공학석사 학위논문

Inter-cell Interference Separation-based Resource Allocation Strategy for Enhancing Uplink Capacity of VoLTE

VoLTE 시스템의 상향링크 용량향상을 위한 셀간 간섭분리전략 기반 자원할당 기법

2012년 8월

서울대학교 대학원

전기정보공학부

조 병 갑

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지도 교수 최 성 현

이 논문을 공학석사 학위논문으로 제출함

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조병갑의 석사 학위논문을 인준함

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Abstract

Inter-cell Interference Separation-based Resource Allocation Strategy for Enhancing Uplink Capacity of VoLTE

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Since LTE is designed to operate in fully packet-switched network, Voice over Internet Protocol (VoIP) on top of LTE (VoLTE) has been adopted as a standard technology by 3GPP. The VoLTE service, however, is confronted by lots of challenges due to different Quality-of-Service (QoS) requirements of VoIP traffic, such as low delay bound and low tolerance to loss, and certain traffic characteristics including silence suppression and periodic small-sized packet generation. Moreover, in practical LTE deployment scenarios, i.e. multi-cell environment, it is crucial to tackle the inter-cell interference (ICI) problem to improve the system performance. In this thesis, a novel resource scheduling strategy for improving VoIP capacity in LTE uplink system is proposed. This strategy effectively mitigates the ICI by adopting the simple

RSS-to-resource matching rule, which separates the high interference sources of each cell/sector in different sets of resources in an orthogonal manner. The proposed strategy exploits higher bandwidth efficiency while separating the inter-cell interference, whereas other conventional schemes, such as Frequency Reuse Scheme with reuse factor equal to 3 and Fractional Frequency Reuse, limit their frequency resource usage into dedicated sub-bands. Through extensive system level simulations, we demonstrate that our resource allocation scheme outperforms the conventional scheduling algorithms with very low computational complexity.

Keywords: LTE, VoIP Capacity, Resource Allocation Scheduling, Inter-cell Interference Coordination (ICIC), Multi-cell Environment

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Chapter 1

Introduction

The worldwide mobile communications is evolving from the traditional WCDMA technology to the Long-Term Evolution (LTE) technology. The 3rd Generation Mobile System (3GPP) which is a standardization body initially designed the LTE system to operate in fully packet-switched network to support higher system capacity and QoS requirements with limited radio resource, unlike the traditional systems which provide voice services in circuit-switched network while providing data services in packet-switched network. Thus Voice over Internet Protocol (VoIP) technology on top of LTE, often referred to as VoLTE, has been adopted as a standard technology by 3GPP to provide voice service on the packet-switched network. The VoLTE service, however, is confronted by lots of challenges due to different QoS requirements of VoIP traffic, such as low delay bound and low tolerance to loss, and certain traffic characteristics including silence suppression and periodic small-sized packet generation [1].

Orthogonal FDMA (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA) in downlink and uplink respectively have been adopted as physical radio access schemes for LTE. These schemes are suitable to exploit multiuser diversity by performing channel dependent *resource allocation* (RA) scheduling when the localized *resource block* (RB) allocation is used, i.e., a set of contiguous RBs should be allocated to a single UE. As we focus on only uplink system in this thesis, it is noteworthy that the SC-FDMA with localized resource allocation is employed as a standard scheme by 3GPP [2] in order to maintain the single carrier property, i.e., low Peak-to-Average Power (PAPR) property. Due to the fact that the channel dependent scheduling can exploit the frequency selective gain in the LTE uplink system, the overall system performance is highly dependent on the scheduling strategies. It, therefore, has drawn lots of interests to develop the optimum RA scheduling strategy taking into account the characteristics of VoIP traffic.

In practical LTE deployment scenarios (i.e., multi-cell environment) the performance of UEs at cell edge can be degraded due to the poor channel conditions, such as high path loss, multipath fading and inter-cell interferences (ICI). For data service, the cell edge users can be serviced with low throughput, but still they are serviced in the cell. For VoIP service, however, the cell edge users are very likely to suffer from outages because the minimum data rate per UE according to the employed voice codec (e.g. AMR, G.711, G.729, etc.) should be guaranteed to prevent the outages. Even though the path loss and fading of UEs at cell edge are not controllable, ICI can be effectively coordinated by some inter-cell interference coordination (ICIC) method.

Fractional Frequency Reuse (FFR) is a typical ICIC mechanism in which the usable frequency spectrum of cells are partitioned into a number of sub-bands and those partitions are allocated spatial locations within cells in a coordinated manner that minimizes ICI. Although the FFR scheme effectively mitigates ICI, the spectral efficiency becomes worse because it prohibits the UEs allocated with a certain sub-band from using other sub-bands even when the traffic load of the other sub-bands is relatively low. To tackle this problem, various alternative schemes such as dynamic FFR [4] and soft frequency reuse (SFR) [5] have been introduced. These schemes try to mitigate the RA limitation of the FFR scheme by dynamically adjusting the borders of sub-bands (dynamic FFR) and making the sub-bands which are allocated to inner-cell users partly overlapped among neighboring cells (SFR). These schemes still need strict classification of UEs (e.g., typically according to UEs' location) at least on a transmit time interval (TTI), and it leads to low spectral efficiency. In [8], the authors introduce a different kind of approach whose RA method eliminates the borders of sub-bands and differentiates the orders of RBs to be allocated to UEs.

Besides the ICIC mechanism, reducing the interference fluctuation is helpful while performing SINR based VoIP scheduling, in which the interference environment does not change rapidly. If it changes from a subframe to another subframe abruptly all the time, it is difficult to estimate the current interferences based on the interferences from the previous subframe. In [6], the importance and concept of the interference fluctuation reduction method are introduced. The authors' idea uses the *frequency occupation ordering*, which inspires us with some part of our proposed idea.

In this thesis, we propose a new concept of RA scheduling strategy for uplink VoLTE capacity enhancement. Our proposed scheme improves the VoLTE performance simply by ordering UEs according to their received signal strength (RSS) to the eNB and, at the same time, allocating the ordered UEs with RBs in a predefined way. Combined with the fact that VoIP packets are small and periodically generated, this simple strategy effectively separates and minimizes the ICI with very low computational complexity. Our proposed idea exploits bandwidth efficiency of reuse factor one while other ICI schemes do not.

The rest of the thesis is organized as follows: In Chapter 2, VoIP traffic model and parameters are presented. In Chapter 3, we describe the problem formulation and system modeling. In Chapter 4, the proposed resource allocation strategy is explained in detail. In Chapter 5, the proposed scheme is evaluated via extensive system level simulations. We conclude the thesis in Chapter 6 along with the remarks on our future work.

Chapter 2

VoIP Traffic Model and Parameters

2.1 VoIP Model

In this thesis, we adopt the VoIP model and parameter set mostly from [9]. The state of each session alternates between active state and silent state. The duration of each state is exponentially distributed with an average of 2 seconds. We assume that AMR codec with a source rate of 12.2 kbps is used. Thus 40 bytes of voice packets are generated every 20 ms in the active states and 15 bytes of Silence Insertion Descriptor (SID) packets are generated every 160 ms in the inactive states. Detailed VoIP parameters are shown in Table 2-1, and the two-state voice activity model is described in Fig. 2-1.

Parameter	Characterization
PDF of active/inactive state duration	$f_x = \lambda e^{-\lambda x}, x \geq 0, \lambda = \frac{1}{MEAN}$ $\mathrm{MEAN} = 2\mathrm{sec}$
Codec	RTP AMR 12.2 kbps
Encoder frame length	20ms
Voice activity factor (VAF)	50% (a=c=0.01, b=d=0.99)
SID payload	15 bytes (5 bytes + header) SID packet every 160ms during silence
Protocol Overhead with compressed header	10 bits + padding (RTP-header) 4 bytes (RTP/UDP/IP) 2 bytes (RLC/security) 16 bits (CRC)
Total voice payload on air interface	40 bytes (AMR 12.2)

Table 2-1: VoIP Model and Parameters.

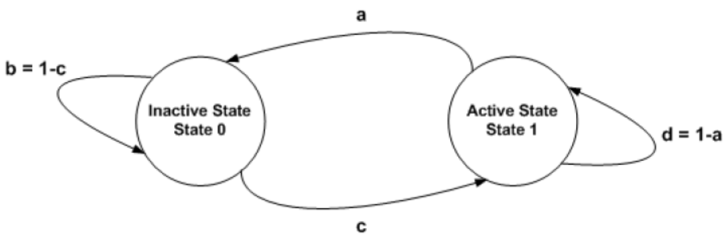


Fig. 2-1: Two-state Voice Activity Model [9].

2.2 VoIP Capacity Criterion

The VoIP capacity is defined as the number of users in the cell when more than 95% of the users are satisfied [9][10]. A VoIP user is in outage (not satisfied) if more than 2% of the VoIP packets are not delivered within 50 ms. This delay bound is derived assuming an end-to-end delay below 200 ms for mobile-to-mobile communications. In short, the VoIP capacity can be expressed by the equation below:

$$C_u = \sup\left(N_{tot}\middle|\frac{N_{sat}}{N_{tot}} \geq 0.95\right). \tag{1}$$

where N_{tot} and N_{sat} denote the total number of users and satisfied users per sector respectively.

2.3 VoIP Scheduling in LTE Uplink

In conventional dynamic scheduling, both initial transmissions and retransmissions of VoIP packets are scheduled dynamically by L1/L2 control signaling (i.e., RBs-UEs allocation can be changed every transmission chance). Therefore, the benefits of frequency selective scheduling and time selective scheduling can be fully exploited. In dynamic scheduling, however, the large number of downlink control channels (i.e., PDCCH) should be consumed to support large number of VoIP users, and it can become a bottleneck.

For that reason, 3GPP has adopted the semi-persistent scheduling as a scheduling method for VoIP in LTE. The concept of the semi-persistent scheduling can be explained as follows: persistent scheduling for initial transmission and dynamic scheduling for retransmission. At the initial transmission of VoIP packets of UEs in active state, each UE is allocated a set of persistent RBs. During the talk spurt the UE can keep sending the packets on the same RBs set without receiving uplink resource grant signaling via Physical Downlink Control Channel (PDCCH). This scheme has been developed taking into consideration the characteristics of VoIP packets which have relatively changeless length and fixed interval. In semi-persistent scheduling, retransmissions can still exploit the benefits of frequency selective scheduling because they are always dynamically scheduled. Fig. 2-2 describes how the resource allocation is made via semi-persistent scheduling.

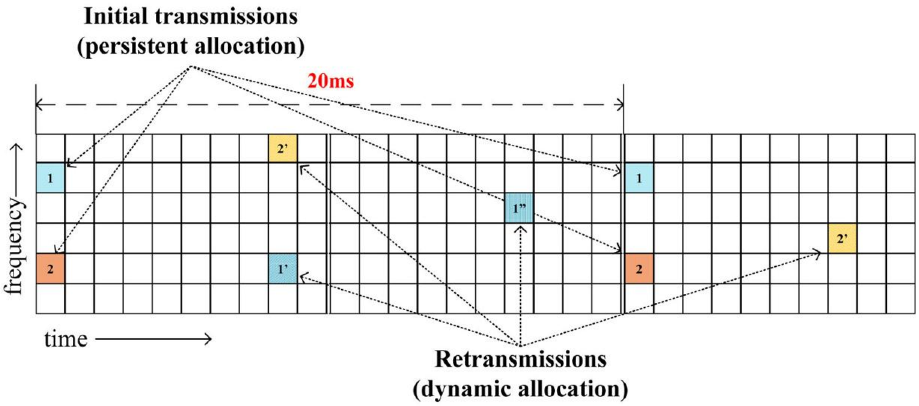


Fig. 2-2: Semi-persistent Scheduling.

Chapter 3

System Model and Problem Formulation

3.1 System Model and Resource Allocation Principles

In our system, we consider LTE uplink system in a multi-cell environment which is implemented by a 19 hexagonal cell wrap-around model as shown in Fig. 3-1. Each cell consists of three sectors, and frequency reuse factor of each sector is one, which means each sector utilizes the whole system bandwidth. Each sector antenna has the same antenna pattern as specified in [11]. The same number of UEs is in each sector and the UEs are randomly distributed within the sector.

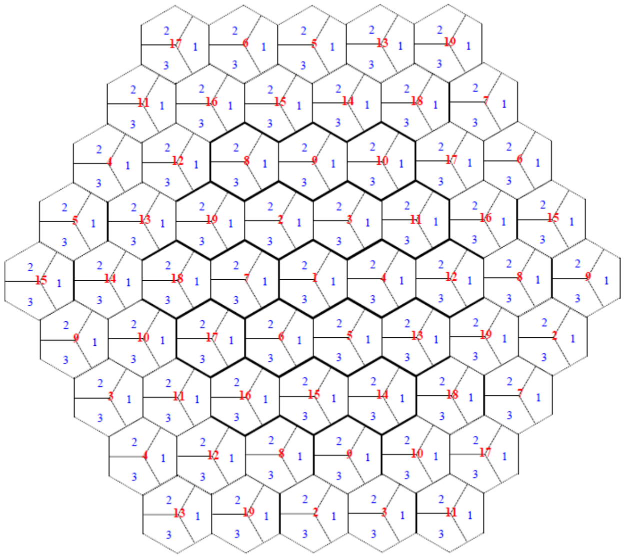


Fig. 3-1: 19-Hexacell Wraparound Model.

The allocation unit of time-frequency resources is Resource Block (RB), which occupies one time slot (0.5 ms, 7 OFDM symbols with normal CP) in time domain and 12 subcarriers of 15 kHz each in frequency domain. The resource allocation is executed every TTI of 1 ms spanning 2 time slots. Accordingly, the minimum unit of scheduling is called a RB pair which consists of 14 OFDM symbols.

VoIP packets are composed of voice packets and SID (Silence Indication Descriptor) packets, which represent active and inactive state of a call session. In our considered environment using the AMR 12.2 kbps voice codec, voice packets are 40 bytes long and generated every 20 ms. On the other hand, SID packets are 15 bytes long and generated every 160 ms. As a basic scheduling method, semi-persistent scheduling is used. Therefore the original packets from each state are persistently scheduled and the retransmission packets are dynamically scheduled as explained in Section 2.3. LTE uplink system supports both the synchronous adaptive/non-adaptive HARQ (Hybrid

Automatic Repeat reQuest) schemes for error control. In this thesis we adopts synchronous adaptive HARQ, which means retransmissions occur in predetermined interval (i.e., 8 ms) and can be allocated on different RBs than the initial transmissions to achieve frequency diversity. In every TTI the persistently scheduled UEs are allocated first according to their previously allocated RB positions and the rest of RBs can be dynamically allocated, in frequency domain, to the UEs who perform retransmission and are changing its state between active and inactive states vice versa.

3.2 Uplink Fractional Power Control

UEs' transmission power for the Physical Uplink Shared Channel (PUSCH) is determined by an open-loop Fractional Power Control (FPC) algorithm [3]:

$$P_{PUSCH} = \min\{P_{\max},\ P_0 + \alpha \cdot PL_{DL} + 10\log M_0\}, \qquad (2)$$

where $P_{\max}$ is the UE's maximum transmission power, P_0 is a cell specific parameter, α is the cell-specific path loss compensation factor, and PL_{DL} is the downlink path-loss estimation based on the downlink reference signal strength measured in the UE and M_0 is the number of assigned RBs to the UE.

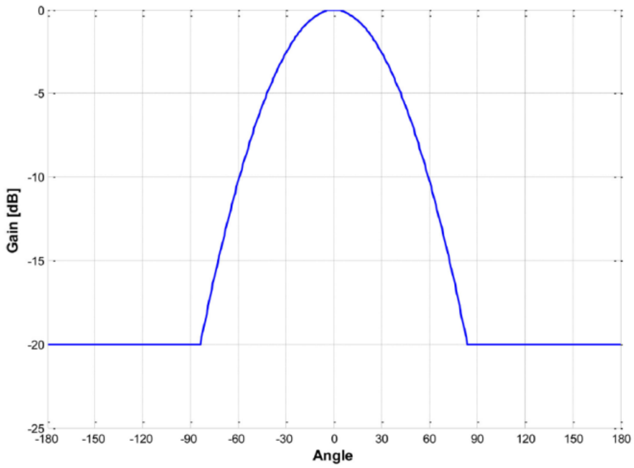


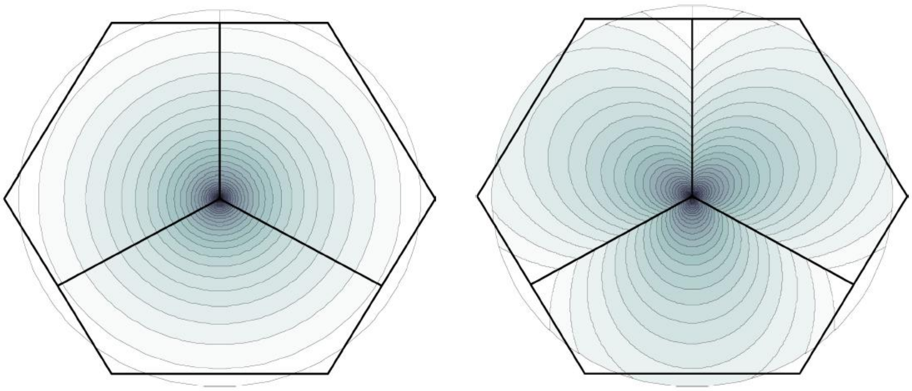
Fig. 3-2: Antenna Pattern of a Sector in Tri-sectorized Cell.

Modeling of the UEs' transmission power according to their location in tri-sectorized cells, however, may not be done properly in many literatures such as [6-8]. They only considered the distance between the UE and the serving eNB when calculating the path-loss estimation value as shown in Eq. (3).

$$PL_{DL} = 128.1 + 37.6 \log d \ \text{(in km)}, \tag{3}$$

In realistic situations, however, the downlink reference signal strength is also affected by antenna gain variation according to the UE's location based on the antenna pattern of the sector. The antenna pattern is depicted in Fig. 3-2 [11]. Therefore the path-loss calculation should be modified as following:

$$PL_{DL,\text{mod}} = PL_{DL} - G_{ant}. \tag{4}$$



(a) Without Antenna Pattern. (b) With Antenna Pattern.

Fig. 3-3: Uplink Transmission Power determined by FPC.

Fig. 3-3 is the contour plots that describe the regions in which the UEs' transmission powers are the same. In Fig. 3-3(b), we observe that the UE located in a higher angular position in the sector transmits in a larger power than one located in a lower angular position even though their distances to the eNB are the same. This observation inspires us with an idea that the UEs in high angular positions can be the major interference sources toward the neighboring sectors. The details are explained in the following chapters.

3.3 Problem Formulation

In this section, we formally define our objective function and the problems to solve. In terms of maximizing the VoIP capacity of LTE uplink system, the objective function can be stated as follows:

$$\max C(U), \qquad C(U) = C_U = \sup\left(N_{tot}\middle|\frac{N_{sat}}{N_{tot}} \geq 0.95\right), \tag{5}$$

where U is the set of u_r, which is the index of a user allocated to the RB $r \in$

R (i.e., $U = \{u_r | r \in R\}$) when letting R be the set of RB indexes. Let K be the set of users. Then our objective is to find the optimum RBs-UEs mapping U and expressed as:

$$\arg\min_{U} \sum_{K \in K_{sched}} \alpha_{k,prob}, \qquad \text{for } \forall r \in R, \tag{6}$$

$$\alpha_{k,prob} = \begin{cases} 1, & \text{if } P_{drop}^{k} > 0.02 \\ 0, & \text{otherwise} \end{cases}, \qquad \text{for } \forall r \in R, \tag{7}$$

where K_{sched} is the set of users to be scheduled at the TTI and P_{drop}^{k} is the packet drop *probability* considering the remaining retransmission chances within the packet's delay bound of 50 ms.

Let $n \in \{0, 1, 2, \cdots, N_{max}\}$ be the packet's retransmission number (e.g., when n equals zero, it indicates the initial transmission) and N_{max} is the maximum retransmission number where the packet's delay bound is met (i.e., 6, assuming the delay bound is 50 ms and HARQ round trip time (RTT) is 8 ms). Then the packet drop probability P_{drop}^{k} is calculated as follows:

$$P_{drop}^{k} = \prod_{n=n_k}^{N_{\max}} P_{e,n,pkt}^{k}, \tag{8}$$

$$P_{e,n,pkt}^{k} = 1 - \prod_{r=R_{start}^{k}}^{R_{end}^{k}} [1 - P_{e,n,r}^{k}(\gamma_{n,r,accum}^{k})]. \tag{9}$$

where $P_{e,n,pkt}^{k}$ is the packet error probability of UE k at the n^{th} retransmission and $P_{e,n,r}^{k}$ is the error probability of the r^{th} RB of UE k at the n^{th} retransmission, which is a function of $\gamma_{n,r,accum}^{k}$. $\gamma_{n,r,accum}^{k}$ is the SINR estimation value when UE k is allocated resource on the r^{th} RB which is added by the accumulated SINR value at the n^{th} HARQ retransmission.

Chapter 4

PROPOSED RESOURCE ALLOCATION STRATEGY

In this chapter, we propose our strategy which effectively improves VoIP capacity by mitigating the inter-cell interference and optimizing the frequency selective scheduling gain. As explained in previous chapters, VoIP packets are small and periodically generated. It means that the number of RBs which are allocated to each UE is small and our proposed strategy separates the major interference sources in a confined frequency region which is assigned to each sector. This interference source separation is done by a two-step ordering rule: *UE scheduling priority ordering rule* and *frequency allocation ordering rule*. By applying our simple ordering strategy, the inter-cell interference is effectively separated between sectors so that the SINR estimation accuracy can be improved.

4.1 Uplink Resource Scheduling Principle

Before describing our proposed strategy, it is necessary to explain the principle of uplink frequency-selective scheduling as backgrounds. Basically eNB performs the channel quality estimation for the frequency-selective resource scheduling. Sounding Reference Signal (SRS) is used to enable the eNB to determine the best channel (i.e., RBs) for each UE. SRS are transmitted by any UE within the cell and the subframes in which the SRS transmissions occur are indicated by cell-specific broadcast signaling. The SRS transmissions are always in the last SC-FDMA symbol in the configured subframes. The eNB may configure a UE to transmit SRS periodically and the periodicity may be any of 2, 5, 10, 20, 40, 80, 160 or 320 ms. The SRS may span on the whole system bandwidth or some part of it (i.e., called ‘SRS Bandwidth’). The minimum SRS bandwidth supported is four RBs [2]. The SRS bandwidth with size of full system bandwidth is most effective setting to use because it provides the channel quality of the full bandwidth in a single SRS transmission. Since UE, however, has a limitation on its maximum transmission power, the channel quality estimation can be inaccurate for some bandwidth on which UEs are confronted by their maximum power constraint. On the other hand the SRS with smaller bandwidth can provide more accurate estimation especially for the case of smaller data packet transmission environment such as VoIP transmission. In the case of small SRS bandwidth, the frequency hopping method which covers the whole system bandwidth by several SRS transmissions is used. We assume in this thesis that the SRS bandwidth is four RBs and the SRS transmission periodicity is 320 ms, which is a reasonable value for all UEs in a sector to send the SRSs covering the whole system bandwidth.

4.2 Basic Strategy

The basic strategy is divided into two steps: *UE Scheduling Priority Ordering* and *Frequency Allocation Ordering*. In the first step the scheduler determines the scheduling priority among several candidate UEs waiting for their voice packet transmission according to their packet generation interval. Then, the UEs sorted by the priority measure are allocated the frequency resources which are also sorted by another rule. The detailed rules are explained in the following sections.

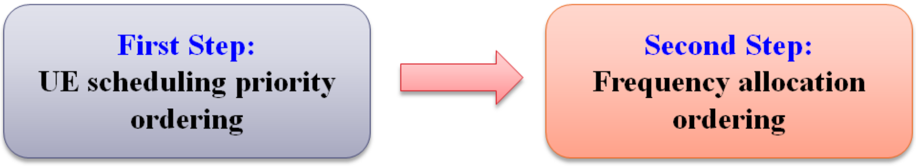


Fig. 4-1: Basic Strategy.

4.3 UE ordering rule

In LTE system, when UEs transmit packets the transmission power is controlled by the uplink power control formula. In this thesis only the open-loop power control formula is considered. The formula is shown below in Eq. (10).

$$P_t = \min\{P_{\max},\ P_0 + \alpha \cdot PathLoss + 10\log M_0\}, \qquad (10)$$

where P_t is the uplink transmission power, $P_{\max}$ is the maximum transmission power of UE, P_0 is the target received power, α is the path loss compensation factor and M_0 is the number of RBs used by the UE.

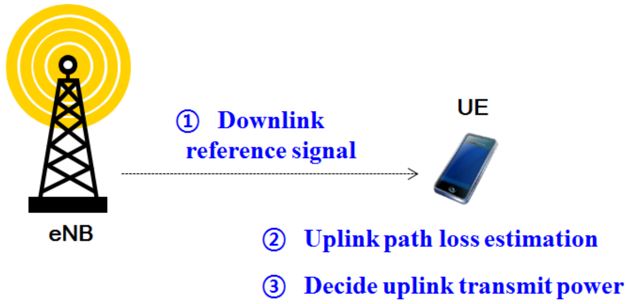


Fig. 4-2: Uplink Transmission Power Control.

The UE's uplink power is determined by first measuring the downlink reference signal strength. Assuming the channel reciprocity the UE estimates the uplink path loss by measuring downlink reference signal strength. After the path loss is estimated, the UE put the value to the power control formula and determines its transmission power. In three sectorized cells, the downlink reference signal strength is affected by the UE's angle to the sector eNB as well as the path loss. Therefore the UE's transmission power distribution according to their position in the sector is depicted as in Fig. 4-3.

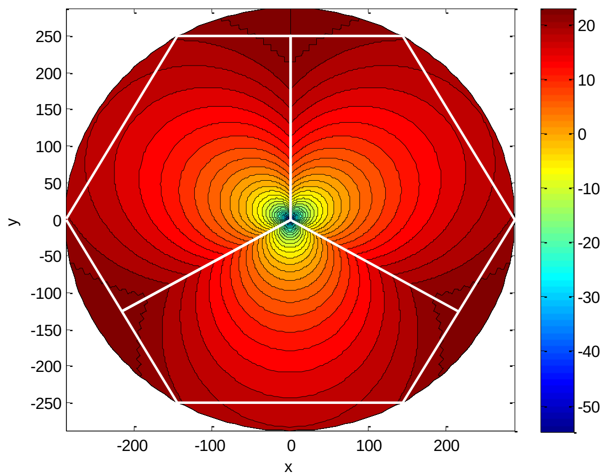


Fig. 4-3: Uplink Transmission Power Distribution.

As a result, the uplink received signal strength (RSS) of packet transmitted by UEs according to their locations shows a similar trend as shown in Fig. 4-4.

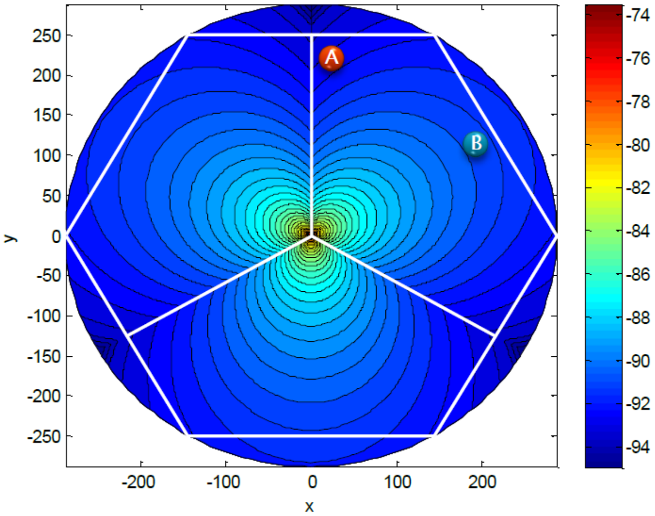


Fig 4.4: Uplink Received Signal Strength Distribution.

Assume that UE A and UE B are located in the same sector and positioned as shown in Fig. 4-5. If we consider the susceptibility of interference in neighboring sectors, UE A is definitely giving higher interference to neighboring sectors than UE B. Looking at Fig. 4.4, UE A has lower RSS than UE B's. Considering the RSS distribution and interference effect to neighbors leads us to an idea that we need to separate the UEs around the region where UE A is located. Therefore the first UE ordering metric should be the RSS values of UEs in ascending order, i.e., the UE with lowest RSS has highest priority.

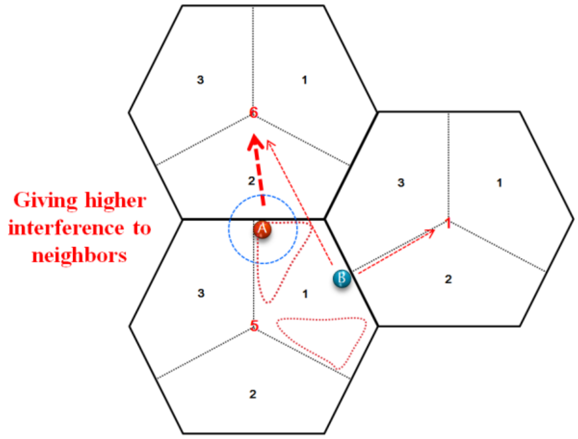


Fig. 4-5: Comparison of Interference to Neighbors by UE locations.

However, if we stick to only the RSS metric when we make priority order of UEs, the retransmission UEs or allocation failed UEs with relatively low RSS values will keep having lower priority. It can result in consecutive scheduling failure of such UEs. Therefore we need to take additional priority metrics into consideration.

In order for allocating more priority metric values to above mentioned UEs, the number of retransmissions and the number of allocation failures of the UE is added to the priority metric as following in Eq. (11).

$$Metric = RSS - \omega_{RETX} \cdot N_{RETX} - \omega_{AllocFail} \cdot N_{AllocFail}\,, \qquad (11)$$

where ω_{RETX} and $\omega_{AllocFail}$ are weighting factors and N_{RETX} and $N_{AllocFail}$ are the number of retransmissions and allocation failures of the UE respectively. According to our extensive simulations, those weighting factors affect the system performance of our proposed scheme especially in the high cell loading situation, i.e., the number of UEs in the cell is large.

4.4 Frequency Allocation Ordering

After the UE scheduling priority ordering is done, the scheduler sets the rule of frequency allocation order. First the whole system bandwidth is divided into three sub-bands, and each sector is assigned its preferred sub-band in an orthogonal manner. Then the allocation starts from the center position of the preferred sub-band. Staring from the center position the next allocation position spreads out to the outer resources in the preferred sub-band and the traverse direction alternates from right to left and vice versa. This allocation rule is depicted in Fig. 4-6.

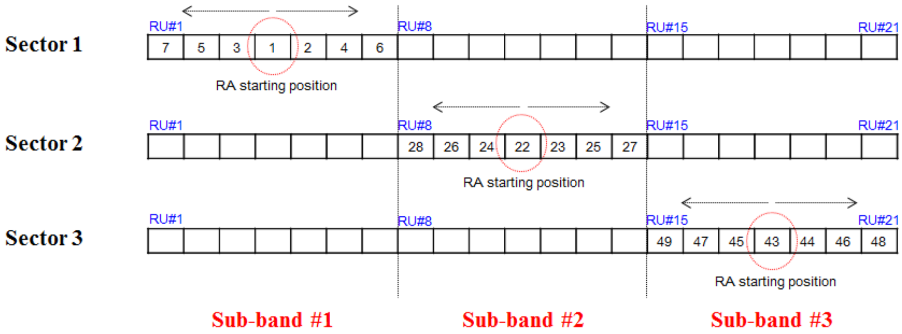


Fig. 4-6: Frequency Allocation Order in Preferred Sub-band.

When the frequency resources in the preferred sub-band depletes, allocation in other sub-bands begins. Before that, the scheduler refers to the neighboring sector number which each UE gives the maximum interference to. According to [12], in order to support handovers and scheduler operation, UEs measure the downlink reference symbol received power (RSRP) from neighboring eNBs around the UEs locations and report the relevant information to their serving eNB in a regular basis. Therefore the serving eNB can recognize each UE’s victim sector in neighboring cell and record the information.

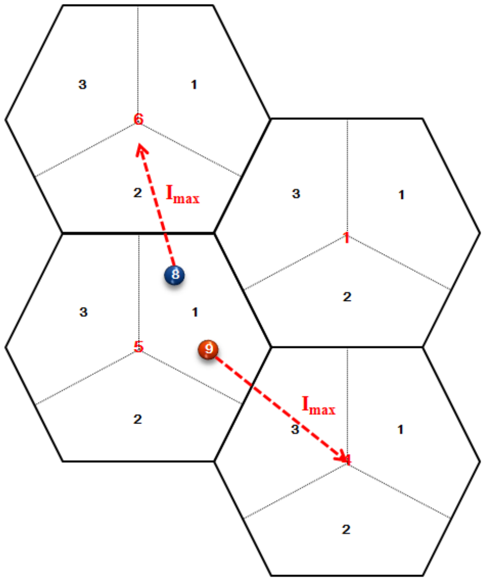


Fig. 4-7: Biggest Interference Victims.

Returning to the frequency allocation ordering rule, when the resources in the preferred sub-band are all possessed by other UEs already, the scheduler allocates each UE in such a way that the UE avoids being allocated in the other sub-band which is the biggest interference victim sector's preferred sub-band. In the example illustrated in Fig. 4-7, UE 8's biggest interference victim is sector 2 in cell 6. In this case the UE 8 is allocated in sub-band 3. UE 9 is allocated in sub-band 2 for the same reason.

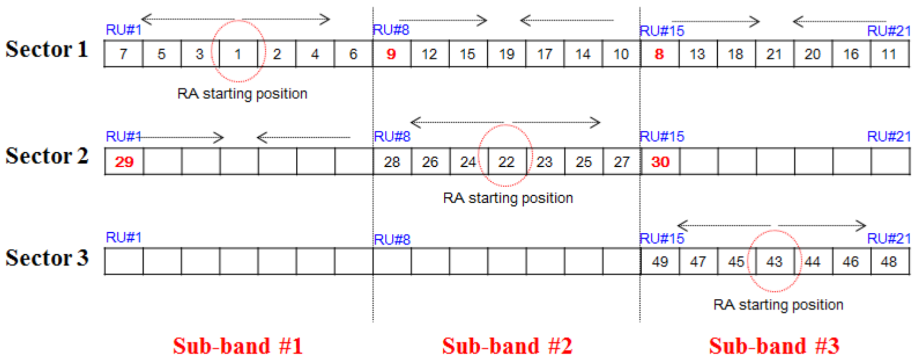


Fig. 4-8: Frequency Allocation in Other Sub-bands.

When the UE is allocated resources in non-preferred subbands, the resource position order is reversed to the order in its preferred subband, i.e. from the outer positions to the center position. The reason why doing in this way is to allocate higher interference sources into the positions where less vulnerable UEs in other sectors' preferred subbands is located. Each sector gives interferences to other sectors, and suffers from interference from other sectors at the same time. Therefore by allocating UEs who are sorted mainly by RSS to resources which are ordered as in Fig. 4-9, higher interference-giving positions and higher interference-immune positions vice versa in other sectors can be matched so that inter-cell interferences can be better mitigated.

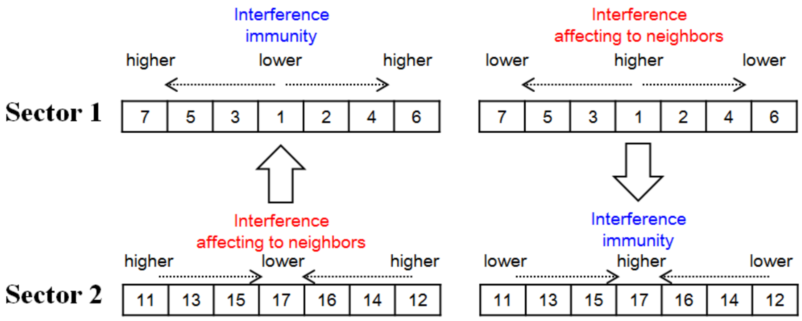


Fig. 4-9: Interference Mitigation in a Subband.

According to the frequency resource order, each sorted UE in turn finds its appropriate resources by applying the VoIP capacity maximization criterion presented from Eq. (6) to Eq. (9) in Chapter 3. Note that this resource allocation is only applied to the UEs which are initially persistently allocated and the retransmission UEs and the UEs who transmit Silence Indication Descriptor (SID) packets. The initially allocated persistent UEs use the same frequency resource position after 20 ms and so on. The Modulation and Coding Scheme (MCS) adaptation is also performed in a consistent manner. The scheduler first starts with the highest MCS for a candidate UE and resources. The VoIP capacity maximization criterion is applied and the UE-resource suitability is determined. If they are not suitable, the MCS level is decreased to one-step down. Therefore an adjacent RB becomes the resource candidate together with the formerly selected resources. This continues until the lowest MCS is tested and then moves to the next ordered resources.

4.5 Enhancing SINR Estimation Accuracy

When the cell-size gets smaller, the effect to accurate SINR estimation becomes more dependent on estimating the inter-cell interference than the channel fluctuation caused by fading. In VoIP environment, however, each UE possesses only a small portion of resources in the whole system bandwidth. This peculiarity of VoIP packets other than ordinary data packets makes estimating the ICI more difficult. By exploiting the fact that VoIP packet generation is periodic and the semi-persistent scheduling is used as a basis scheme, we can enhance the SINR estimation accuracy by utilizing the 20ms prior interference information on all the RBs. When the semi-persistent scheduling is applied, the persistently scheduled UEs use same frequency resource position every 20 ms. Therefore the 20 ms prior interference information can be more useful because the interference patterns according to the frequency band position are more likely to be same with 20 ms ago.

4.6 Optimum Power Control Parameters

As introduced in previous chapters, the uplink transmission power is set by below formula:

$$P_t = \min\{P_{\max},\ P_0 + \alpha \cdot PathLoss + 10\log M_0\}, \tag{12}$$

where P_0 and α are the cell-specific parameters broadcasted by the serving eNB. According to [13], the optimum P_0 and α values depend on the cell size, the maximum transmit power and the number of RBs used for each UE. It implies that the optimum power control parameters in VoIP traffic scenario can differ from other types of traffic scenarios. However, finding the optimum parameters analytically can be complicated because too much randomness exists.

Therefore we try to find the optimum power control parameters by combining results of the off-line simulation and the on-line system level simulation which is presented in the next chapter. The off-line simulation is performed in the same cellular topology as our system level simulation environment.

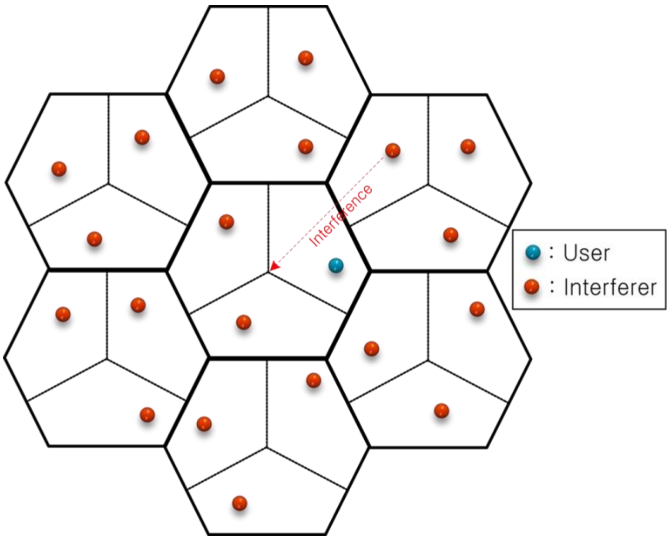


Fig. 4-10: Off-line simulation scenario.

The method for finding the optimum power control parameters is as follows. In one simulation loop we put UEs in random positions in all the sectors as depicted in Fig. 4-10. The UE in the first sector of the center cell is regarded as a user. All the other UEs are regarded as interferers. The interferers are also located randomly. The average interference which the user suffers from is expressed as Eq. (13) below:

$$\overline{I_{ji}} = \iint_{\{neighbors\}} I_{ji}(x_j, y_j, P_0, \alpha)\, f(x_j, y_j)\, dx_j dy_j\,, \tag{13}$$

where $I_{ji}(x_j, y_j, P_0, \alpha)$ is the amount of interference which interferer j affects to user i and (x_j, y_j) is the interferer's location in its sector. The interferers' transmission powers are attenuated by $f(x_j, y_j)$. Then the user's SINR is calculated by using the calculated average interference and the user's uplink received signal strength. The calculated SINR is put into our BLER versus SINR curve and the error probability P_{err} is calculated. The average outage probability is calculated as below:

$$P_{out} \cong \iint_{\{in-\sec tor\}} P_{err}(x_i, y_i, P_0, \alpha)\, g(x_i, y_i)\, dx_i dy_i\,. \tag{14}$$

This process is iterated for 100,000 times. By changing P_0 and α values, the average outage probability graph is drawn as shown in Fig. 4-11.

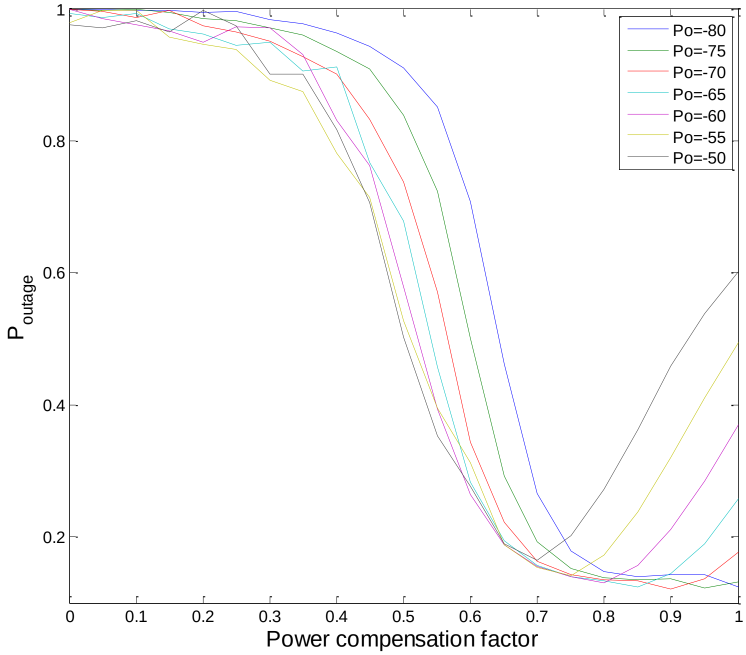


Fig. 4-11: Optimum power control parameters.

By observing the result, we set the candidate optimum parameter sets, which are (P_0, α) = (-75, 0.8), (-75, 0.9), (-75, 1.0), (-70, 0.8), (-70, 0.9), (-70, 1.0), (-65, 0.8), (-65, 0.9), (-65, 1.0). Then we apply each set to our system level simulator. We find that (P_0, α) = (-65, 0.9) shows the best performance among those candidates.

4.7 Effectiveness of Proposed Strategy

In our proposed strategy, UEs' scheduling priority is sorted mostly according to their RSS values. Their interference influences and vulnerabilities to/from neighboring cells are effectively aligned by applying the simple frequency resource allocation rule. In many scheduling problems, dealing with the computational complexity of searching the optimal resources for each UE is another significant issue. Especially in the VoIP traffic environment where interference fluctuation is pretty high, the computational complexity of the exhaustive search can be $O(N^2)$. Therefore the conventional algorithms deal with this problem by setting UE scheduling priority and searching the appropriate resources which satisfy their utility functions considering throughput, fairness, best CNR and so on. Even in this case, however, the computational complexity is $O(N)$ because the scheduler should consider all the available resources to schedule each single UE.

The computational complexity of the proposed strategy can be from $O(1)$ to $O(N)$ depending on the cell loading. The scheduler may find the sub-optimal resources for each UE in a few tries with high probability because the interference effects are aligned along with the frequency resource order. In the next chapter, we show that our proposed strategy outperforms the conventional schemes such as FFR, Frequency Reuse 3 with low computational complexity.

Chapter 5

Performance Evaluation

In this chapter, the proposed resource allocation strategy is evaluated via an extensive system level simulator developed on C++. Both user satisfaction ratio and average resource utility ratio will be presented to demonstrate that the proposed scheme outperforms the other conventional schemes such as FFR and Reuse 3 schemes.

5.1 Simulation Environment

The simulation model and parameters are presented in Table 5-1. We adopt the 19-cell 2-tier wrap-around model with three sectorized cell sites in order to avoid edge effect when calculating the inter-cell interference as previously shown in Fig. 3-1.

System Model	
Cell deployment	Hexagonal grid, 19 cell wraparound, 3 sectors per site
Inter-site distance	500m (Urban macro-cell)
System Bandwidth	5MHz (24 RBs for PUSCH and 1 RB for PUCCH)
UE's maximum output power	23dBm (= P_{max})
Channel Model	Path loss + Multipath fading (Rayleigh Model)
Noise Figure	5dB (at eNB)
Penetration Loss	20dB
HARQ	Synchronous adaptive with chase combining
Power control scheme	$\mathrm{Max}(P_{max}, P_0+\alpha \cdot \mathrm{PathLoss}+10\log_{10}M)$
	P_0 = -65dBm, α=0.9
Simulation Time	Number of subframes = 20,000 (20 sec duration) with 3 times iterations for each round

Table 5-1: Simulation Parameters [10].

5.2 Comparison Schemes

For the performance evaluation of the proposed scheme, the following three comparison schemes are also evaluated:

- Proposed scheme without maximum interference information, referred to as “Propose w/o I_{max}”
- Frequency Reuse 3, referred to as “Reuse 3”
- Fractional Frequency Reuse with protection ratio of 0.1, referred to as “FFR”

The proposed scheme without maximum interference information is the same as our proposed scheme only except that it does not use the information about which neighboring sector each UE gives the biggest interference to. In this comparison scheme, therefore, when the preferred subband is not available to use, one of two non-preferred subbands is randomly selected. The concept is depicted in Fig. 5-1.

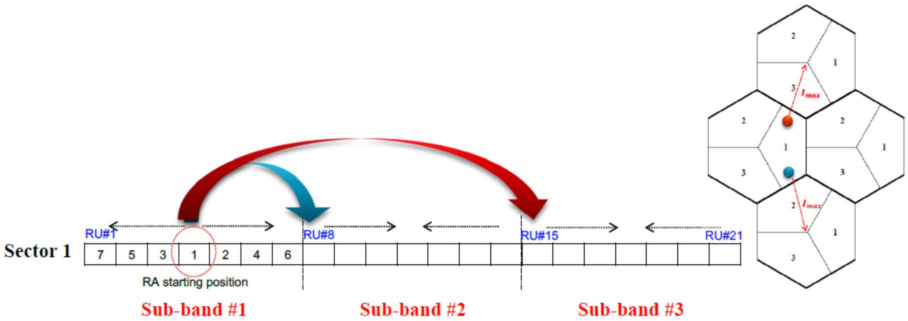
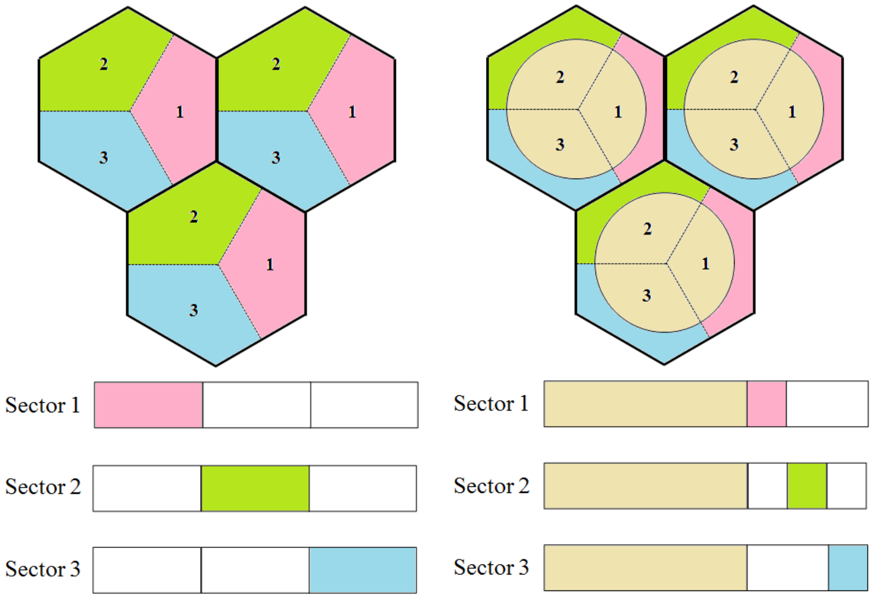


Fig. 5-1: Proposed Scheme without Max Interference Information.

Fig. 5-2 shows the other two comparison schemes: Reuse 3 and FFR. In Reuse 3, the system bandwidth is divided into three subbands and each subband is dedicated to a sector. In FFR scheme, the cell-center users utilize the common subband together with users in neighboring sectors, and the cell-edge users are allocated a dedicated subband as in Reuse 3 scheme. The protection ratio, i.e., the fraction of system bandwidth which is allocated to cell edge UEs, is set to 0.1. It means the lowest 10% of the cell edge UEs are protected in the dedicated protection subband.



(a) Frequency Reuse 3 (b) FFR

Fig. 5-2: Comparison Schemes.

5.3 Simulation Results

The considered performance metrics are user satisfaction ratio, resource utility ratio in total simulation time, and average interference level in each sub-band. The number of users in each simulation run varies from 260 to 380 with increment of 20. A simulation duration is 20,000 subframes for each scheme, and is iterated three times and averaged.

Fig. 5-3 shows the user satisfaction ratio. As explained in Chapter 2, the VoIP capacity is defined as the number of users per sector when the user satisfaction ratio exceeds 95%. From the figure, we observe that the VoIP capacity of two proposed schemes is about 300 users per sector, while other two comparison schemes achieve much lower capacities.

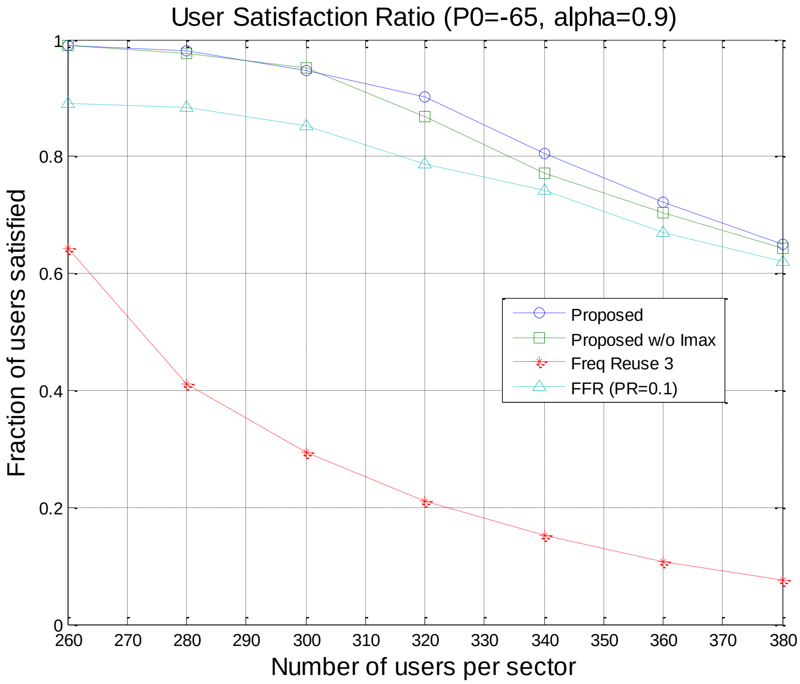


Fig. 5-3: User Satisfaction Ratio.

The resource utility ratio is the average fraction of the whole system bandwidth utilized, and is shown in Fig. 5-4. It is easily shown that FFR and Reuse 3 schemes have limitation on resource utilization in compensation of inter-cell interference coordination. However, two proposed schemes utilize resources more than two comparison schemes so that they achieve better system performance.

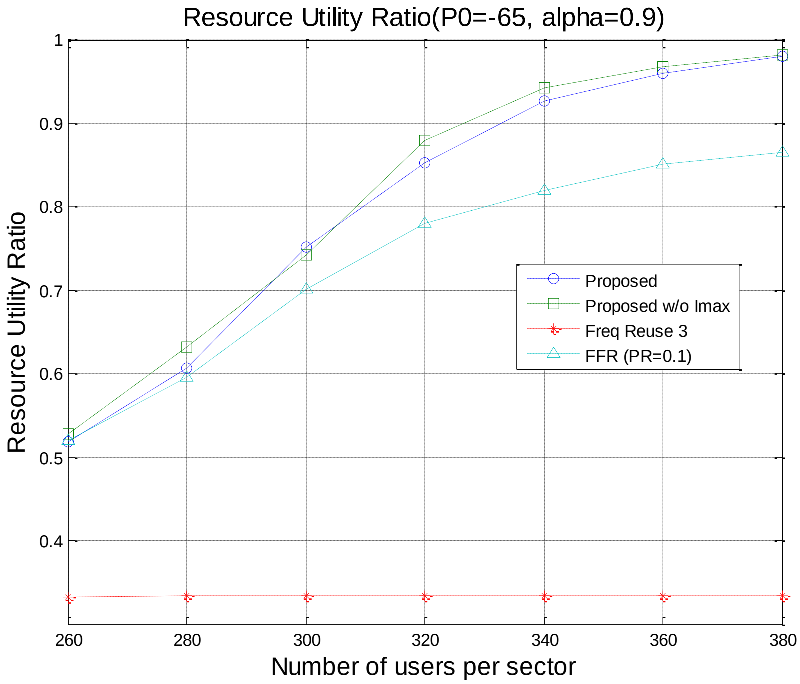


Fig. 5-4: Resource Utility Ratio.

Fig. 5-5 shows the inter-cell interference alignment effect of the proposed scheme. In the figure, the average interference levels in each sector's preferred subband are lower than the levels in other non-preferred subbands. In less interfered frequency resources, more vulnerable and at the same time more threatening UEs are allocated. By doing so, the inter-cell interference can be effectively separated in an orthogonal manner without limiting their bandwidth usage boundaries. This is the beauty of the proposed strategy.

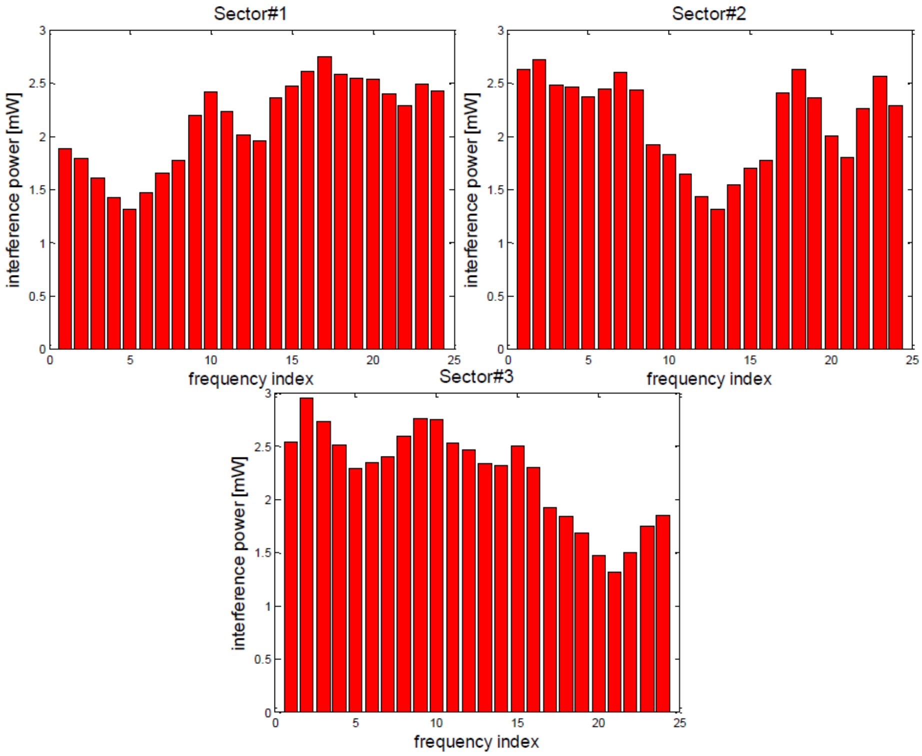


Fig. 5-5: Average Interference over Frequency Resources

Chapter 6

Conclusion

In this thesis, a new and effective resource allocation strategy is proposed. The proposed scheme has strengths in its effects on inter-cell interference separation and its low computational complexity. The inter-cell interference mitigation is achieved by separating vulnerable and threatening UEs in each sector in an orthogonal manner. This strategy has already been considered in FFR based algorithms. However, the FFR-based schemes have limitation in that they strictly set the frequency allocation boundaries, thus limiting the resource usage efficiency. Our proposed algorithm overcomes this limitation by simply adopting UE prioritization via RSS and frequency resource ordering.

This work is done based on the assumption that the semi-persistent scheduling is used for VoLTE scheduling. Recently the effectiveness of semi-persistent scheduling over dynamic scheduling is being argued among many entities in industry. Those argues, however, do not explain the way of how to estimate the inter-cell interferences as accurate as possible in VoIP traffic with multi-cell scenarios. Intuitively we assert that our proposed scheme with semi-persistent scheduling will make better performance than dynamic scheduling because the inter-cell interference estimation becomes a very complicated problem when dynamic scheduling is applied. The proof and evaluation will be one of our future works.

In addition, in our work the number of UEs in a cell is fixed and is applied evenly to all the other cells. If the cell loading changes, the situation may also change. We also plan to consider different cell loading scenarios as our future work.

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한글 초록

LTE 기술은 전 구간 패킷-스위칭 네트워크 운영을 목표로 개발된 시스템이므로, 3GPP에서는 LTE에서의 VoIP 기술, 즉 VoLTE 기술을 LTE의 음성통화지원 표준기술로 채택하였다. 그러나, VoLTE 서비스는 짧은 delay bound, 낮은 loss tolerance 그리고 silence suppression, 주기적/작은 크기의 패킷생성 등의 특징 때문에 패킷기반 LTE 네트워크에서 구현하는데 많은 어려움이 따른다. 또한 상용 LTE시스템 구축 시나리오, 즉 다중 셀 환경에서 시스템 성능을 높이기 위해서는 셀 간 간섭제어 문제를 해결하는 것이 필수적이다. 본 논문에서는 LTE 상향링크에서의 VoIP 용량을 향상시키기 위한 새로운 자원할당 스케줄링 알고리즘을 제안한다. 본 논문이 제안하는 알고리즘은 단말로부터 전송된 신호의 수신 신호세기(RSS) 대 자원위치 간의 간단한 맵핑 방법을 적용함으로써 효과적으로 셀 간 간섭을 완화시키는 규칙을 포함하고 있는데, 이 규칙에 의하여 각 셀에서의 가장 큰 간섭 소스들을 서로 orthogonal 하게 분리시키는 효과가 나타난다. 또한 본 알고리즘은 여러 단말과 여러 주파수 자원블럭(Resource Block) 간의 최적의 조합을 찾는 자원할당 문제에 있어서 기존의 다른 알고리즘에 비해 계산부담을 현저하게 낮음으로써 전력 및 프로세싱 파워에 대한 요구사항을 낮

출 수 있다. 본 논문에서는 시스템 레벨 시뮬레이션을 통하여 제안하는 알고리즘이 다른 기존의 자원할당 알고리즘에 비해 상당한 성능향상을 이끌어 냄을 보인다.

주요어: LTE, VoIP 용량, 자원할당 스케줄링, Inter-cell Interference Coordination (ICIC), 다중 셀 환경
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