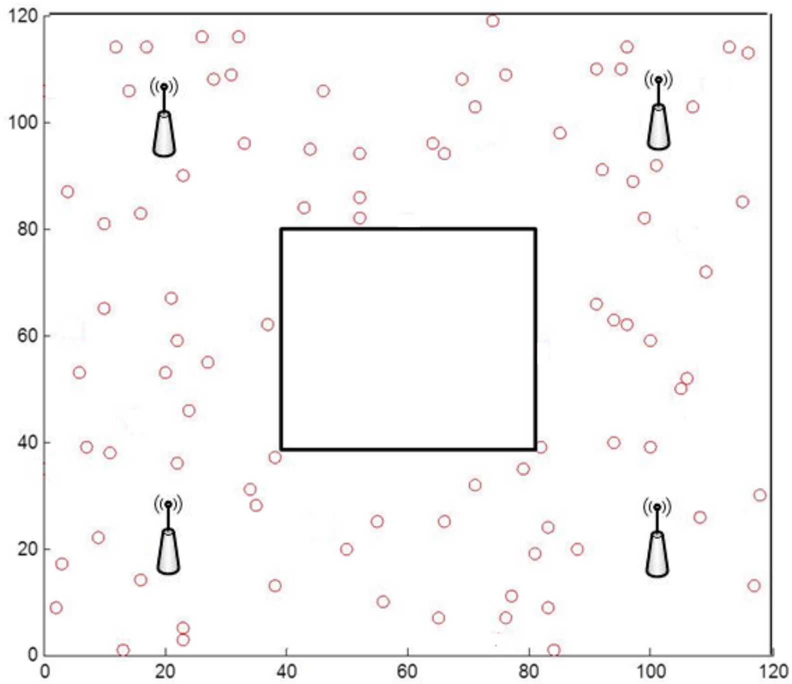

Figure10. Second map of BSs and UEs

These two shapes of building are used because they represent two typical scenarios. In figure10, all the BSs have fair locations which mean that the cell areas are absolute symmetric and every cell has two neighbouring cells. While in figure9, the cell in center location has four neighbours yet the cell in wing position has only one neighbour.

Available frequencies are assumed to be reused in each cell. Both the transmit antennas of BS and the mobile user's receive antennas are considered to be omnidirectional. SISO system will be used and only DL is considered in this thesis. The base station which can provide best channel (SINR) is the serving BS of the user. In each cell, the user can be determined as an edge-user or a center-user according to a SINR threshold.

4.2. Variations of traffic load

In this thesis, different kinds of traffic load is defined and applied in the system to estimate every scheme.

Uniform:

Uniform traffic load is also called homogeneous traffic load which means the serving user number is same in every cell.

This is an ideal model and can be employed with low level dynamic scheme directly. In real system an absolute uniform traffic load cannot happen in most of cases. However, in indoor situation it can reply the reality in some point of view. For example, at the time of study in the university the traffic load is supposed to be more than 80% in every classroom. At lunch time, the traffic load probably decreases to 30%. After school, it may drop to 10%, for only quite a few of students left in the classroom and study by themselves.

Concentration:

Concentration traffic load is a special situation of heterogeneous traffic load. The user concentrates to one cell. Of course, some users still need to stay in their own cell else there is no inter-interference at all.

In this thesis, this part is also set as an ideal model that the concentration traffic load has variation degree from 10% to 100% and the other cell has around 20% UE traffic. It is a reasonable model, for example in an office building, during meeting time, a great number of people gather to a conference room. There will be people left in their own cell because maybe not all the people need to be present in that meeting.

Chaos:

Chaos traffic load can also be considered as heterogeneous situation. This time, there is no regular for the client’s distribution. The users exist in each cell randomly. Chaos complies with the reality, so it can verify the scheme in a most accurate point of view.

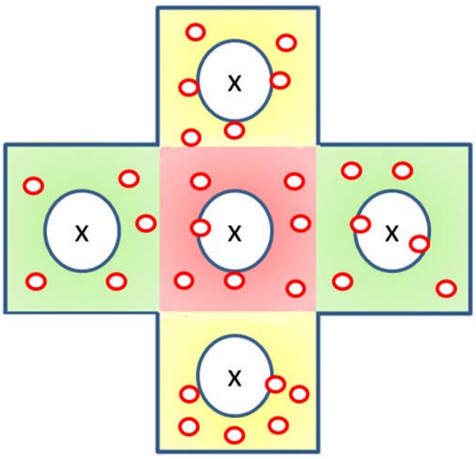

Figure11(a).Best frequency allocation with homogeneous traffic load

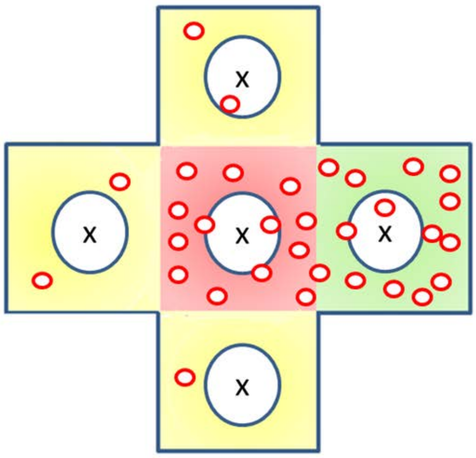

Figure11(b). Best frequency allocation with heterogeneous traffic load

There are two figures that can illustrate the necessity of analyzing both homogeneous and heterogeneous situations more clearly. Figure11(a) is an example of homogeneous traffic load, while Figure11(b) is an example of concentration client’s distribution. It can be clearly observed that, even if only sub-band number equals three is considered, the best choice of frequency allocation is still different. The other parameters such as power ratio may have different values too.

Variation of traffic load is a significant factor in dynamic scheme which is not well studied in existing paper either.

4.3. Path loss model

The path loss model in indoor situation is as follows [18]:

$$PL(\mathrm{dB}) = 16.9\log_{10}(d[m]) + 46.8 + 20\log_{10}(f[GHz]/5) \quad (1)$$

If there are walls in the transmission path, $5n_w$ will be added. n_w is the number of walls between base station and mobile user.

PL is short for pass loss. d[m] represents the distance between UE and BS with unit in meter and f[GHz] means the carrier frequency with unit in GHz.

4.4. Rayleigh fading model

To simulate the randomness of signal magnitude after it passed through a transmission medium, Rayleigh fading model is used. Rayleigh fading model has significant effect on propagation environment on a radio signal. If there is no dominant line of sight propagation between the transmitter and receiver, it is used. The envelope of the channel response approximately obeys Rayleigh distribution.

The Rayleigh probability density function is

$$f(x) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2} (x \geq 0) \quad (2)$$

If received power is supposed as a random variable R,

$$p_R(r) = \frac{2r}{\Omega} e^{-r^2/\Omega}, r \geq 0, \Omega = E(R^2) \quad (3)$$

Equation (2) and (3) is according to [19].

4.5. SINR threshold

SINR threshold is used to distinguish edge user and center user. The user is set to be edge user if its SINR is below the threshold, thus it can acquire a higher transition power. The threshold has a basic value that can be used as standard in first turn. After first turn, if most of the users are set as one type (cell center or cell edge), which exceed the capacity, the system will start a modification algorithm with which the users will be sorted by SINR. The threshold can increase or decrease to make the number of edge users and center users balanced.

4.6. Calculation process

Suppose p_e is power for edge user and p_c is the power for center user. Let power ratio $\alpha = pe/pc$ is bigger than 1. There are K sub-bands in total in one cell. If cell i and cell j are labeled with same number, we write $Ci = Cj$, else, we write $Ci \neq Cj$. The total gain between cell antenna of i and user with sub-band k is denoted as g_{ik} .

The SINR of the cell edge user is

$$SINR_{ik} = \frac{p_e g_{ik}}{\sum_{Cj=Ci, i\neq j} p_e g_{jk} + \sum_{Cj\neq Ci, i\neq j} p_c g_{jk} + \sigma^2} \qquad (4)$$

i means the serving cell, k is the number of sub-band frequency. σ^2 is noise effect.

To talk about SINR of the cell center user, an array about antenna's power is given. The data has only two value p_e and p_c . We use p_{ik} to present the power in each cell and each sub-band.

The SINR of the cell center user is

$$SINR_{ik} = \frac{p_c g_{ik}}{\sum_{Cj=Ci, i\neq j} p_{jk} g_{jk} + \sigma^2} \qquad (5)$$

Equation (4) and (5) is modified from [20], and Shannon equation (6) is according to [19].

The total throughput of the system and the throughput of edge user can be calculated according to Shannon formula.

$$R\max = B * \log_2(1 + SINR) \qquad (6)$$

SINR limit

Usually, according to the limitation of hardware technique, the devices such as the mobile phone cannot support a too much high SINR. In other word, there is always a maximum throughput that the devices can handle. If there is limitation in effective SINR γ_{lim}, the real SINR can be calculated by equation as introduced in [21]:

$$\frac{1}{\gamma_{\text{real}}} = \frac{1}{\gamma_{\text{lim}}} + \frac{1}{\gamma_{\text{ideal}}} \qquad (7)$$

4.7. System parameters

The shape of building is assumed to be 120 meter long and 120 meter wide. The distance between each BS is from 40m to 80m which is approximately agreed with the requirement in indoor situation (60 meter)[22].

The antenna type is omni-directional. The maximum number of sub-channels in each cell is supposed to be 30. So the total user number is 150 in system with figure9 and 120 in system with figure10 when it is full traffic load.

The other parameters used in simulation are as shown in Table 1.

Table 1. Simulation parameters [18,22,23]

Parameter	Assumption
Inter-site distance	40~80m
BS antenna height	4m
User antenna height	1m
Carrier Frequency	3.4 GHz
Total BS TX power	21dBm for 20MHz
BS noise figure	5dB
Thermal noise	-174dBm/Hz
BS antenna gain	5dB
Sub-channel per cell	30
Bandwidth of one LTE resource block	180kHz
Antenna type	omnidirectional

5. Result

5.1. Best set of parameters

The uniform and concentration traffic load in Table2 represent the distribution of users in each cell, which has be given the definition in chapter 4.2. Letter S is short for square building and C is short for cross building.

Table 2. Best set of parameters

Label	Situation	Set
S1	Square building Uniform traffic load 10%~80%	Power ratio: 2.6 Sub-band number: 3 Frequency allocation:figure12(a)
S2	Square building Uniform traffic load 90%~100%	Power ratio: 2.6 Sub-band number: 2 Frequency allocation:figure12(b)
S3	Square building Concentration traffic load 10%~70%	Power ratio: 2.6 Sub-band number: 3 Frequency allocation:figure12(a)
S4	Square building Concentration traffic load 10%~70%	Power ratio: 2.6 Sub-band number: 2 Frequency allocation:figure12(b)
C1	Cross building Uniform traffic load 10%~70%	Power ratio: 2.6 Sub-band number: 3 Frequency allocation:figure13(a)
C2	Cross building Uniform traffic load 80%~100%	Power ratio: 2.6 Sub-band number: 2 Frequency allocation:figure13(b)

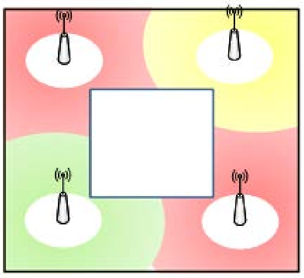

Figure12(a).frequency scheduling with 3 sub-bands in square building

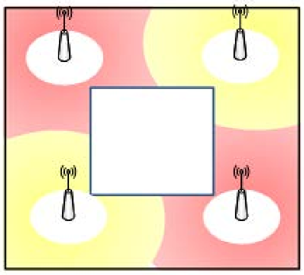

Figure12(b).frequency scheduling with 2 sub-bands in square building

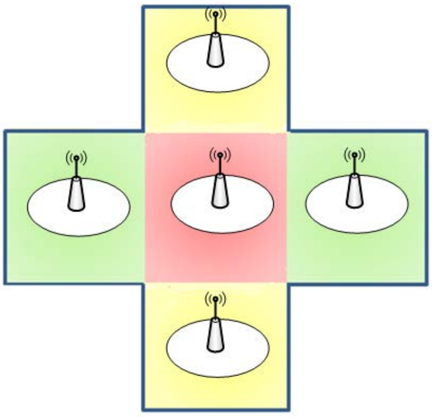

Figure13(a).frequency scheduling with 3 sub-bands in cross building

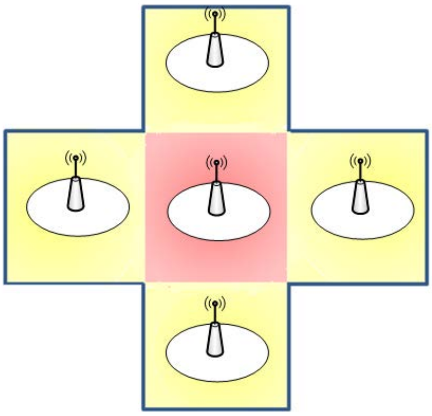

Figure13(b).frequency scheduling with 2 sub-bands in cross building

The data in table2 is the simulation result. The performance metric is the 10 percentile user average throughput. It can be seen that best set has several choices. The boundary of different traffic load in C1 and C2 represents the judgment condition. Four UC traffic situations in S building represent judgment conditions which is similar with C building. These data are used in static scheme and low level dynamic scheme as listed in table3.

Table 3. Best set and its usage

Label	Static scheme	Low level dynamic scheme
S1	/	Used as Set 2 in figure8
S2	Used since it is for full traffic load	Used as Set 1 in figure8
S3	/	Used as Set 4 in figure8
S4	/	Used as Set 3 in figure8
C1	/	Used as Set 2 in figure7
C2	Used since it is for full traffic load	Used as Set 1 in figure7

Table3 lists the label and usage in static scheme and low level dynamic scheme. S2 and C2 are used for static scheme since they are for full traffic load. All the best sets corresponding to one set in low level dynamic scheme. For example best set for C1 used as set2 and best set for C2 used as set1 in figure7.

5.2. Result for the homogeneous traffic load

First of all, 10 percentile user's average throughput which means the 10% of the total user with worst performance is analyzed. It is because the most significant goal of ICIC scheme is to improve the commination quality of user with bad channel so that the system can achieve balance. Figure14 shows the 10 percentile user's average throughput with different traffic load in concentric square shaped situation. The distribution of users is supposed to be uniform in each cell which means that clients are distributed uniformly in the environment. If the user quantity in the system is decreased, the user in each cell reduced correspondingly. 10% in x label means the entire users in the whole system achieves 10% of the system capacity and 100% means full traffic load.

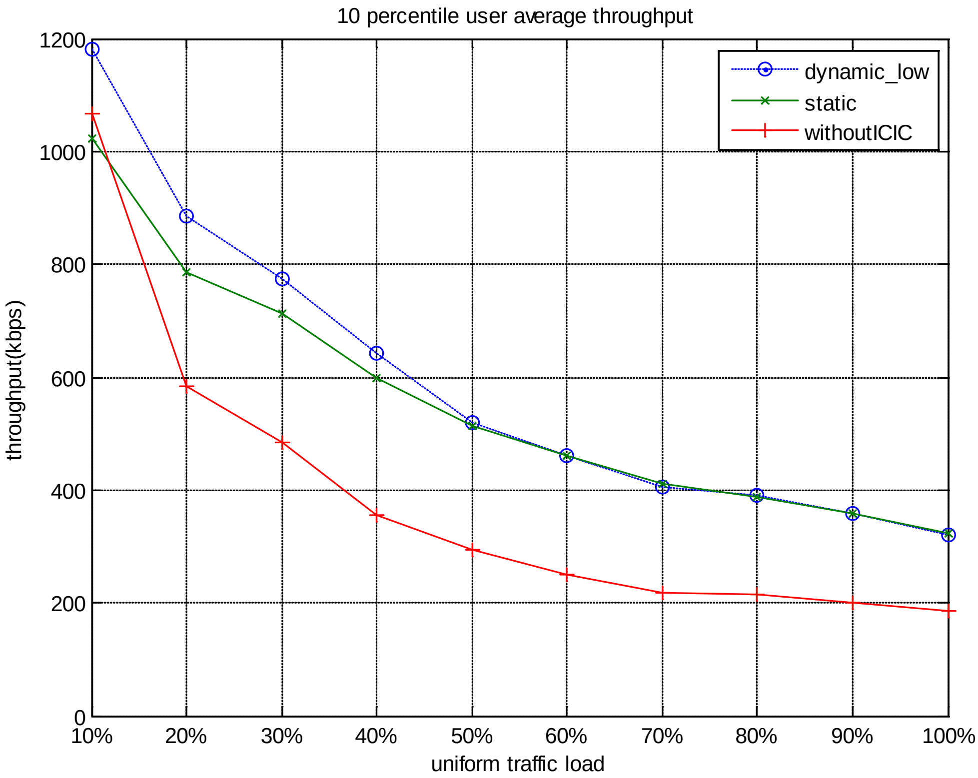

Figure14. 10 percentile user average throughput with uniform traffic load in concentric square building

As shown in figure14, the red line represents the throughput of 10 percentile user without using any ICIC scheme and the green line shows the result after using static scheme. It is obviously to see that as long as ICIC scheme is used, the performance of user with worse communication quality has a great improvement.

Then the total throughput of whole users in the system is analyzed in figure15.

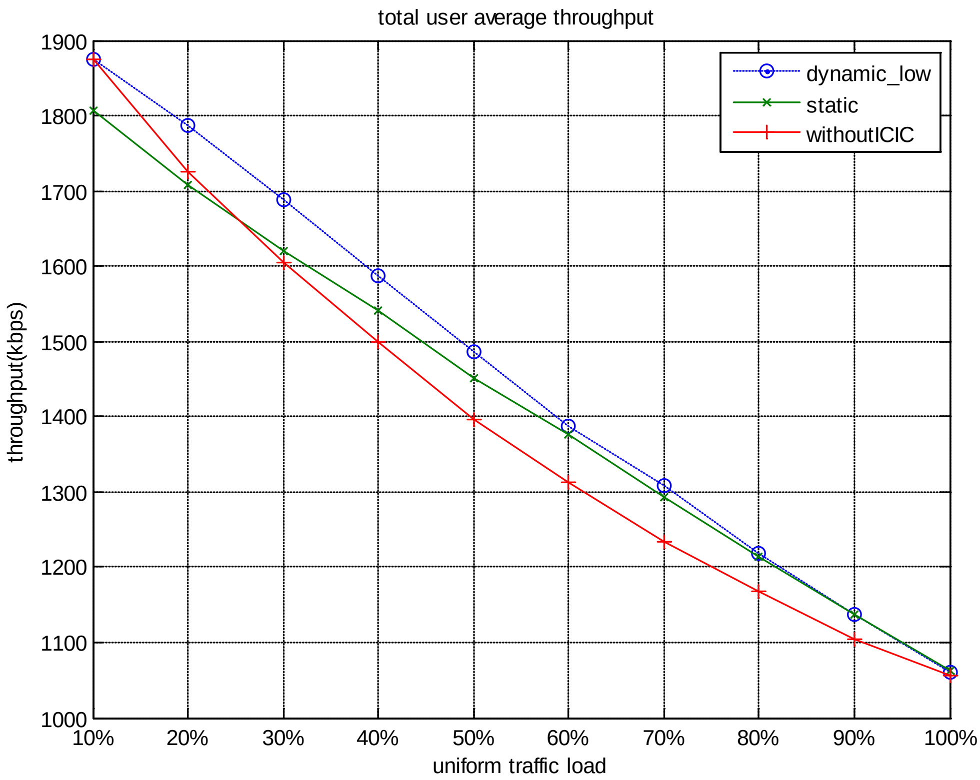

Figure15.Total user average throughput with uniform traffic load in concentric square building

In figure15, the system performance after using static ICIC scheme is not always better than it is without using ICIC scheme. When there are fewer clients in the system, the total throughput decreases seeing from green line and red line. However, ICIC scheme behaves trade off in some respects. If the client at disadvantageous position or having bad channel condition can always get benefit, a little loss in whole system performance is still acceptable. The point is whether the clients with low SINR can always acquiring better communication qualities after using ICIC scheme directly.

To answer this question, first of all, static scheme has to be applied in different building. Afterwards, other traffic load situations such as concentration and chaos will be discussed.

Figure16 contains both the 10 percentile throughput and the total throughput in the whole system. The difference is that the building changes from concentric square shape to cross shape. The traffic load in each cell is still uniform. The upper group which consist of red, green and blue line denote total throughput. The lower group which consist of cyan, yellow and purple line denote 10 percentile throughputs.

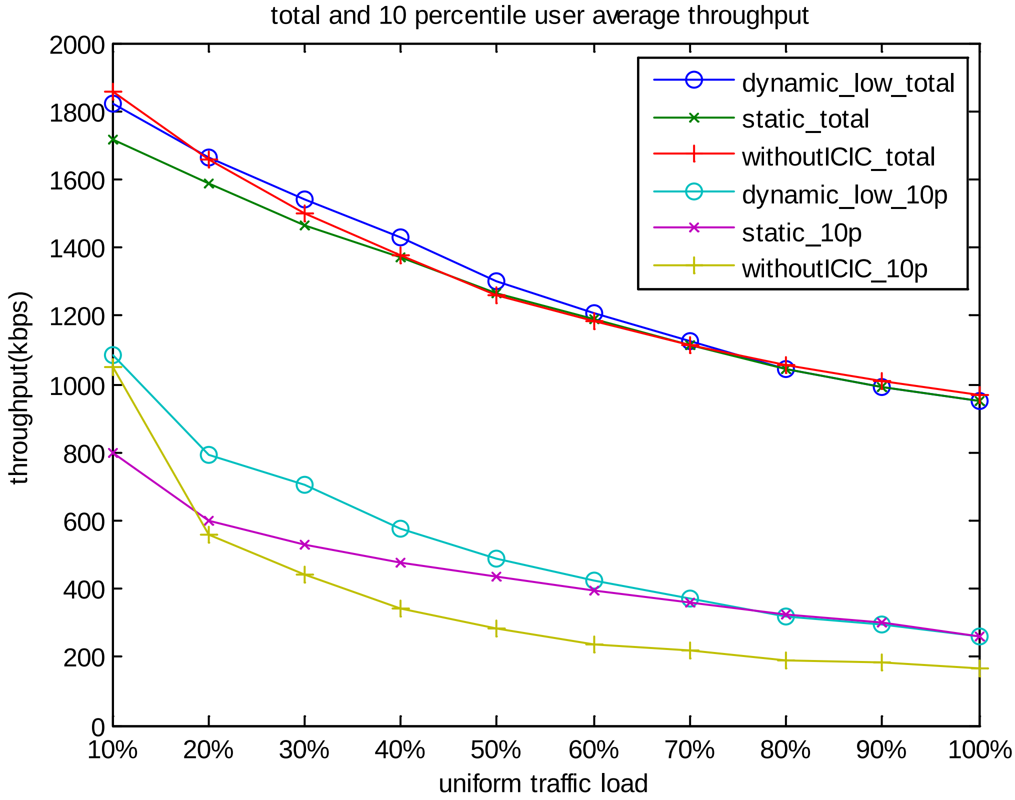

Figure16.Total and 10 percentile user average throughput with uniform traffic load in cross building

Purple line which represents throughput for unlucky users after applying static ICIC scheme is lower than yellow line. It gives a negative answer to the question proposed before. To say more specifically, without considering the whole performance, the 10 percentile users cannot be sure to get improvement if only static scheme is used.

So, a more reliable scheme has to be used.

In figure14, figure15 and figure16, another result for low-level dynamic also be showed. Observing from figure14 and figure15, the communication quality for unlucky user can be sure to increase which is better than static one. However, the low dynamic scheme gives similar result with static one when the traffic load is high. For example the similar result is given when traffic load is more than 80 percentages in cross shape. This value is even smaller in concentric square shape. The similar result is given as long as the traffic load is bigger than 50 percent. That is because the low-level dynamic scheme and static scheme use same optimal set with same parameters when traffic load is high. Since the performance of user with lower SINR are more concerned when there is big amount quantity UEs in the system, a better result for it will be expected.

The intermediate level dynamic scheme is employed in figure17.

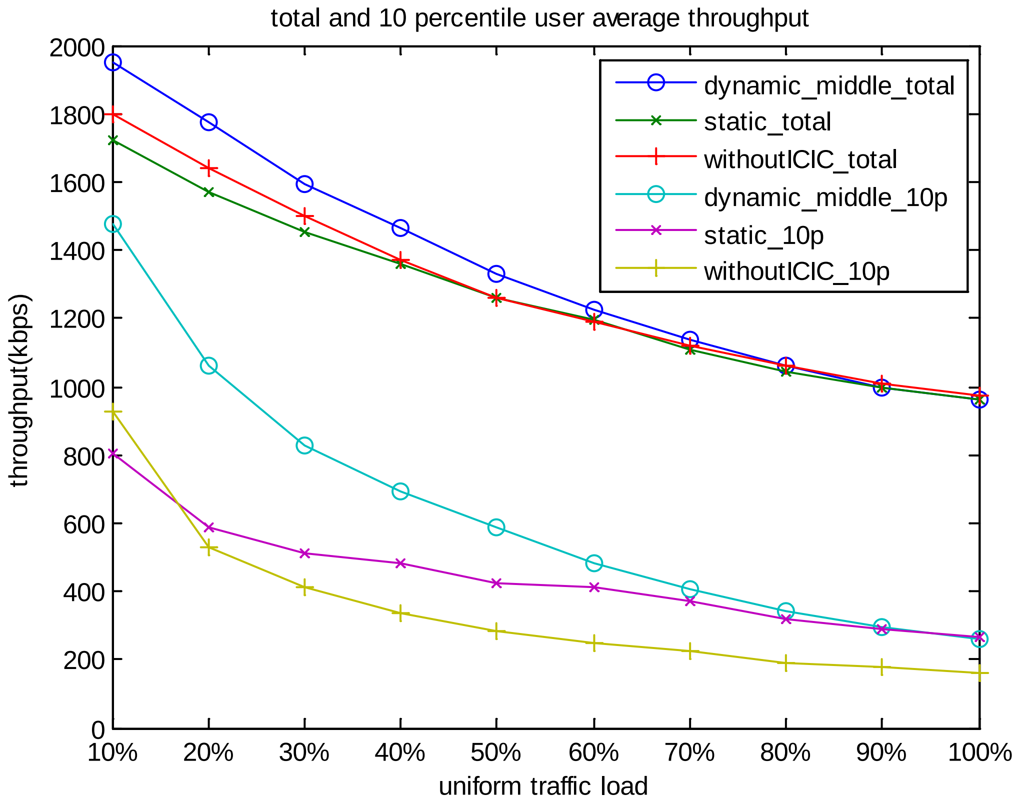

Figure17.Total and 10 percentile user average throughput with uniform traffic load in cross building employed intermediate level dynamic scheme

The cyan line in figure17 changes from low level dynamic scheme to intermediate dynamic scheme. This time, the throughput for user with lower SINR can always get an improvement than static one except for full traffic load. Even in concentric square shape which has even serious problem, similar result can be got.

Since the trend of lines are similar in Square building. The figures are omitted.

5.3. Result for the concentration traffic load

The entire above figures are based on homogeneous traffic load. In the following figures, the performance for different schemes and without ICIC scheme deploying concentration traffic load will be analyzed.

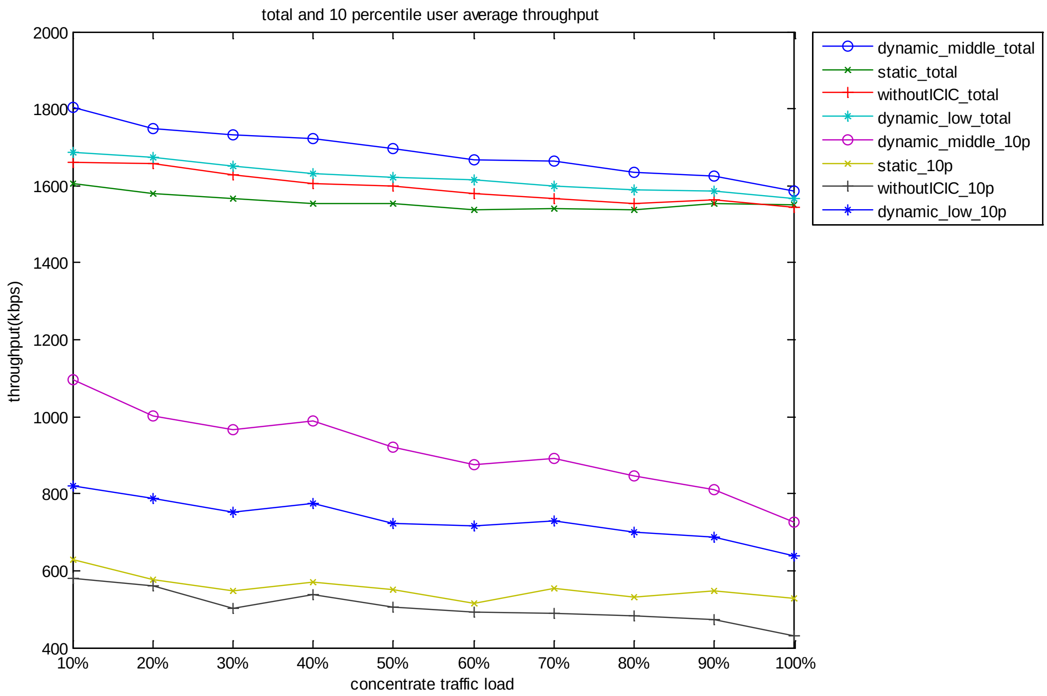

Figure18.User average throughput in cross building with concentration traffic load at wing position

Figure18 and figure19 show throughputs after trying intermediate level dynamic scheme, static scheme, without using ICIC scheme and low level dynamic scheme with same traffic load respectively. The difference is that, in figure18, the cell having concentrate requirements at wing position in cross shape, while in figure19; the concentration cell is at central location. Values in x axis are the UE traffic in concentration cell which varied from 10% to full load. All the other cells in system has 20% traffic load of cell capacity as introduced in section 4.2.

It can be easily observed that these two figures has different trend of line. In figure18, since no line crossed and overlapped with each other, a small conclusion can be got that intermediate level dynamic scheme give best result and without using ICIC gives worst result; in medium part, low level dynamic scheme is better than static ICIC according to the position of lower group of lines.

Seeing from the upper group of line, the green line which represents static scheme is always lower than red line. From this point of view, a small conclusion can be got that using static scheme directly has great loss in whole system performance. It also proves the necessity of dynamic scheme.

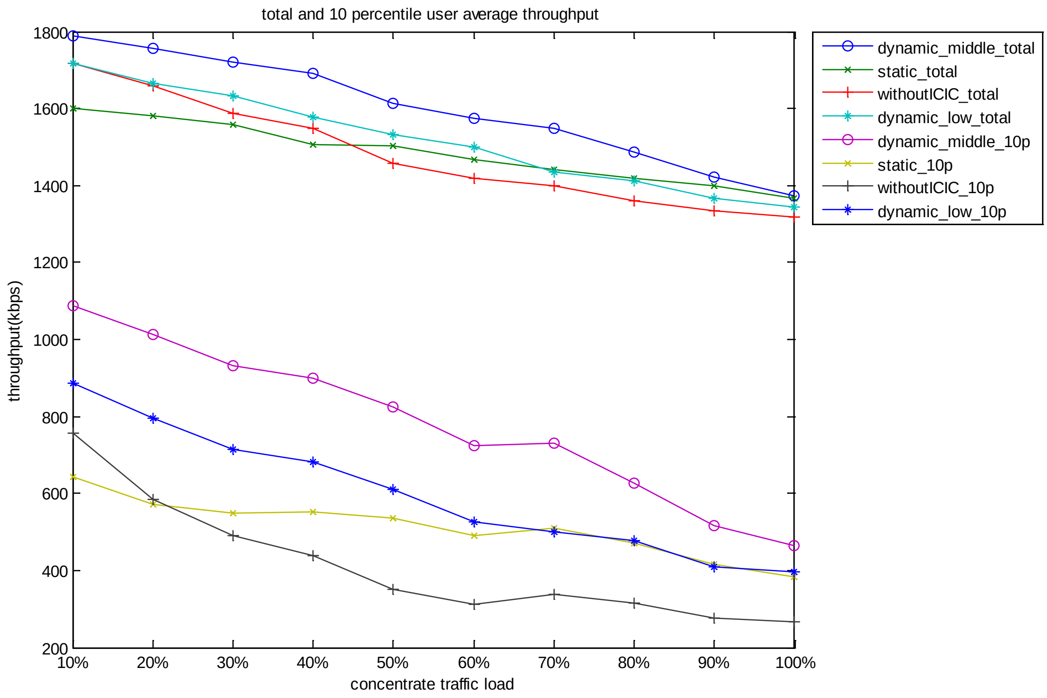

Figure19.User average throughput in cross building with concentration traffic load in central location

In figure19, some lines are crossed and some lines are overlapped. It demonstrates that the location of cell with concentrate traffic load affect the result very much. Especially for the low level dynamic scheme, if best performance is expected, not only the number of users in each cell but also the location of busy server's cell has to be considered in. It makes the algorithm more complicated if the building is big and has special shape. Since intermediate level dynamic is already proposed, modification for low level dynamic algorithm is not discussed more.

The lines are not gathered to same point when x axis labeled 100%, that is because only the concentrate cell has full users. It is different from uniform traffic load situation. So, the improvement is more obviously here.

The building with concentric square shape is symmetric, so the above problem does not exist. A similar result it shows, thus it is not mentioned here anymore.

5.4. Result for the chaos traffic load

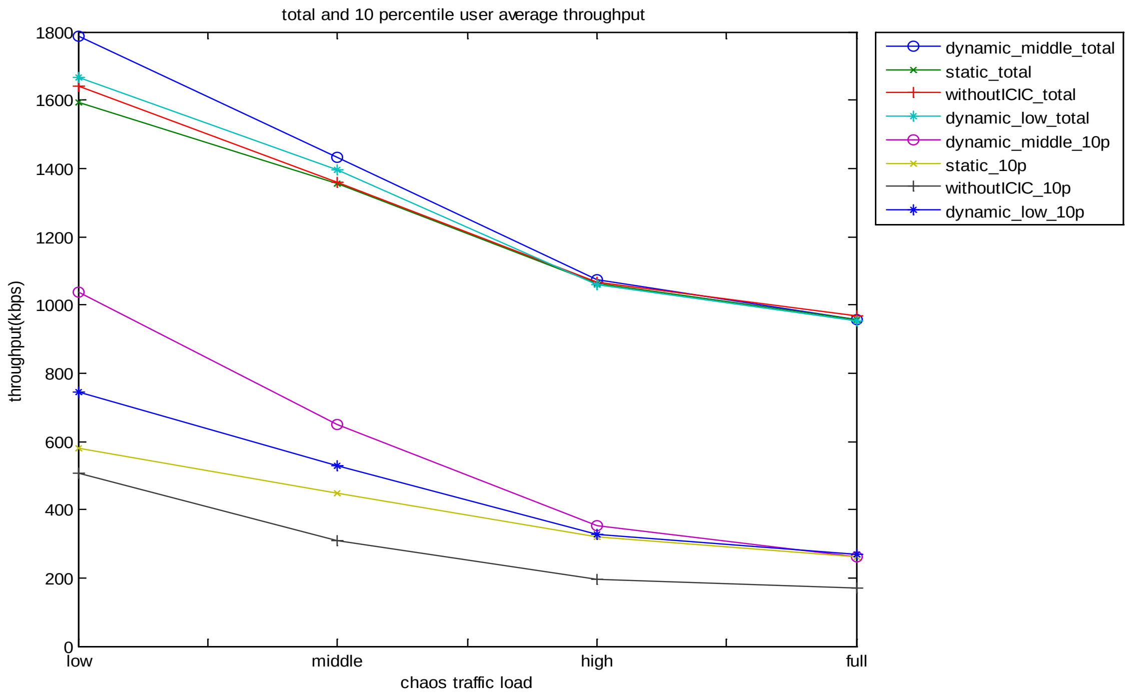

Figure20.User average throughput with chaos traffic load in cross building

Now comes to the chaos situation. The distribution of user is chaos and has no regular, so the traffic load is labeled as low, intermediate, high and full according to general UE quantity. Different degrees of improvement are given which is similar with the conclusion of figure18. So, different schemes can be chosen according to different actual conditions.

6. Conclusion

In this thesis, whether it is good to use ICIC scheme in indoor situation is answered. After studying the existing ICIC schemes, static and dynamic ICIC schemes in three levels aiming at indoor environment are proposed in this thesis. These schemes are simulated in two typical shapes of building with different parameters respectively.

Summarizing from the result, generally speaking, the performance of user with worse channel condition acquire great improvement after making use of ICIC. In most of the cases, the static scheme can get improvement in performance of 10 percentile users. However, the performance of the whole system decreases sometimes, especially when it is concentration traffic load.

The overall system performance and 10 percentile user's performance after employing the low level dynamic scheme and the intermediate level dynamic scheme can always get improvements. However the improvements are in different degrees. Intermediate level dynamic scheme get much better result than any other schemes. Also, as introduced in chapter 3, low level dynamic scheme may not work if there is no best set in some special situation. So, intermediate level dynamic scheme is a more reliable way no matter from scheme itself or from its result.

Considering the system running efficiency and the reliability and speed of the connection situation between each server, static, low level dynamic or intermediate level dynamic scheme can be chosen. Also, these schemes can be used according to the system's own requirement. Then different performance will get.

In this thesis, channel model such as Rayleigh fading is considered, but the performance of channel is not a factor in determining the scheme. The future work is about the high level dynamic scheme which considering this factor. Also, all the users are supposed to use sub frequency with equal width in this thesis. This problem can also be improved in high level dynamic scheme.

Reference

[1]"An Introduction to LTE". 3GPP LTE Encyclopedia. http://sites.google.com/site/lteencyclopedia/home. Retrieved 2011-05-20.

[2]E. Dahlman, “3G Evolution - HSPA and LTE for Mobile Broadband”, 2nd Edition, Wiley 2008.

[3]R1-050841, “Further Analysis of Soft Frequency Reuse Scheme”, Huawei

[4]R1-051059, “Inter-Cell Interference Mitigation for EUTRA”, Texas Instruments

[5]R1-060358, “Performance of Inter-Cell Interference Mitigation with Semi-Static Frequency Planning for EUTRA Downlink”, Texas Instruments

[6]S. H.Ali and Victor C. M. Leung, “Dynamic Frequency Allocation in Fractional Frequency Reused OFDMA Networks”, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 8, NO. 8, AUGUST 2009, Page(s): 60 – 65.

[7] R. Kwan, C. Leung. “A survey of scheduling and interference mitigation in LTE”, Journal of Electrical and Computer Engineering Volume 2010 (2010), Article ID 273486, 10 pages

[8] V. Pauli, J. D. Naranjo, E. Seidel, Heterogeneous LTE Networks and Inter-Cell Interference Coordination, White Paper, Nomor Research, December 2010

[9]R1-051051, “Standard aspects of Interference coordination for EUTRA”, LG Electronics

[10]Y. Xiang, J. Luo, “Inter-cell interference mitigation through flexible resource reuse in OFDMA based communication networks,” in Proc. of the 13th European Wireless Conference (EW2007), pp. 1-7, Paris, France, April 2007.

[11] L. Chen, D. Yuan. “Soft Frequency Reuse in Large Networks with Irregular Cell Pattern: How Much Gain To Expect?”, 2009 IEEE 20th International Symposium on. pp1467 - 1471, 2009.

[12]L. Chen, D. Yuan. “Beyond conventional fractional frequency reuse for networks with irregular cell layout: An optimization approach and performance evaluation”, Wireless Internet Conference (WICON), 2010 The 5th Annual ICST, pp1-7, 2010.

[13]L. Chen, D. Yuan. “Generalized Frequency Reuse Schemes for OFDMA Networks: Optimization and Comparison”, Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st pp1-5, 2010.

[14]M. Rahman, H. Yanikomeroglu, and W. Wong, “Interference Avoidance with Dynamic Inter-Cell Coordination for Downlink LTE System,” Proc. IEEE WCNC 2009.

[15]R1-062150, “Adaptive Fractional Frequency Reuse”, Nortel

[16]S. Kumar, G. Monghal, J. Nin, I. Ordas, K. I. Pedersen, and P.E. Mogensen, “Autonomous inter cell interference avoidance under fractional load for downlink long term evolution,” in Proceedings of the IEEE Vehicular Technology Conference (VTC’09), April 2009.

[17]M. Rahman and H. Yanikomeroglu, “Interference avoidance through dynamic downlink OFDMA subchannel allocation using intercell coordination," in Proc. IEEE Veh. Technol. Conf. (VTC2008-Spring), May 2008, pp. 1630-1635.

[18]IEEE 802.16m Evaluation Methodology Document (EMD) IEEE 802.16 Broadband Wireless Access Working Group IEEE 802.16m-08/004r5

[19]L. Ahlin, J. Zander, and B. Slimane, “Principles of Wireless Communications 2nd Edition” (MSc level basic course textbook), Student literature,2006

[20] G. Fodor et al, “Intercell Interference Coordination in OFDMA Networks and in the 3GPP Long Term Evolution System,” Journal of Communications, vol. 4, no. 7, 2009.

[21] S. Sesia et al, LTE The UMTS Long Term Evolution, From Theory to Practice, Wiley, 2009,Eq(18-4)

[22]R1-083014, “Evaluation Model for LTE-Advanced”, Jeju, Korea

[23]R1-084026, “Text proposal for evaluation methodology”, Ericsson, Huawei, Nokia, Motorola.

TRITA-ICT-EX-2011:278