A Study on Resource Allocation for Wireless Relaying Networks

March 2009

Rui Zhou

Contents

Chapter 1

General Introduction

Wireless communication becomes a part of our daily lives, not only for convenience but also as a culture. As an example, mobile phones are used for communications, e-mail services and internet. The fast growth of the Internet and the broadband technology has fundamentally changed the way to distribute and access information. Meanwhile, portable digital devices have become increasingly popular among businesses and consumers.

1.1 Wireless Systems

1.1.1 Basic Concepts

A wireless access system provides terminals within the service area to receive information. Conveyed by the wireless link, information should be transmitted by a signal through the transmission medium. Fig. 1.1 illustrates the basic principle of wireless communications.

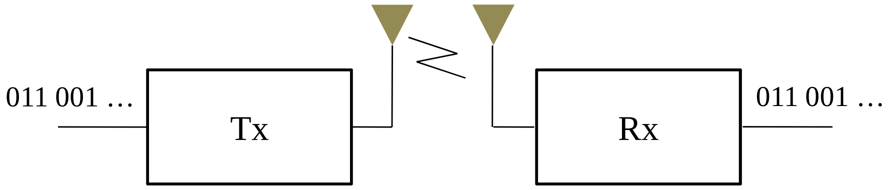


Figure 1.1 Basic communication concepts.

The wireless network should facilitate the seamless operation of the various Internet applications and protocols, so that a user perceives it to be of equivalent quality to a broadband wire line service [1.1]. Wireless spectrum is scarce. Mobile wireless communications make achieving high spectral efficiency a challenge.

Fig. 1.2 shows the development of the mobile communications with the last decade. People use 2G for e-mail and web access services and 3G for video call and online visual games. From B3G, people can gain real environment information and some object related applications. To satisfy the future user needs, limitations of the system used now should be solved to increase the system performance.

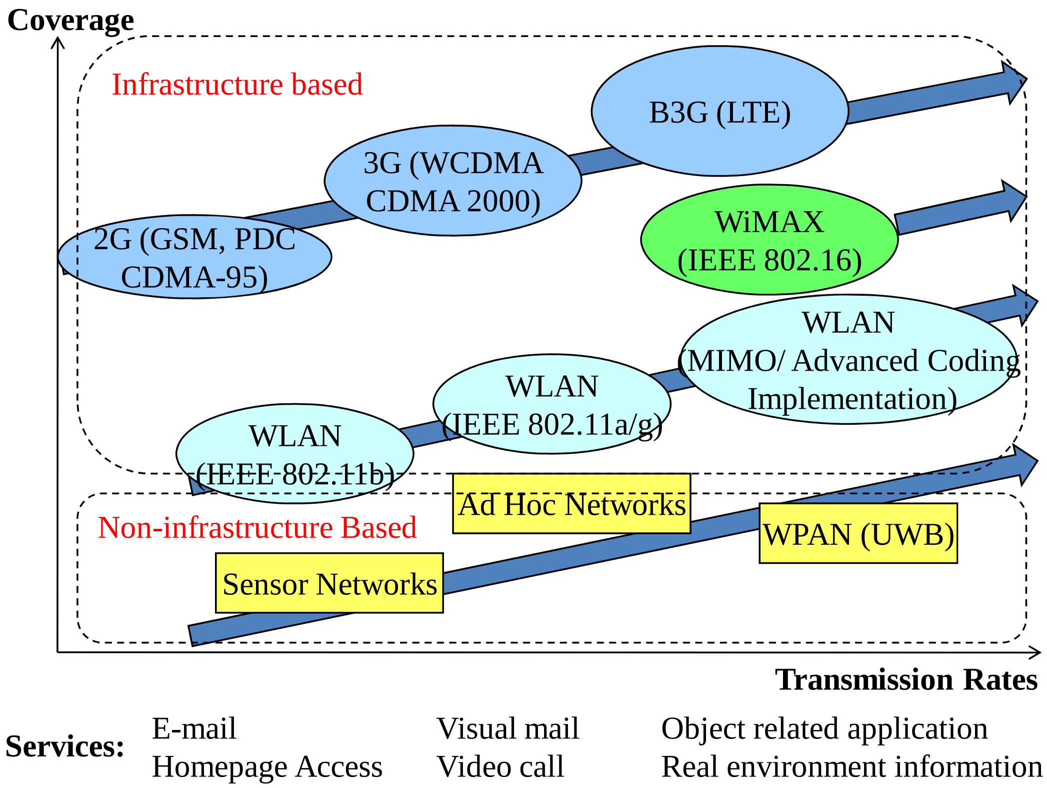


Figure 1.2 Mobile communications.

Beyond 3G, demands for the communication systems have been greatly increased, as follows:

- Very high data rate transmission,
- High quality of link,
- Transmission of increasing multimedia data throughput,
- Guarantee of user fairness,
- Low latency,
- Small / light terminal device,

- Power saving.

Many key techniques are appeared to lead the way to the next generation communication, such as multicarrier code division multiple access (MC-CDMA) and orthogonal frequency division multiplexing (OFDM) for the broadband wireless access technology, all IP core network technology, and wireless ad hoc network technology. In the thesis, we focus on the network and wireless access technologies.

1.1.2 Resource Management

In many for wireless communication systems, the primary goal is to provide network access to a large number of mobile or stationary users. The key problem in such a system is the proper management of the scarce resources is the system to satisfy both the provider of services and the user of these communication services [1.2]. The provider wants a high and efficient utilization of the system since it derives more revenues by being capable of providing services to more users. The user in turn wants a good Quality of Service (QoS), like the throughput, response time or the message delay. In most resource management problems, the operators aim to increase the number of users served, and the capacity of the system is in conflict with the user’s desire to achieve a higher service quality. Efficient frequency resource management can improve both the capacity as well as the efficiency of the system.

1.2 Previous Works

1.2.1 Multiple Access Schemes

The wireless communication industry has rapidly evolved in the past decade to provide high transmission rate wireless communications in the form of cellular mobile and wireless local area networks. Current mobile communication networks are based on a single-hop network architecture, where every user connects to the base station (BS) directly. Therefore, the cell coverage and system throughput are limited by the BS’s transmission capability. In order to provide high speed access, large user’s signal to interference ratio (SIR) is required. Increasing the transmission power of BSs can extend their coverage. However in interference limited systems, such as code division multiple access (CDMA) systems, increasing signal power intended for a user also increases the interference to other users.

Another solution is to increase the BS density and reduce individual BS's coverage resulting in higher infrastructure cost. To solve such problems, there has been an upsurge of interest in multihop architecture networks [1.3]. Examples are cellular ad hoc networks, mesh networks in IEEE 802.16, and the coverage extension of HyperLAN/2. A concept and the related performance evaluation for a wireless broadband system based on fixed relay stations acting as wireless bridges are presented in [1.4].

Many researches have demonstrated the ability of ad hoc communication to extend wireless coverage. However, pure ad hoc networks suffer from low throughput due to inefficient routing and power limitation. A hybrid model with both mobile and fixed users, which is proposed in [1.5], is also inefficient due to the same reason, although the usage of BSs yields high throughput.

Multihop CDMA cellular networks have been proposed recently where the coverage and throughput are increased by using independent wired or wireless stations for relaying signals to users who might have insufficient SIR when connecting directly to a BS. Lin and Hsu propose a practical multi-hop wireless connection scheme for cellular systems by forwarding data packets from one user to another [1.6]. Zhao and Terence consider a cellular CDMA system with out-of-band ad hoc traffic relaying, the dual-mode mobile stations can choose available relay to improve cellular capacity [1.7]. The approaches for relay node placement in cellular space could extend BS's coverage by planning of ad hoc relay network [1.8]. However, there is a tradeoff between the ad hoc network and cellular systems. Data may be forwarded in a multi-hop fashion to increase coverage of BS, but it provides only a slight advantage in system capacity because of the low performance of the mobile terminal [1.9].

1.2.2 Resource Allocations

Providing quality of service (QoS) is one of the crucial requirements in wireless high speed data networks which exploit adaptive multi-rate shared channels, such as beyond third generation (B3G) wireless networks and IEEE 802.16 wireless metropolitan area networks (WirelessMAN). In order to achieve user fairness, Round Robin (RR) scheduling algorithm is proposed. On the other hand, maximum carrier to interference ratio (MCIR) scheduling algorithm can be used to achieve high system throughput. However, as the wireless channel condition is varying, existing scheduling algorithms do not utilize channel resources efficiently [1.10] [1.11].

Recently, opportunistic scheduling has drawn much research interests due to the efficient usage of channel resources, by developing rate adaptation schemes to increase data transmissions selectively on a link when it offers good channel quality [1.10]. In contrast, opportunistic manner always causes unfair to users who experience poor channel quality. The modified largest delay weight algorithm [1.12] is considered as a throughput optimal proportional fairness scheduling, which provides packets with long waiting time higher priority to be served. Furthermore, to provide QoS requirement for different traffic classes (delay sensitive traffic and delay tolerant traffic) [1.13], the proportional fairness based scheduling algorithms have been proposed in [1.14] - [1.17], where different traffic classes are distinguished, and delay bounded packet scheduling algorithms are provided. However, in these studies, high priority is given to delay sensitive packets, whereas a lot of delay tolerant packets would suffer long delay. More seriously, compared with users having good channel condition, the users with poor channel condition have to suffer from low priority. Thus, the low performance of such users becomes the bottleneck of scheduling design for system throughput enhancement.

In contrast to the conventional cellular systems, which use base stations (BSs) to transmit packets to mobile stations (MSs) directly, wireless relaying cellular network architecture has been proposed [1.18], by taking the advantages from the multi-hop networks, where the throughput-optimal scheduling strategies are considered with the queuing systems and routing for time varying channels [1.19] [1.10]. In the architecture, a MS can access the core network by connecting to BS directly in cellular mode or via other terminals, which operate as relays forwarding packets of MSs [1.21] [1.22]. A unified cellular and ad-hoc is proposed in [1.23] by introducing a routing protocol and proportional fairness scheduling in extension of 3G cellular.

The explosive growth of internet services needs the wireless communication network to overcome the limitation of wireless resources such as bandwidth constrains. Based on orthogonal frequency division multiple access (OFDMA), IEEE 802.16e standard is considered as a promising candidate for next generation wireless communications [1.24]. The IEEE 802.16e is also known as mobile worldwide interoperability for micro wave access (Mobile-WiMAX) [1.25]. Due to the flexibility of OFDMA, resource management plays a key role in such wireless networks. Generally, there is a tradeoff between transmission energy and channel efficiency, where the faded mobile users have to require the BS to increase the power [1.26]. Thus, the BS has to choose to reduce the power on other users or extend the service duration on the faded user with low transmission rates. Aim to coverage extension, throughput enhancement and spectrum efficiency, the newly formed IEEE 802.16j is focusing on mobile multi hop relay (MMR) networks for Mobile WiMAX [1.27]. Although MMR can benefit the network by introducing low cost relay stations, there still requires infrastructure support and complex system configuration.

Recently, cooperative communication is introduced as a new form of spatial diversity via the cooperation of users with others which do not directly participate in transmission [1.28] [1.29]. It enables tremendous improvements in robustness, throughput, and delay, significant reduction in interference, and coverage extension [1.30]. Cooperative communication usually has two phases to perform spatial diversity. Take time duplex as an example, transmission is divided into two time slots. In the first time slot, source broadcasts its information while both the relay and destination receive faded versions of the signal. The destination stores the signal for future processing. In the second time slot, the relay forwards the copy of the signal. Then the destination combines its buffered signal with the new version from the relay for decoding. In contrast to physical layer cooperative communications, several works focus on the MAC layer cooperation. CoopMAC is proposed for wireless LAN to improve throughput and delay performance with low overhead [1.31].

Relay selection is a critical issue addressed to cooperative networks, which should make tradeoffs between the system capacity and bandwidth efficiency [1.32]. OFDMA provides the flexible resource management in terms of power, subcarrier and time slots. Ng and Yu show that the capacity can be optimized with proper allocation on power and subcarrier [1.33].

1.3 Thesis Outlines

The fundamental issues for the wireless communication systems are that the system should be realized on efficiently use of frequency bandwidth, achieving high capacity and performance. Previous researches show the possibilities of the system performance due to the multi hop wireless networks. However, the resource management schemes have not been developed the networks due to the complexity. Furthermore, most of the previous researches on resource management focus on the issues in the single hop network. Our objective it to propose joint relay selection and resource management schemes to improve the capacity of cellular networks.

In this thesis, we focus on the objectives by developing the resource management schemes to improve the network performance. Fig. 1.3 shows the MAC layer design with consideration of Network and Physical layers in this thesis.

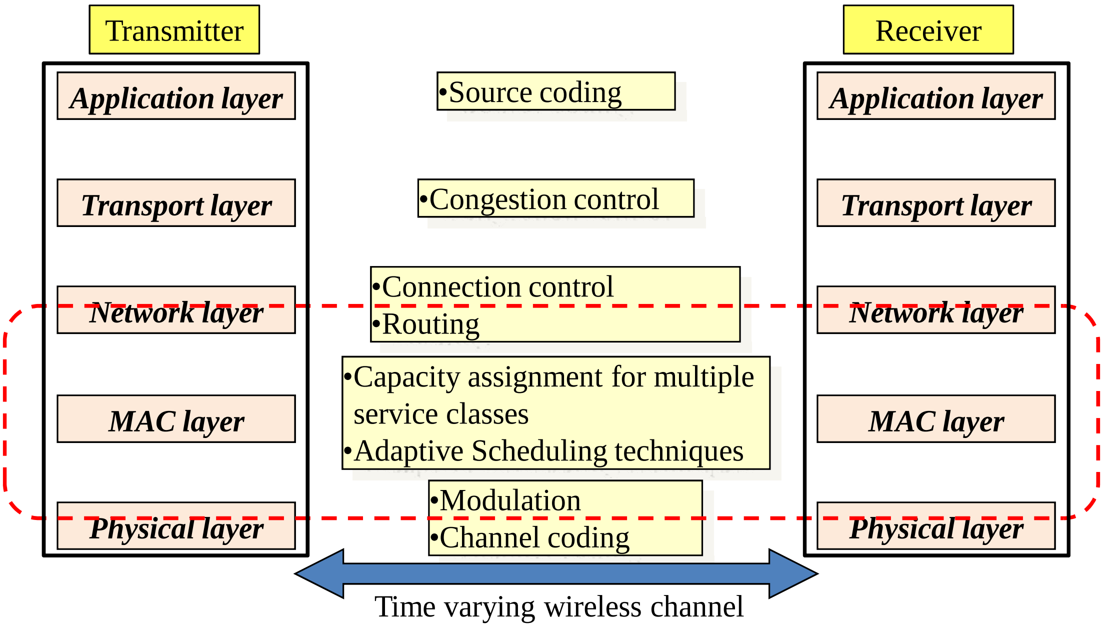


Figure 1.3 MAC layer design with consideration of Network and Physical layers.

Providing high data rate, large capacity and low cost service is one of the crucial requirements in wireless networks. Current mobile communication networks are based on single hop network architecture, while cell coverage and system throughput are limited. To achieve the flexibility and efficiency of coverage, frequency usage and transmission power, relay using in the cellular network is considered as a promising technique for the next generation wireless networks.

This dissertation proposes a number of resource allocation schemes and analyzes the performance enhancement for the cellular relay networks. Analysis and simulation results show the improvement of throughput, packet loss rate by using the scheduling schemes. Fig. 1.4 shows the organization of the thesis.

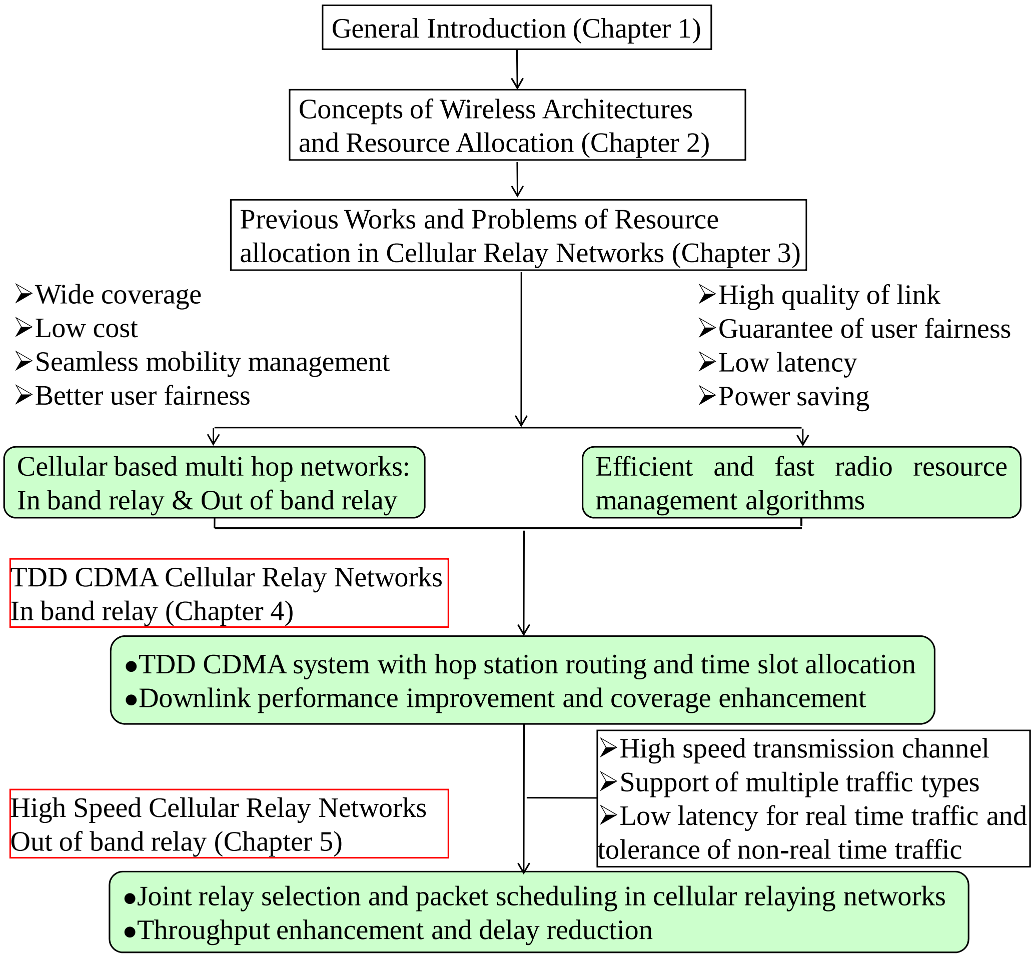


Figure 1.4 Organization of the thesis.

Chapter 1 gives an overview of the wireless networks and some main technologies for the next generation wireless communication systems.

Chapter 2 introduces key concepts of wireless architectures and resource allocation technologies as a liquid background for the research. In contrast to infrastructure base cellular networks, fixed relay network and ad hoc network are introduced due to their flexibility. However, the routing, scheduling problems limit their performance. Furthermore, we provide an overview of the resource allocation schemes.

Chapter 3 describes the previous works and problems of resource allocation in cellular relay networks. Since the time slot allocations and packet scheduling schemes have been studied in only a single hop fashion. In order to improve and evaluate the performance for cellular relay networks, we discuss the problem by exploiting time slot allocation and scheduling schemes into cellular relay networks.

Table 1.1 An overview of chapter 4 and chapter 5.

Chapter 4:	**Downlink Performance Improvement of TDD CDMA Cellular Networks**
Objectives	➢ To improve the system capacity of TDD CDMA multi hop network.
Problems in past works	➢ Increasing power of the BS causes the interference. ➢ Inefficient routing and scheduling schemes. ➢ High outage probability when a large number of users are active in the cell.
Solutions	➢ Hop stations are selected among the fixed user. ➢ Traffic dependent routing is introduced to improve the system efficiency. ➢ Time slot allocation is introduced to gain efficient frequency reuse.
Effects	➢ Coverage of one BS is enhanced. ➢ More users can connect to the BS through the hop stations. ➢ The Outage probability gets better as compared to the conventional single hop network.
Chapter 5:	**Packet Scheduling for Cellular Relay Networks**
Objectives	➢ Improve the system performance by introducing the efficient scheduling schemes.
Problems in past works	➢ Inefficient relay selection and scheduling schemes. ➢ Low throughput when a large number of users are active in the cell. ➢ Long packet delay for best effort traffic
Solutions	➢ Proposal of a utility based scheduling scheme. ➢ Selection of a user with good cellular channel condition as a relay. ➢ Traffic categorizing for different transmission requirements.
Effects	➢ The Outage probability gets better as compared to the conventional network. ➢ Improvement of aggregated network throughput. ➢ Reduction of packet loss. ➢ Better fairness in terms of received throughput for each mobile users

Chapter 4 proposes a joint hopping station selection and time slot allocation scheme to improve downlink performance for TDD CDMA cellular relay networks. In the network, a number of fixed subscriber stations act as hopping stations between base stations and far-away subscriber stations, by combining of cellular and ad hoc mobile network architectures. The proposed system is able to provide lower outage probability (i.e. more users can connect to the networks with required SIR). The computer simulation results show that the proposed networks can provide better outage probability compared to the conventional single hop networks.

Chapter 5 proposes a packet scheduling algorithm for cellular relay networks by considering relay selection, variation of channel quality and packet delay. In the networks, mobile users are equipped with not only cellular but also user relaying radio interfaces, where base station exploits adaptive high speed downlink channel. Our proposed algorithm selects a user with good cellular channel condition as a relay station for other users with bad cellular channel condition but can get access to relay link with good quality. This can achieve flexible packet scheduling by adjusting transmission rates of cellular link. Packets are scheduled for transmission depending on scheduling indexes which are calculated based on user’s achieved transmission rate, packet utility and proportional fairness of their throughput. The performance results obtained by using computer simulation show that the proposed scheduling algorithm is able to achieve high network capacity, low packet loss and good fairness in terms of received throughput of mobile users. Table 1.1 shows an overview of chapter 4 and chapter 5.

Chapter 6 concludes the dissertation.

References

[1.1] R. Laroia, S. Uppala and J. Li, "A Designing a Mobile Broadband Wireless Access Network", *IEEE Signal Processing Mag.*, pp. 20-28, Sep. 2004.

[1.2] J. Zander and S. L. Kim, *Radio Resource Management for Wireless Networks*, Artech House, 2001.

[1.3] R. Pabst, B. H. Walke, D. C. Schultz and P. Herhold, “Relay-Based Deployment Concepts for Wireless and Mobile Broadband Radio,” *IEEE Commun. Mag.*, pp. 80-89, Sep. 2004.

[1.4] N. Esseling, B. H. Walke and R. Pabst, “Performance Evaluation of a Fixed Relay Concept for Next Generation Wireless Systems,” *IEEE PIMRC*, Barcelona, Spain, pp. 744-751. Sep. 2004.

[1.5] B. Liu, Z. Liu and D. Towsley, “On the Capacity of Hybrid Wireless Networks,” *IEEE Infocom*, San Francisco, USA, pp. 1543-1552, Mar. 2003.

[1.6] Y. D. Lin and Y. C. Hsu, “Multihop Cellular: A New Architecture for Wireless Communications,” *IEEE Infocom*, Tel Aviv, Israel, pp. 1273-1282, Mar. 2000.

[1.7] D. Zhao and T. D. Todd, “Cellular CDMA Capacity Improvement using Ad Hoc Relaying,” *IEEE PIMRC*, Barcelona, Spain, pp. 719-723, Sep. 2004.

[1.8] H. Wei, S. Ganguly and R. Izmailov, “Ad Hoc Relay Network Planning for Improving Cellular Data Coverage,” *IEEE PIMRC*, Barcelona, Spain, pp. 769-773, Sep. 2004.

[1.9] A. Fujiwara, S. Takeda, H. Yoshino and N. Umeda, “Evaluation of Cell Coverage and Throughput in the Multihop CDMA Cellular Network,” *IEEE VTC*, Milan, Italy, pp. 2375-2378, May 2004.

[1.10] H. Fattah and C. Leung, “An Overview of Scheduling Algorithms in Wireless Multimedia Networks,” *IEEE Wireless Commun.*, pp. 76-83, Oct. 2002.

[1.11] Y. Ofuji, A. Morimoto, S. Abeta, and M. Sawahashi, “Comparison of Packet Scheduling Algorithms Focusing on User Throughput in High Speed Downlink Packet Access,” *IEEE PIMRC*, Lisboa, Portugal, pp. 1462-1466, Sep. 2002.

[1.12] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R. Vijayakumar, “Providing Quality of Service over a Shared wireless Link,” *IEEE Commun. Mag.*, pp. 150-154, Feb. 2001.

[1.13] D. Zhao, X. Shen and J. W. Mark, “Radio Resource Management for Cellular CDMA Systems Supporting Heterogeneous Services”, *IEEE Trans. on Mobile Computing*, Vol. 2, No. 2, pp. 147-160, April-June 2003.

[1.14] M. Andrews and L. Zhang, “Scheduling over a Time-Varying User-Dependent Channel with Applications to High-Speed Wireless Data,” *J. of the ACM*, vol.52, No.5, pp. 809-834, Sep. 2005.

[1.15] Q. Liu, S. Zhou and G. B. Giannakis, “Cross-Layer Scheduling with Prescribed QoS Guarantees in Adaptive Wireless Networks,” *IEEE J. on Selected Areas in Commun.*, vol. 23, No. 5, pp. 1056-1066, May 2005.

[1.16] H. Jiang, W. Zhuang, and X. Shen, “Cross-Layer Design for Resource Allocation in 3G Wireless Networks and Beyond,” *IEEE Commun. Mag.*, pp. 120-126, Dec. 2005.

[1.17] F. D. Angelis, I. Habib, G. Giambene and S. Giannetti, “Scheduling for Differentiated Traffic Types in HSDPA Cellular Systems,” *IEEE Globecom*, pp. 36-40, St. Louis, USA, Dec. 2005.

[1.18] H. Wu, C. Qiao, S. De and O. Tonguz, “Integrated Cellular and Ad Hoc Relaying Systems: iCAR,” *IEEE J. of Selected Areas in Commun.*, Vol. 19, pp. 1105-2115, Oct. 2001.

[1.19] L. Tassiulas and A. Ephremides, “Stability Properties of Constrained Queueing Systems and Scheduling Policies for Maximum Throughput in Multihop Radio Networks,” *IEEE Transactions on Automatic Control*, Vol. 37, Issue 12, pp. 1936-1948, Dec. 1992.

[1.20] M.J.Neely, E. Modiano and C.E. Rohrs, “Dynamic Power Allocation and Routing for Time Varying Wireless Networks,” *IEEE Infocom*, Vol. 1, pp. 745-755, San Francisco, USA, Mar. 2003.

[1.21] D. Cavalcanti, D. Agrawal, C. Cordeiro, B. Xie and A. Kumar, “Issues in Integrating Cellular Networks, WLANs, and MANETs: A Futuristic Heterogeneous Wireless Network,” *IEEE Wireless Commun.*, pp. 30-41, June 2005.

[1.22] D. Zhao and T. D. Todd, “Cellular CDMA Capacity with Out-of-Band Multihop Relaying”, *IEEE Trans. on Mobile Computing*, Vol. 5, No. 2, pp. 170-178, Feb. 2006.

[1.23] H. Luo, R. Ramjeey, P. Sinhaz, L. Liy and S. Lu, “UCAN: A Unified Cellular and Ad-Hoc Network Architecture,” *ACM MobiCom*, San Diego, USA, pp. 353-367, Sep. 2003.

[1.24] 802.16e-2005 and IEEE Std 802.16-2004/Cor1-2005, IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and

Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, IEEE press, 2006.

[1.25] Mobile WiMAX -- Part I: A Technical Overview and Performance Evaluation, WiMAX Forum, Aug. 2006.

[1.26] C. Reuven, K. Liran and R. Romeo, “On the Trade-Off between Energy and Multicast Efficiency in 802.16e-Like Mobile Networks,” *IEEE Trans. on Mobile Computing*, vol. 7, Issue 3, pp. 346-357, March 2008.

[1.27] IEEE 802.16j-06/026r4, P802.16j Baseline Document, IEEE 802.16's Relay Task Group, May 2007.

[1.28] A. Nosratinia, T. E. Hunter and A. Hedayat, “Cooperative Communications in Wireless Networks,” *IEEE Commun. Mag.*, pp. 74-80, Oct. 2004.

[1.29] J.N. Laneman, D. Tse, and G. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,’’ *IEEE Trans. Inform. Theory*, vol. 50, no. 12, pp. 3037–3063, Dec. 2004.

[1.30] A. Sendonaris, E. Erkip and B. Aazhang, “User cooperation diversity - Part I and II,” *IEEE Trans. Commun.*, vol. 51, pp. 1927-1938, Nov. 2003.

[1.31] P. Liu, Z. Tao, S. Narayanan, T. Korakis, and S. S. Panwar, “CoopMAC: A Cooperative MAC for Wireless LANs,” *IEEE J. on Selected Areas in Commun.*, Vol. 25, No. 2, Feb. 2007.

[1.32] A. S. Ibrahim, A. K. Sadek, W. Su and K. J. R. Liu “Relay Selection in Mulit-Node Cooperative Communications: When to Cooperate and Whom to Cooperate with?” *IEEE Globecom*, San Francisco, USA, Nov. 2006.

[1.33] T.C.-Y. Ng, and W. Yu, “Joint optimization of relay strategies and resource allocations in cooperative cellular networks,” *IEEE J. on Selected Areas in Commun.*, Vol. 25, Issue 2, pp. 328-339, Feb. 2007.

Chapter 2

Concepts of Wireless Architectures and Resource Allocation

The mobile communications from 2G to 3G, the cell / star model is used, which is the centralized architecture. Service areas are divided into several cells, while the base station (BS) controls the cell and connects to the mobile users directly. In this chapter the multi hop wireless network architecture is introduced. There are two main system models: fixed relay network and mobile relay network (wireless ad hoc network). As the multi hop can solve many problems caused by the limitation of the cell / star networks, it became a reasonable solution for the next generation mobile communication.

Next-generation wireless systems (4G and beyond) are envisioned to provide ubiquitous high speed access over heterogeneous radio technologies, such as cellular network, ad hoc network and local area network (LAN). The integration of cellular networks and wireless LAN (WLAN) has drawn considerable attention from the research and commercial communities [2.1]. The mobile terminals could provide flexibility and system performance enhancement by providing seamless connections to the cellular core network or configuring within several terminals their selves.

At present, WLANs supporting broadband multimedia communications are being developed and deployed around the world. Standards include high performance local area network type 2 (HIPERLAN/2) and the IEEE 802.11 family. It is likely that fixed WLANs will become an important complementary technology to 3G cellular systems for their high frequency band and high bit rate and will typically be used to provide hotspot coverage [2.2].

Several multihop networks have been introduced; there are mainly two tapes: fixed multihop network and mobile multihop network. The fixed multihop networks can provide high frequency band and high throughput, on the other hand, the user could not move and the mobile phone. Therefore, they are usually considered to be a complementary technology for the cellular network. However, as the user requirement to the communication capacity and performance, the multihop network should be considered for both fixed users and mobile users.

2.1 Cellular and Infrastructure-Based Wireless Networks

Most of current mobile communication networks are based on a single-hop network architecture, where every user connects with an access point (base station-BS) directly. Therefore, the cell coverage and system throughput are limited by the BS's transmission capability. In order to provide high speed access, high user's signal to interference ratio (SIR) is required. Fig. 2.1 shows a general cellular system with 19 neighbor cells.

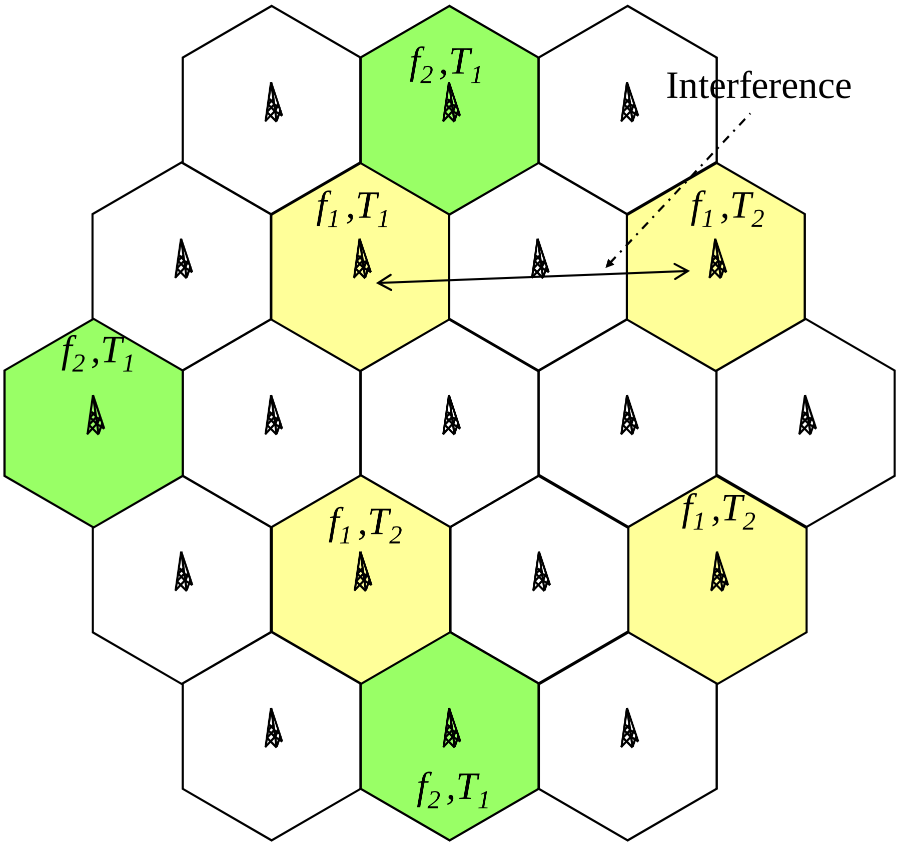


Figure 2.1　Cellular system.

Frequency reuse (especially for FDMA and TDMA systems) is shown in Fig. 2.1, where the neighbor cells use different frequency bands to avoid interferences. On the other hand, orthogonal CDMA system could reuse the whole frequency band. However, all of these systems are interference limited. Increasing the transmission power of BSs can increase both the signal and interferences for other cells. Technologies such as sector antennas and power control could reduce intra-cell and inter-cell interferences.

2.2 Multihop Networks

2.2.1 Fixed Relay Networks

The broadband wireless access industry, which provides high-rate network connections to stationary sites, has matured to the point at which it now has a standard for second-generation wireless metropolitan area networks. IEEE Standard 802.16, with its wireless metropolitan area network (WirelessMAN) air interface, sets the stage for widespread and effective deployments worldwide [2.3].

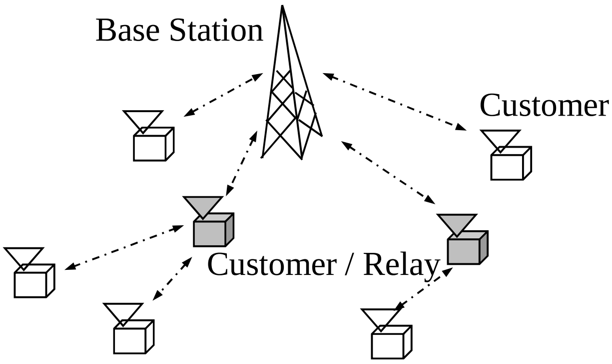


Figure 2.2 Wireless MAN.

Fig. 2.2 shows a WirelessMAN network. IEEE Standard 802.16 [2.4] defines the air interface specification for WirelessMAN. The completion of this standard heralds the entry of broadband wireless access as a major new tool in the effort to link homes and businesses to core telecommunications networks worldwide.

As currently defined through IEEE Standard 802.16, a wireless MAN provides network access to buildings through exterior antennas communicating with central radio BSs. Because wireless systems have the capacity to address broad geographic areas without the costly infrastructure development required in deploying cable links to individual sites, the technology may prove less expensive to deploy and may lead to more ubiquitous broadband access. IEEE Standard 802.16 was designed to evolve as a set of air interfaces based on a common medium access control (MAC) protocol but with physical layer specifications dependent on the spectrum of use and the associated regulations. The standard, as approved in 2001, addresses frequencies from 10 to 66 GHz, where extensive spectrum is currently available worldwide but at which the short wavelengths introduce significant deployment challenges. The IEEE 802.16a [2.5] extends the air interface support to lower frequencies in the 2-11 GHz band, including both licensed and license-exempt spectra. Table 2.1 gives an overview of the IEEE 802.16 standard.

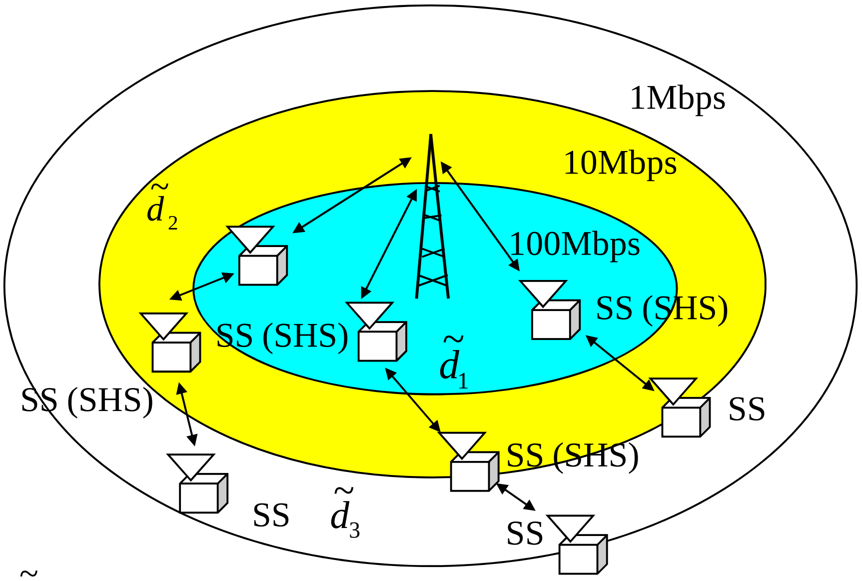
Table 2.1 Description of IEEE 802.16.

IEEE 802.16 Air Interface Standard	
P802.16 (Original)	Air Interface for Fixed Broadband Wireless Access Systems
P802.16a	Amendment 2, Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz
P802.16b	Amendment 1, Detailed System Profiles for 10-66 GHz
P802.16d	Amendment 3: Detailed System Profiles for 2-11 GHz
P802.16e	Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands
802.16.2	Coexistence of Fixed Broadband Wireless Access Systems

The IEEE 802.16 MAC protocol was designed for point-to-multipoint broadband wireless access applications. It addresses the need for very high bit rates, both uplink (to the BS) and downlink (from the BS). Access and bandwidth allocation algorithms must accommodate hundreds of terminals per channel, with terminals that may be shared by multiple end users.

The mesh network has more complex channel considerations than point-to-multipoint, such as avoiding “hidden terminal” collisions, selection of links, synchronization, excellent spectral efficiency and capacity and complete flexibility in service delivery. The combination of these attributes makes a mesh solution suitable for mass-market deployment, bringing multimedia services to domestic as well as small office home office (SoHo) and business clients.

The choice of modulation scheme has a significant impact on network scalability as it can easily be altered to support a higher rate [2.6]. There are many factors that affect system performance of spectral efficient schemes. Modulation schemes, such as BPSK, QPSK, 16/64QAM, can be used in the system. Multicarrier modulation such as orthogonal frequency division multiplexing (OFDM) also can offer a number of advantages.



$\tilde{d}_n$: Pathloss in the real system
SS : Subscriber station
SHS: Subscriber hopping station

Figure 2.3 Adaptive modulation scheme.

Fig. 2.3 shows a modulation plan in one cell, and Table 2.2 compares some main modulation schemes. QPSK is currently the most popular choice primarily due to cell overlap control considerations and good tolerance to distortion. The network capacity can be augmented by increasing the order of modulation due to higher spectral efficiencies. However, such increase is achieved at the expense of higher equipment cost because of escalated receiver structure complexity and more severe cell-to-cell interference. This may significantly decrease the area of coverage, and co-channel interference. Moreover, a reduction in coverage range also results with each increase, from QPSK to 16 and from 16 to 64-QAM, roughly halving cell size. Generally, selecting higher-order QAM when expansion in capacity is required with reduction in range and noise performance can maximize bandwidth utilization.

Table 2.2 A comparison of different modulation schemes.

Scheme	Spectral efficiency	Number of sectors	Relative coverage	Relative link margin
QPSK	1.5 (b/s/Hz)	16	100 (%)	0 (dB)
		8	79	-3
		4	62	-6
16QAM	3	16	49	-9
		8	37	-12
		4	28	-15
64QAM	4.5	16	23	-17
		8	16	-20
		4	12	-23

The access methodology affects how end user sites share the wireless network connection. Most existing systems apply either TDMA or FDMA methods for both the upstream and downstream links. In either method, the link efficiency is primarily determined by the way bandwidth is allocated. The use of TDD is generally preferred to utilize the available bandwidth in noncontiguous blocks over FDD. This is because the transmitter-to-receiver frequency spacing has to be carefully controlled in order to avoid unnecessarily complex filter and duplexer designs that also lead to a higher demand for additional guard-band.

In TDMA bandwidth allocation for each customer link is based on data bursts from the customer site. In contrast, in FDMA bandwidth is allocated approximately constant in time to a customer. Dynamic allocation of bandwidth maximizes the channel efficiency, and adaptive power control provides partial compensation.

2.2.2 Ad Hoc Networks

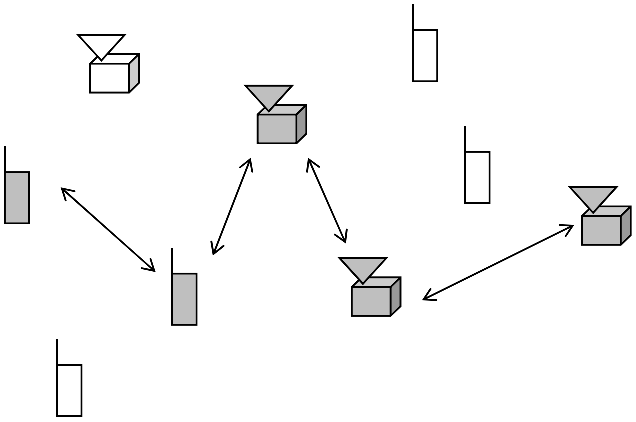


Figure 2.4 Wireless Ad Hoc network.

A mobile ad hoc network is an autonomous system of mobile terminals connected by wireless links. Fig. 2.4 shows a wireless ad hoc network. The terminals are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion or be connected to the internet for several applications.

Wireless ad hoc networks are expected to play an important role in the future ubiquitous society. The characteristics of ubiquitous devices make wireless networks the natural solution for their interconnection. Ad hoc networks are expected to be the basic building blocks of pervasive computing environments. Devices can thus communicate in areas without a central infrastructure, such as BS, or when such an infrastructure needs to be extended.

The ad hoc architecture has many benefits, such as self reconfiguration and adaptability to highly variable mobile characteristics such as power and transmission conditions, traffic distribution variations, and load balancing. However, the benefits come with some new challenges which mainly reside in the unpredictability of network topology due to mobility of nodes, which coupled with the local broadcast capability cause a set of concerns in designing a communication system on ad hoc wireless networks, such as routing and scheduling problems.

The notion of QoS is a guarantee by the network to satisfy a set of predetermined service performance constraints for the user in terms of the end-to-end delay statistics, available bandwidth, probability of packet loss, and so on. Obviously, enough network resources must be available during the service invocation to honor the guarantee. The first essential task is to find a suitable path through the network, or route, between the source and destination(s) that will have the necessary resources available to meet the QoS constraints for the desired service [2.7].

Determining the QoS capability of candidate links is not simple for such scenarios; for multicast services, the difficulties are even larger. Especially, for ad hoc networks, the routing is a significant part affecting the QoS. We have already noted that the route computation cannot take “too long.” Consequently, the computational complexity of route selection criteria must also be taken into account.

Table 2.3 Routing techniques

Source routing	A feasible path is locally computed at the source node using the locally stored global state information, and then all other nodes along this feasible path are notified by the source of their adjacent preceding and successor nodes.
Distributed routing	Sources as well as other nodes are involved in path computation by identifying the adjacent router to which the source must forward the packet associated with the flow.
Hierarchical routing	Aggregated partial global state information to determine a feasible path using source routing where the intermediate nodes are actually logical nodes representing a cluster.

Routing is considered to be the most important issue because the topology of the network we discussed before. As the quality of service should be guaranteed for the network, the QoS routing should be considered. While the network information may be assumed to be always available at any particular node, the information is constructed by exchanging for every node among all the network nodes at appropriate moments. The process of updating the information of the routing is also loosely called topology updates, and as we have observed already, may significantly affect the QoS performance of the network. Table 2.3 shows three types of routing algorithms.

According to the discussion about single hop and multi hop networks, we conclude the differences between two schemes as in Fig. 2.5.

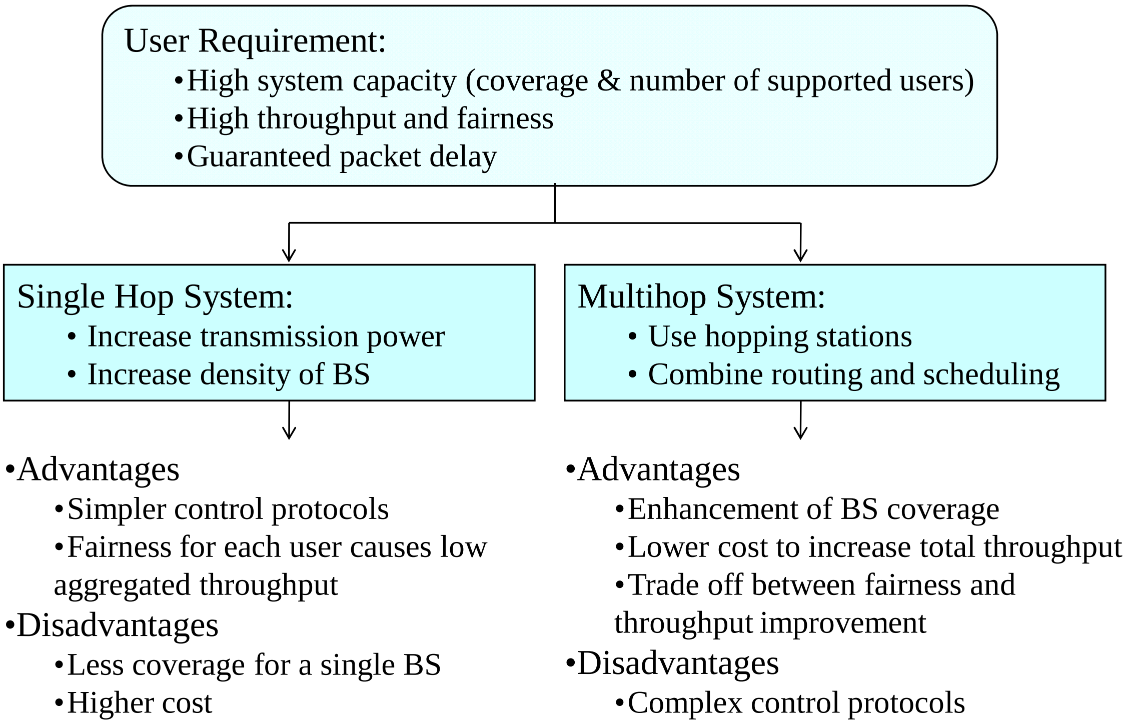


Figure 2.5 Comparison of Single Hop and Multi Hop.

2.3 Resource Allocation

Resource allocation deals with the resource in wireless networks in terms of bandwidth, power and time slots, which can be divided into handover, power control, admission control, load control and packet scheduling functionalities [2.8]. Fundamental Problems in Wireless Networks are:

- Path Loss,
- Thermal Noise, and
- The Limited Spectrum.

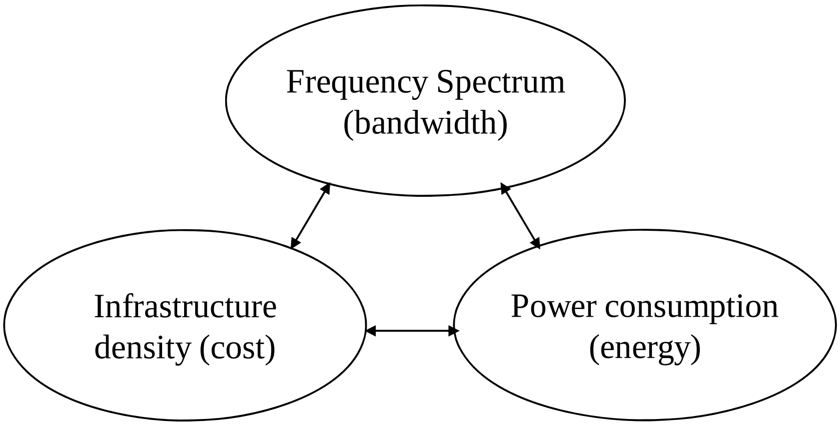


Figure 2.6 Limiting factors in wireless network design.

The limiting factors in wireless network design are shown in Fig. 2.6. In third generation networks other radio resource management algorithms – admission control, load control and packet scheduling – are required to guarantee the quality of service and to maximize the system throughput with a mix of different bit rates, services and quality requirements.

2.3.1 Packet Scheduling

In this thesis we focus on the packet scheduling for the multihop wireless network. Scheduling algorithms are important components in the provision of guaranteed quality of service parameters such as delay, delay jitter, packet loss rate, or throughput. The design of scheduling algorithms for mobile communication networks is especially challenging given the highly variable link error rates and capacities, and the changing mobile station connectivity typically encountered in such networks.

It is important that certain quality of service targets be met. As an example, the Internet is a continuously evolving entity which is being used by a growing number of mobile applications with diverse QoS requirements. Table 2.4 shows typical QoS requirements for several service classes: non-real-time variable bit rate (nrt-VBR), available bit rate (ABR), unspecified bit rate (UBR), constant bit rate (CBR) and real-time VBR (rt-VBR).

Table 2.4 QoS requirements for different applications.

Class	Application	Bandwidth (b/s)	Delay bound (ms)	Loss rate
CBR	Voice	32k-2M	30-60	10^{-2}
nrt-VBR	Digital video	1M-10M	Large	10^{-6}
rt-VBR	Video conference	128k-6M	40-90	10^{-3}
UBR	File transfer	1M-10M	Large	10^{-8}
ABR	Web browsing	1M-10M	Large	10^{-8}

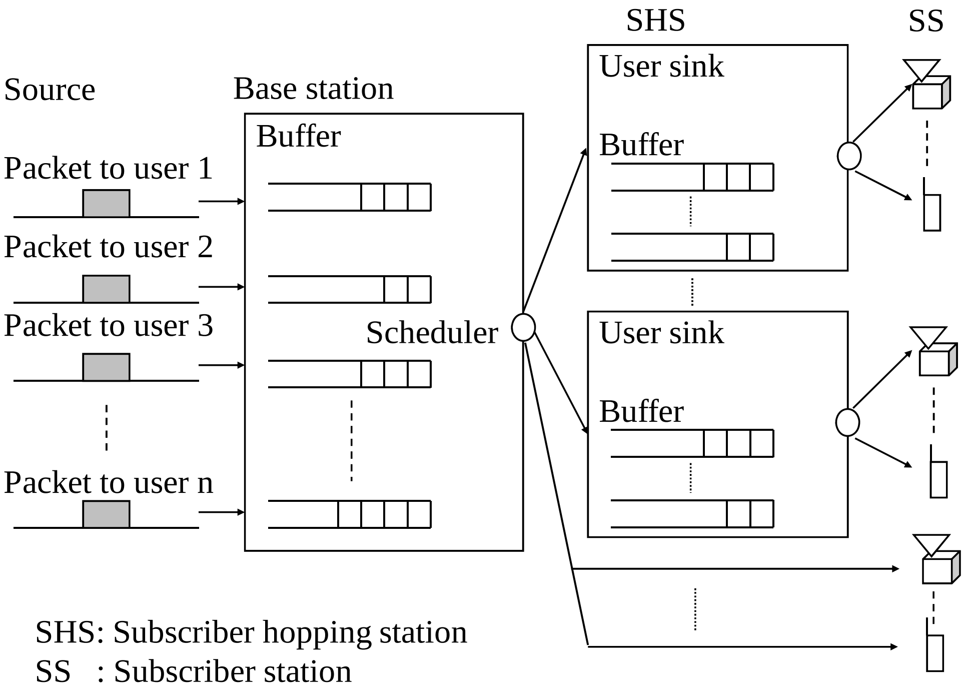


Figure 2.7 A typical wireless scheduling for multihop wireless network.

As illustrated in Fig. 2.7, the function of a scheduling algorithm is to select the session whose packet is to be transmitted next. This selection process is based on the QoS requirements of each session for both BS and subscriber hopping station (SHS). Each user can support one or more sessions at any given time. Wireless links generally possess characteristics that are quite different from those of wire line links. They are subject to time and location dependent signal attenuation, fading, interference, and noise that result in bursty errors and time-varying channel capacities.

Table 2.5 Features of a scheduling algorithm.

Features	Descriptions
Efficient link utilization	A transmission slot should not be assigned to a session with a currently bad link since the transmission will simply be wasted.
Delay bound	The algorithm must be able to provide delay bound guarantees for individual sessions in order to support delay-sensitive applications.
Fairness	Fairness among error-free sessions (short-term fairness) and error-prone sessions (long-term fairness) should be provided.
Throughput	Guaranteed short-term throughputs for error free sessions and guaranteed long-term throughputs for all sessions should be ensured.
Implementation complexity	A low-complexity algorithm is a necessity in high-speed networks in which scheduling decisions have to be made very rapidly.
Graceful service degradation	A session that has received excess service at the expense of sessions whose links were bad should experience smooth service degradation when relinquishing the excess service to lagging sessions whose links are now good.
Isolation	The QoS guarantees for a session should be maintained even in the presence of sessions whose demands are in excess of their reserved values.
Energy consumption	The need to prolong the MS battery life should be considered.
Delay/bandwidth decoupling	A higher reserved rate provides a lower delay, however, some high-bandwidth applications, can tolerate relatively large delays.
Scalability	As the number of sessions sharing the channel increases, system should be operated efficiently.

Table 2.5 shows the main features the scheduling algorithms should satisfy. In a CDMA network, the total interference at an SHS / SS must be small enough to ensure an adequate SIR for each session, thereby enabling its target BER to be met. The BS / SHS should ensure that the number of simultaneous transmissions in the network is not so high as to result in excessive interference. A multi hop network model is appropriate when little infrastructure exists, for example hop stations.

2.3.2 Scheduling in Multi Hop Networks

Development of the scheduling algorithm for the multihop network is much more complex than the single hop system. As the number of users increases, a multihop network may emerge in which not all users can communicate directly with each other [2.9]. In addition to the scheduler properties mentioned earlier, it is desirable for a multi-hop scheduler to possess topology transparency which is the scheduling algorithm should work efficiently regardless of how frequently and unpredictably the topology changes, and Low connectivity information requirement, since communicating the information consumes bandwidth, it should be kept to a minimum.

As the evaluation of the proposed fixed multi hop network, we introduce a hybrid multi hop network including both mobile and fixed users. By using the TDD CDMA and scheduling on the time slots, the capacity of the proposed system is investigated in this chapter.

On the other hand, the explosive growth of internet services needs the wireless communication network to overcome the limitation of wireless resources such as bandwidth constrains. Based on orthogonal frequency division multiple access (OFDMA), IEEE 802.16e standard is considered as a promising candidate for next generation wireless communications [2.10]. The IEEE 802.16e is also known as mobile worldwide interoperability for micro wave access (Mobile-WiMAX) [2.11]. Due to the flexibility of OFDMA, resource management plays a key role in such wireless networks. Generally, there is a tradeoff between transmission energy and channel efficiency, where the faded mobile users have to require the base station to increase the power [2.12]. Thus, the BS has to choose to reduce the power on other users or extend the service duration on the faded user with low transmission rates.

References

[2.1] H. Wei and R. D. Gitlin, “Two-Hop-Relay Architecture for Next Generation WWAN/WLAN Integration,” *IEEE Commun. Mag.*, pp. 24-30, Apr. 2004.

[2.2] A. Doufexi, E. Tameh, A. Nix, S. Armour and A. Molina, “Hotspot Wireless LANs to Enhance the Performance of 3G and Beyond Cellular Networks,” *IEEE Commun. Mag.* , pp. 58-65, Jul. 2003.

[2.3] C. Eklund, R. B. Marks, K. L. Stanwood and S. Wang, “IEEE Standard 802.16: A Technical Overview of the WirelessMAN Air Interface for Broadband Wireless Access,” *IEEE Commun. Mag.*, pp. 98-107, June 2002.

[2.4] IEEE 802.16-2001, “IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed Broadband Wireless Access Systems,” Apr., 2002.

[2.5] IEEE P802.16a / D3-2001: “Draft Amendment to IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed Wireless Access Systems - Medium Access Control Modifications and Additional Physical Layers Specifications for 2-11 GHz,” Mar., 2002.

[2.6] B. Fong, N. Ansari, A. C. M. Fong, G. Y. Hong and P. B. Rapajic, “On the Scalability of Fixed Broadband Wireless Access Network Deployment,” *IEEE Radio Commun*., pp. S12-S18, Sep. 2004.

[2.7] S. Chakrabarti and A. Mishra, “QoS Issues in Ad Hoc Wireless Networks,” *IEEE Commun. Mag.*, pp. 142-148, Feb. 2001.

[2.8] H. Holma and A. Toskala, *WCDMA for UMTS*, John Wiley & Sons, 2001.

[2.9] H. Fattah and C. Leung, “An Overview of Scheduling Algorithms in Wireless Multimedia Networks,” *IEEE Wireless Comm*., Oct. 2002.

[2.10] 802.16e-2005 and IEEE Std. 802.16-2004 / Cor1-2005, IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, 2006.

[2.11] Mobile WiMAX -- Part I: A Technical Overview and Performance Evaluation, WiMAX Forum, Aug. 2006.

[2.12] C. Reuven, K. Liran and R. Romeo, “On the Trade-Off between Energy and Multicast Efficiency in 802.16e-Like Mobile Networks,” *IEEE Trans. on Mobile Comp.*, vol. 7, pp. 346 - 357, Mar. 2008.

Chapter 3

Previous Works and Problems of Resource Allocation in Cellular Relay Networks

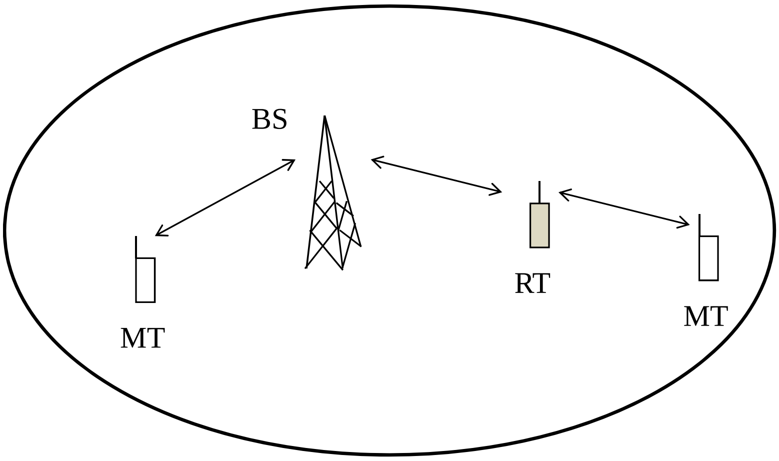
3.1 Cellular Relay Networks

Combined with ad hoc network, cellular CDMA system with out-of-band ad hoc traffic relaying has been proposed to improve cellular capacity, where the dual-mode mobile stations can choose available relay [3.1]. However, in order to control the mobile terminals in a centralized fashion, the multihop connection scheme has been proposed for mobile terminals using the same access scheme between an end user terminal and its destination base station (BS) [3.2]. Since coverage area and system throughput are closely interrelated in a general radio communication system, multihop cellular network is a promising candidate for beyond the third generation to improve coverage area and system throughput. Due to the differences between the relay link and cellular link, there are two types of cellular relay networks: in band and out of band relaying. In band relaying refers to the bandwidth used for relay which is a part of the cellular bandwidth. Out of band relaying usually means that the relaying link use a different interface compared to cellular link.

3.1.1 In Band Relaying Networks

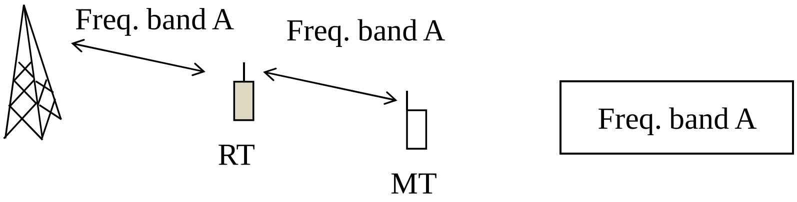
In mobile assisted data forwarding (MADF) [3.3], forwarding channels are allocated from resources used by the existing cellular network. These channels are then used for relaying traffic between cells. The objective in this case is to load-balance the system, especially in the case where traffic hotspots are present.

Fig. 3.1 shows a CDMA cellular system, employing a multihop connection. This scheme is different from the conventional cellular system in that relay transmissions between mobile terminals (MTs). The relay terminal (RT) receives a signal from BS (an MT in the uplink). RT performs demodulation, decoding, re-encoding and re-modulation for the signal and then re-transmits the signal to a destination station.

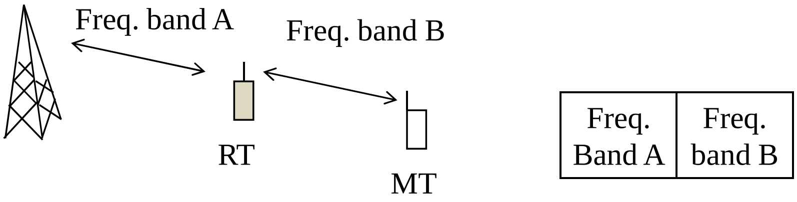


BS: Base station   RT: Relay terminal   MT: Mobile terminal

Figure 3.1 Multihop cellular system.



a) Code division / Time division duplexing scheme



b) Frequency division duplexing scheme

RT: Relay terminal   MT: Mobile terminal

Figure 3.2 Duplexing schemes for multihop cellular.

Fig. 3.2 shows relay schemes using frequency division or code division duplexing investigated in [3.2]. In Fig. 3.2(a) the frequency of the transmissions between terminals is separated from those between BS and terminal. Each portion of the separated frequency bandwidth becomes smaller than that of the conventional cellular system, which is based on a single-hop connection. This division loss may decrease bandwidth efficiency. In Fig. 3.2 (b), channels for all transmissions share interfere with each other in the same frequency range. These transmissions may, therefore, interfere each other.

3.1.2 Out of Band Relay Networks

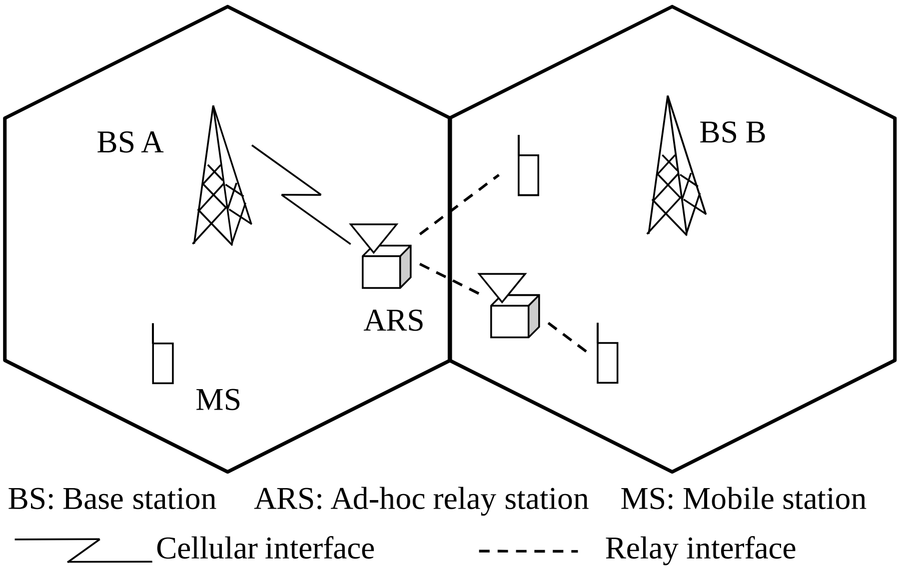


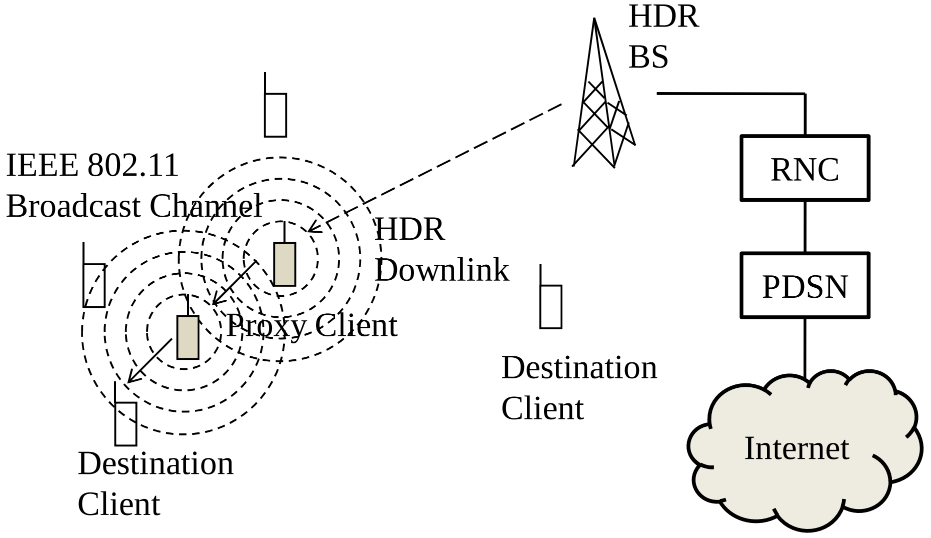
Figure 3.3 A relaying cellular with two ad hoc relaying stations.

In contrast to the in band relay cellular systems, which use the same interface for relay to transmit packets to mobile stations, out of band wireless relaying cellular network architecture has been proposed [3.3], by taking the advantages from the multi interfaces. The objective in this case is to load-balance the system, especially in the case where traffic hotspots are present. The approach in the integrated cellular and ad hoc relay (iCAR) system [3.4] uses preinstalled ad hoc relay stations (RSs) to move traffic between cells. It addresses the congestion problem due to unbalanced traffic in a cellular system and provides interoperability for heterogeneous networks. The iCAR system can efficiently balance traffic loads between cells by using ad hoc relaying stations (ARS) to relay traffic from one cell to another dynamically. This not only increases the system's capacity cost effectively, but also reduces transmission power for mobile hosts and extends system coverage, which is shown in Fig. 3.3.

In [3.5], the authors presented a hierarchical structure for wireless mobile systems with a fixed backbone. In order to access the backbone, all MHs have to go through a mobile base station (which can be thought of as a cluster head). It is similar to iCAR in that the cellular infrastructure in iCAR is also fixed, and the ARSs can be mobile and used to relay between MSs and the fixed BSs. However, in iCAR, the MSs have two air (or radio) interfaces so that they may communicate with BSs directly without going through ARSs. In addition, each ARS is under the control of a MSC and has limited mobility. Such a feature is important to ensure that a relaying route can be set up fast and maintained with a high degree of stability. Routing in iCAR is similar to that of having a hybrid structure in [3.6] for efficient routing and handoffs in mobile ATM networks. The difference between the two is that in the latter, relaying is between two BSs through direct wired links.

In the multihop cellular systems approach [3.7] and the mobile- assisted connection admission (MACA) system [3.8], relaying is performed by MSs, and thus that approach shares many disadvantages in terms of security (authentication, privacy), billing, and mobility management (of the MSs) with mobile ad hoc networks. In addition, the main goal of the multihop cellular systems is to reduce the number of BSs or the transmission power of each BS, but it can no longer guarantee a full coverage of the area. In fact, even in the ideal case where every MS in an area uncovered by any BS can find a relaying route (through other MSs), the multihop approach will neither increase the system capacity nor decrease the call blocking/dropping probability, unless a large percentage of the calls are intracellular calls (i.e., calls whose source and destination are in the same cell), which usually is not the case in practice. Note that the proposed relaying through ARSs is useful in any cellular system where congestion may occur, even though a call may not be allocated a dedicated channel all the time (or in other words, during the entire call duration). Also, if one simply treats the 2.4-GHz band as an additional set of channels that can be used in a cellular system, one will not be able to balance loads among cells or to eliminate congestion in hot-spot cells via relaying. Other approaches such as those using microwave links between BSs, cell splitting, cell sectorization, and cell breathing cannot serve as a replacement for relaying in iCAR either, although they may be used in conjunction with our approach.

In contrast to the fixed relay, mobile terminals with 802.11 based peer to peer links could forward packets for destination clients with poor channel quality [3.9], which is shown as Fig. 3.4.



HDR: High data rate RCN: Radio network controller
PDSN: Packet data serving node

Figure 3.4 UCAN architecture.

3.1.3 Problems in the Cellular Relay Networks

Most of the previous works focus on the architecture of the relaying networks, there is little research considering the interaction between the relay selections and scheduling algorithms according to our knowledge. In high speed wireless networks, the scheduling decision should be made very quickly time slot by time slot, where the selection for scheduled user affects the system throughput significantly. Furthermore, the selection of the relay might be the bottleneck if the scheduled user has to receive its packets via a relay. Thus, in order to improve the system capacity and packet QoS support, more efficient packet scheduling algorithms are needed in relaying networks.

3.2 Time Slot Allocation for TDD CDMA Networks

3.2.1 TDD CDMA Networks

The third generation networks and services present opportunities to offer multimedia applications and services that meet end-to-end QoS requirements [3.10]. The key parts of the standards are already in place, and 3G services have already been turned on. The QoS framework for a 3G air interface must be flexible for building various services and should also provide a means for effective negotiation between the service provider and end user. In some 3G standards, such as WCDMA, cdma2000 and TD-SCDMA, CDMA was selected as the preferred technology for the air interface. Existing QoS schemes for the CDMA air interface focus on satisfying the needs of specific applications. Typically, they provide hard QoS guarantees to real time applications such as voice and video, and best effort service to non-real-time applications such as packet data.

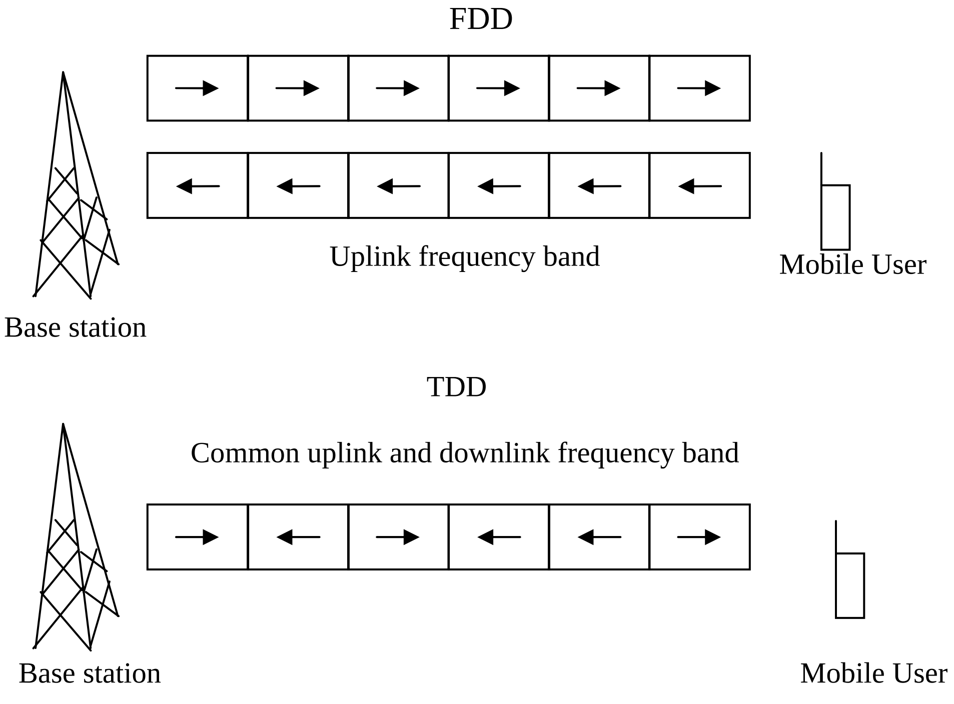


Figure 3.5 TDD and FDD schemes.

Due to the low bandwidth efficiency, the time division duplex (TDD) schemes seem to be gradually gaining favor, at the expense of the more broadly used frequency division duplex (FDD) mode [3.11]. CDMA is used for the 3G wireless communications, however, the systems almost use the FDD scheme because the complexity of TDD scheme. Fig. 3.5 shows the differences between two schemes. Beyond 3G, TDD is a proper technique to gain high performance, as it provides flexible network access. Radio resource management is responsible for utilization of the air interface resources. RRM is needed to guarantee QoS, to maintain the planned coverage area and to offer high capacity. Radio resource management (RRM) is a difficult issue for wireless multi hop networks, in this chapter we focus on the routing and scheduling as they are considered the key techniques for the next generation wireless system.

Duplex transmission of information between two users can be accomplished in several ways. TDD systems accomplish two way communications by allowing each party to communicate over the same frequency band by alternately transmitting and receiving [3.12]. A TDD system uses the same frequency channel for full duplex transmission and reception of signals on the downlink and uplink. This is accomplished by sharing the channel between the uplink and downlink transmissions by way of allocating certain times for each transmission and switching alternately between the two links. The length of uplink and downlink slots are either set by the communication system and broadcast to mobile terminals who wish to connect to the system or are fixed by the standards.

The length of slots can be unequal or the number of the uplink and downlink slots per frame can be different as in Fig. 3.6. The TDD mode of operation is flexible in sharing the total bandwidth capacity between the uplink and downlink as traffic requirements change. In contrast, in FDD operation, the uplink or downlink frequency bands, once assigned, cannot be readily reassigned. There are two main reasons for selecting a TDD mode of operation. One is its more efficient bandwidth utilization that is realized in nonpaired continuous bands. Better usage of frequency spectrum can be accomplished using higher order, more expensive filters. Another reason is the channel reciprocity between the uplink and downlink and the several advantages that result from it.

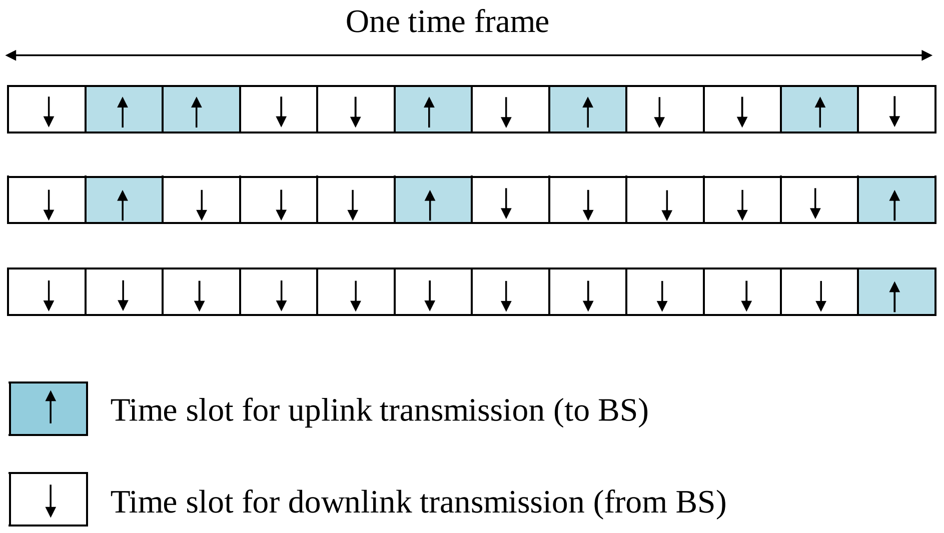


Figure 3.6 Unequal number of uplink and downlink slots per frame.

3.2.2 Time Slot Allocation Schemes

TDD CDMA is increasingly the focus of research and is being experimented with in combination with multicarrier CDMA for fourth generation communication [3.13] [3.14]. The difference between TDD and FDD is that duplex transmission is carried in alternate time slots for the TDD mode in the same frequency channel, whereas FDD uses two separate channels for continuous duplex transmission. By using TDD, the frequency band can be used more efficiently.

Trade-off between interference and usable resources of time slots is considered in assignment of codes to time slots in [3.15]. The proposed algorithm dynamically permutes the time slots based on change of time slots interference. On the other hand, an important issue in wireless multimedia communications is to cope with the traffic asymmetry between uplink and downlink. The result in unequal system capacity for the uplink and downlink of a system is very important for cases where traffic requirements for uplink and downlink are different. For voice traffic, the capacity requirements are more of less the same, although the capacity is limited by the downlink. However, for data traffic, the capacity requirements of the downlink and uplink can be significantly different as traffic requirements are expected to be much larger in the downlink. The fact that internet usage is mostly downloading rather than uploading is expected to be repeated for mobile data communication. The asymmetrical slot allocation in the CDMA systems with TDD mode can be a good solution for this problem [3.16], which is shown in Fig. 3.7. However, the level of traffic asymmetry can be significantly different from cell to cell. The interference in the W-CDMA / TDD system when the slot allocations are made according to traffic patterns of each cell is analyzed, and a time slot allocation scheme considering the traffic asymmetry is proposed in [3.17].

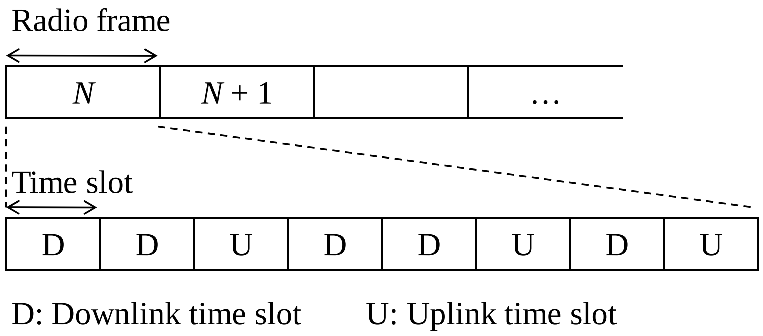


Figure 3.7 Example of TDD frame format (8 time slot / frame).

In [3.16], the authors consider the slot allocation with multi cell model. In this case, the difficulties are incurred from the fact that the degree of traffic asymmetry can be significantly different from cell to cell. With this consideration, we have to find out an optimal slot allocation that maximizes the frequency utilization in terms of whole cellular system.

In the multi hop networks, random access is a common way of resource allocation [3.18]. However, there might be collisions between different links. Therefore, the proposal is to provide an efficient resource management scheme for TDD CDMA cellular network with fixed hopping stations. Packets are scheduled for reception at both hopping stations and the BS to avoid packet loss.

3.2.3 Problems for the TDD CDMA Cellular Relay Networks

By using the TDD CDMA techniques for mobile users, TDD CDMA can get higher frequency usage efficiency because of the flexibility in time slot allocation. However, the previous works in time slot allocation focus on the traffic balance between downlink and uplink transmissions. On the other hand, the time slot allocations for relay cellular networks have only been studies in a random access fashion for a combination of multihop cellular and TDD CDMA networks. Therefore, it is expected that the system capacity can be increased by combining time slot management and relay station selection properly.

3.3 Scheduling in High Speed Networks

3.3.1 Packet Scheduling

In order to achieve user fairness, Round Robin (RR) scheduling algorithm is considered as a simplest and practical scheme. On the other hand, maximum carrier to interference ratio (MCIR) scheduling algorithm can be used to achieve high system throughput, which is shown in Fig. 3.8. However, as the wireless channel condition is varying, existing scheduling algorithms do not utilize channel resources efficiently [3.19] [3.20].

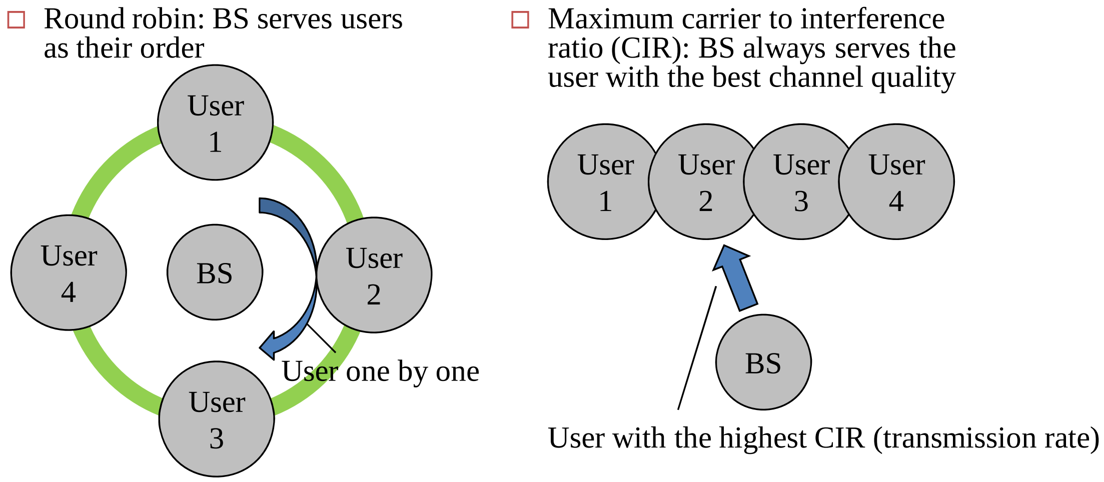


Figure 3.8 Round robin and MCIR scheduling schemes.

Recently, opportunistic scheduling has drawn much research interests due to the efficient usage of channel resources, by developing rate adaptation schemes to increase data transmissions selectively on a link when it offers good channel quality. For the streaming users, the proposed opportunistic policy in [3.21] achieves a significant improvement in terms of the maximum number of the users that can be supported with the desired QoS. In contrast, opportunistic manner always causes unfair to users who experience poor channel quality. The modified largest delay weight algorithm [3.22] is considered as a throughput optimal proportional fairness scheduling, which provides packets with long waiting time higher priority to be served. The comparisons of Round Robin scheme, maximum CIR scheme and proportional fairness scheme in [3.23] indicate that throughput and fairness performance of each scheduling scheme depends on mobile users' location. In general, the Round Robin scheme has the worst throughput performance as compared to the other schemes, where proportional fair scheme can provide relatively better tradeoffs between the throughput and the fairness. The comparisons of fairness and throughput could are shown as Fig. 3.9.

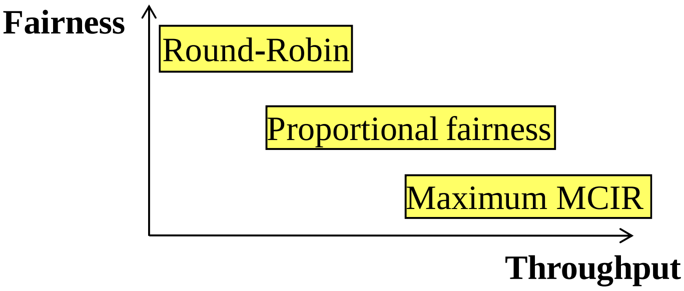


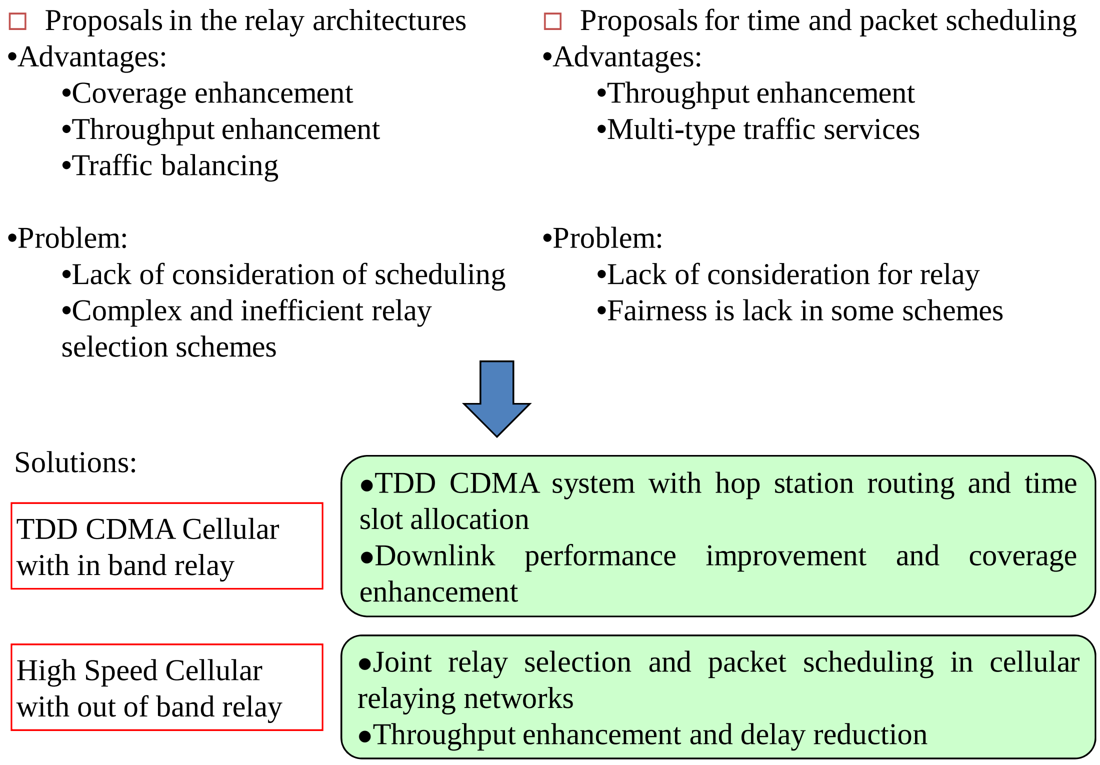
Figure 3.9 Round robin and MCIR scheduling schemes.

3.3.2 Problems for Scheduling in Relay Networks

Since most of the previous works focus on the architecture of the relaying networks, there is little research considering the interaction between the relay selections and scheduling algorithms according to our knowledge. In high speed wireless networks, the scheduling decision should be made very quickly time slot by time slot, where the selection for scheduled user affects the system throughput significantly. Furthermore, the selection of the relay might be the bottleneck if the scheduled user has to receive its packets via a relay. Thus, in order to improve the system capacity and packet QoS support, more efficient packet scheduling algorithms are needed in relaying networks.

3.4 Conclusion

Due to the luck of consideration of MAC layer scheduling in multihop networks, we conclude this chapter as shown in Fig. 3.10.



☐ Proposals in the relay architectures
- Advantages:
    - Coverage enhancement
    - Throughput enhancement
    - Traffic balancing
- Problem:
    - Lack of consideration of scheduling
    - Complex and inefficient relay selection schemes

☐ Proposals for time and packet scheduling
- Advantages:
    - Throughput enhancement
    - Multi-type traffic services
- Problem:
    - Lack of consideration for relay
    - Fairness is lack in some schemes

Solutions:

TDD CDMA Cellular with in band relay	●TDD CDMA system with hop station routing and time slot allocation ●Downlink performance improvement and coverage enhancement
High Speed Cellular with out of band relay	●Joint relay selection and packet scheduling in cellular relaying networks ●Throughput enhancement and delay reduction

Figure 3.10 Problems in the cellular relay networks.

In order to improve and evaluate the performance for TDD CDMA cellular relay networks, we propose a joint relay selection and time slot allocation scheme in chapter 4. In chapter 5, we propose a packet scheduling algorithm for relaying cellular networks by considering relay selection where MSs can use cellular adaptive multi-rate and user relay channels.

References

[3.1] D. Zhao and T. D. Todd, "Cellular CDMA Capacity Improvement Using Ad Hoc Relaying," *IEEE PIMRC*, Barcelona, Spain, pp. 719-723, Sep. 2004.

[3.2] A. Fujiwara, S. Takeda, H. Yoshino and N. Umeda, "Evaluation of Cell Coverage and Throughput in the Multihop CDMA Cellular Network," *IEEE VTC*, Milan, Italy, pp. 2375-2378, May 2004.

[3.3] X. Wu, S.-H.G. Chan and B. Mukherjee, "MADF: A Novel Approach to Add An Ad-Hoc Overlay on A Fixed Cellular Infrastructure," *IEEE WCNC*, Chicago, USA, Vol. 2, pp. 549-554, Sep. 2000.

[3.4] H. Wu, C. Qiao, S. De and O. Tonguz, "Integrated Cellular and Ad Hoc Relaying Systems: iCAR," *IEEE J. of Selected Areas in Commun.*, Vol. 19, pp. 1105-2115, Oct. 2001.

[3.5] I. F. Akyildiz, W. Yen, and B. Yener, "A new hierarchical routing protocol for dynamic multihop wireless networks," in *IEEE Infocom*, Kobe, Japan, pp. 1422-1429, Apr. 1997.

[3.6] S. Maloo and C. Qiao, "Efficient routing and fast handoff in a mobile atm network with a hybrid topology," in *5th Int. Conf. Info. Systems Analysis Synthesis (ISAS)*, Orlando, USA, pp. 614-621, July 1999.

[3.7] Y. D. Lin and Y. C. Hsu, "Multihop cellular: A new architecture for wireless communication," in *IEEE Infocom*, Tel Aviv, Israel, pp. 1273-1282, Mar. 2000.

[3.8] X.Wu, B. Mukherjee, and G. Chan, "MACA—Anefficient channel allocation scheme in cellular networks," in *IEEE Globecom*, San Francisco, USA, pp. 1385-1389, Dec. 2000.

[3.9] H. Luo, R. Ramjee, P. Sinha, L. Li and S. Lu, "UCAN: A Unified Cellular and Ad-Hoc Network Architecture," *ACM MobiCom*, San Diego, USA, pp. 353-367, September 2003

[3.10] S. Dixit, Y. Guo and Z. Antoniou, "Resource Management and Quality of Service in Third Generation Wireless Networks," *IEEE Commun. Mag.*, Vol. 39, pp. 125-133, Feb. 2001

[3.11] R. Esmailzadeh and M. Nakagawa, *TDD-CDMA for Wireless Communications*, Artech House, 2003.

[3.12] R. Esmailzadeh and M. Nakagawa, "Time Division Duplex Method of Transmission of Direct Sequence Spread Spectrum Signals for Power

Control Implementation," *IEICE Trans. on Commun.*, Vol. E76-B, pp. 1030-1038, Aug, 1993.

[3.13] R. Esmailzadeh, M. Nakagawa and E.A. Sourour, "Time-Division Duplex CDMA Communications," *IEEE Personal Commun. Mag.*, pp. 51-56, Apr, 1997.

[3.14] R. Esmailzadeh, M. Nakagawa, and A. Jones, "TDD-CDMA for the 4th generation of wireless communication," *IEEE Wireless Commun.*, Vol. 10, pp. 8-15, Aug, 2003.

[3.15] G. Zhang, "Dynamic permutation based time slot allocation for 3G WCDMA TDD systems," *IEEE PIMRC*, Beijing, China, Vol. 2, pp. 1181-1185, Sept. 2003.

[3.16] D. G. Jeong and W. S. Jeon, "Time Slot Allocation in CDMA/TDD Systems for Mobile Multimedia Services," *IEEE Commun. Letters*, Vol. 4, pp. 59-61 Feb. 2000.

[3.17] J. Lee, Y. Han and D. Kwon, "An adaptive time slot allocation strategy for W-CDMA / TDD system," *IEEE VTC*, Rhodes, Greece, Vol. 4, pp. 2509-2513 May 2001.

[3.18] Y. Mizuno, R. Hasegawa, R. Esmailzadeh, and M. Nakagawa, "Tow-Stage Random-Access for Multi-Hop Systems," *IEICE Trans. on Fundamentals of Electronics, Commun. and Computer Sciences*, Vol. E89-A, pp. 2630-2639, Oct. 2006.

[3.19] H. Fattah and C. Leung, "An Overview of Scheduling Algorithms in Wireless Multimedia Networks," *IEEE Wireless Commun.*, pp. 76-83, Oct. 2002.

[3.20] Y. Ofuji, A. Morimoto, S. Abeta and M. Sawahashi, "Comparison of Packet Scheduling Algorithms Focusing on User Throughput in High Speed Downlink Packet Access," *IEEE PIMRC*, Lisboa, Portugal, pp. 15-18 Sep. 2002.

[3.21] A. Farrokh, and V. Krishnamurthy, "Opportunistic Scheduling for Streaming Users in High Speed Downlink Packet Access (HSDPA)," *IEEE Globecom*, Vol. 6, pp. 4043-4047, Nov. 2004.

[3.22] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting and R. Vijayakumar, "Providing Quality of Service over a Shared wireless Link," *IEEE Comm. Mag.*, pp. 150-154, Feb. 2001.

[3.23] H, Fu and D. I. Kim, "Analysis of throughput and fairness with downlink scheduling in WCDMA networks," *IEEE Trans. on Wireless Commun.*, Vol. 5, pp. 2164-2174, Aug. 2006.

Chapter 4

Downlink Performance Improvement for TDD CDMA Cellular Relay Networks

In this chapter, a time duplex division (TDD) based cellular wireless network with fixed hopping stations is investigated with its downlink capacity. In the network, a number of fixed subscriber stations act as hopping transmission stations between base stations (BSs) and far away subscriber stations, by combining of cellular and ad hoc mobile network architectures. At the radio layer, TDD CDMA (code division multiple access) is selected as the radio interface to gain high frequency usage efficiency. In order to improve the system performance in terms of capacity, we propose the time slot allocation schemes with the usage of fixed hopping stations, which can be selected by either random or distance dependent schemes. Performance results obtained by computer simulation demonstrate the effectiveness of the proposed network to improve downlink system capacity.

4.1 Introduction

The wireless communication industry has rapidly evolved in the past decade to provide high transmission rate wireless communications in the form of cellular mobile and wireless local area networks. Current mobile communication networks are based on a single-hop network architecture, where every user connects to the BS directly. Therefore, the cell coverage and system throughput are limited by the BS's transmission capability. In order to provide high speed access, large user's signal to interference ratio (SIR) is required. Increasing the transmission power of BSs can extend their coverage. However in interference limited systems, such as CDMA systems, increasing signal power intended for a user also increases the interference to other users. Another solution is to increase the BS density and reduce individual BS’s coverage resulting in higher infrastructure cost. To solve such problems, there has been an upsurge of interest in multihop architecture networks [4.1]. Examples are cellular ad hoc networks, mesh networks in IEEE 802.16, and the coverage extension of HyperLAN/2. A concept and the related performance evaluation for a wireless broadband system based on fixed relay stations acting as wireless bridges are presented in [4.2].

Many researches have demonstrated the ability of ad hoc communication to extend wireless coverage. However, pure ad hoc networks suffer from low throughput due to inefficient routing and power limitation. A hybrid model with both mobile and fixed users, which is proposed in [4.3], is also inefficient due to the same reason, although the usage of BSs yields high throughput.

Multihop CDMA cellular networks have been proposed recently where the coverage and throughput are increased by using independent wired or wireless stations for relaying signals to users who might have insufficient SIR when connecting directly to a BS. Lin and Hsu propose a practical multi-hop wireless connection scheme for cellular systems by forwarding data packets from one user to another [4.4]. Zhao and Terence consider a cellular CDMA system with out-of-band ad hoc traffic relaying, the dual-mode mobile stations can choose available relay to improve cellular capacity [4.5]. The approaches for relay node placement in cellular space could extend BS’s coverage by planning of ad hoc relay network [4.6]. However, there is a tradeoff between the ad hoc network and cellular systems. Data may be forwarded in a multi-hop fashion to increase coverage of BS, but it provides only a slight advantage in system capacity because of the low performance of the mobile terminal [4.7].

On the other hand, by using the TDD CDMA techniques for mobile users, TDD CDMA can get higher frequency usage efficiency because of the flexibility in time slot allocation. As single hop TDD CDMA cellular networks have been widely investigated, where both mobile stations and fixed stations can directly connect to the BS. For a combination of multihop cellular and TDD CDMA networks, the congestion-based routing algorithm is proposed in [4.8] to minimize the overall power in the multihop TDD CDMA. However, the network capacity is still small. It is expected that the system capacity can be increased by combining time slot management and relay station selection properly.

In this chapter, we consider a TDD CDMA cellular network with fixed hopping stations, which includes both fixed users and mobile users. Some of fixed users (FUs) act not only as end users but also as subscriber hopping stations (SHSs). It is known in [4.8] that more hops by mobile users do not benefit cellular system on capacity so much, since more hops increase interference and packet delay. Therefore, for practice and simplicity, it is assumed that the maximum hop is limited to 2 hops, where users can connect to BS directly, or via an SHS with 2 hops. In order to improve the system capacity, we consider a combination of time slot allocation and usage of hopping stations. Because the hopping station selection would impact the capacity by relay reusing, we investigate two hopping station selection schemes, in which the hopping station would be allocated randomly or distance dependent. Computer simulations show that the proposed scheme improves the system capacity by relaying and the distance dependent SHS selection scheme achieves better performance.

4.2 System Model

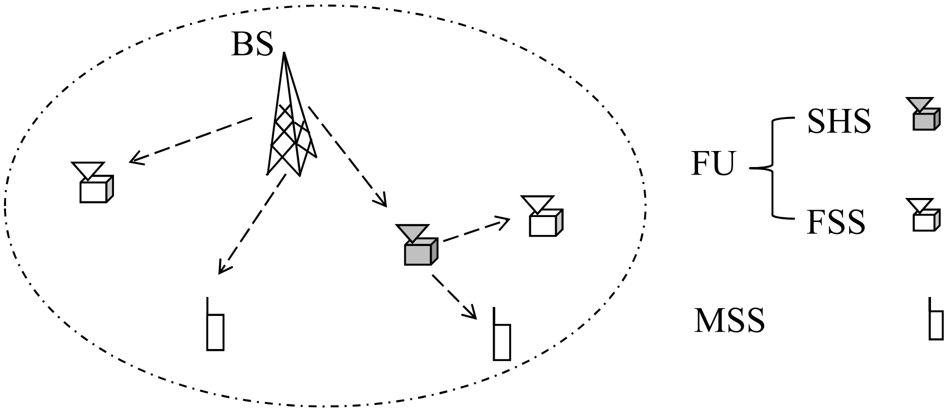


Figure 4.1 TDD CDMA cellular architecture.

The system model of the TDD CDMA cellular network with fixed hopping stations is shown in Fig. 4.1. It is assumed that a subset of FUs is selected as SHSs for receiving signals from BSs. We denote the rest fixed users as fixed subscriber stations (FSSs), mobile users as mobile subscriber stations (MSSs). FSSs and MSSs can connect to BS or SHSs, where all the stations (BSs, SHSs, FSSs and MSSs) are equipped with the omni antennas. X and Y are denoted as the abscissa axis position and vertical axis of the user as shown in Fig. 4.2.

4.2.1 SHS Selection Scheme

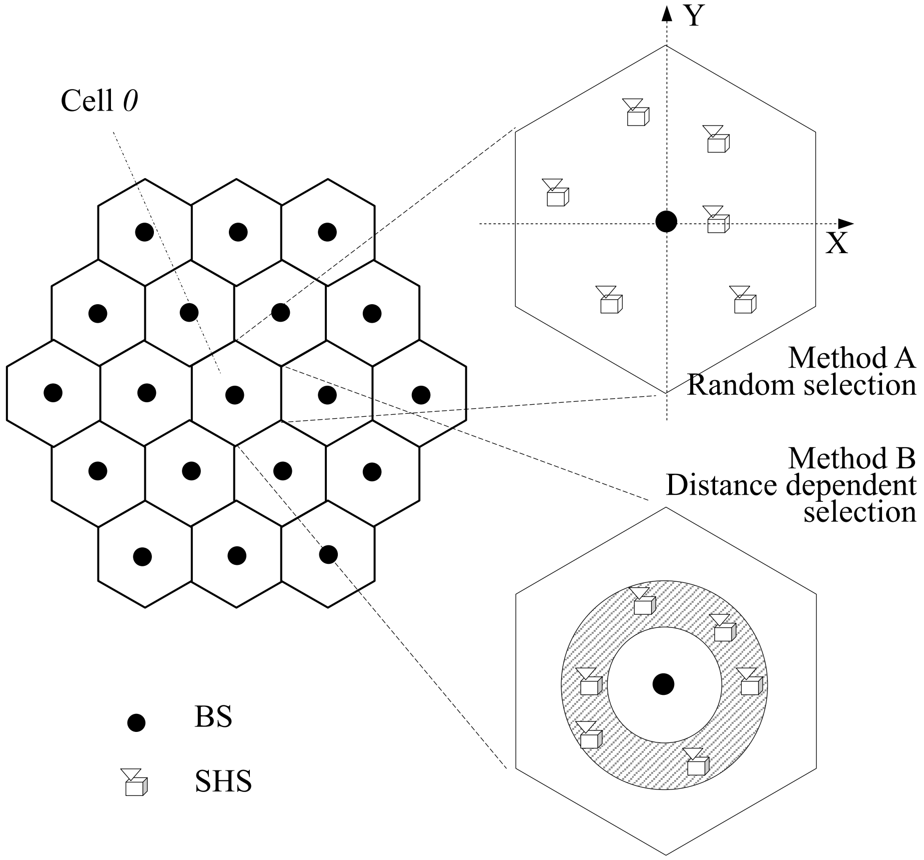


Figure 4.2   SHS selection schemes.

Two methods of SHS selection are introduced. The first one is a random SHS selection scheme. Each FU can be selected to be SHS by using random variable, which is shown as Method A in Fig. 4.2, therefore, the SHS can be allocated in the whole cell. Selection of SHS depends on the value of a random generator with uniform distribution of range [0, 1] for FU, γ, which is the ratio for number of SHSs to total number of FUs. If the random generator of FU is less than or equal to γ, this FU would be selected as a

SHS.

The second method is a distance dependent selection scheme, in Fig. 4.3, which selects SHSs in particular range of the cell. For description, the following notation is used:

- r_C is the radius of the cellular.
- α and β are allocation variables of SHS as shown in Fig. 4.3, and $0 < \alpha < \beta < 0.87$. Here, it is assumed that SHSs are fixed, and all FUs are the candidates for SHSs.
- The number of FUs is n_{FU}, and the number of SHSs is n_{SHS}. γ is used to express the number ratio of SHSs to total fixed stations, $n_{SHS} = \gamma \cdot n_{FU}$, and $0 < \gamma < 1$.

In the second method, the distance, d, from SHS to BS should satisfy: $\alpha \cdot r_C < d < \beta \cdot r_C$, which is shown as Method B in Fig. 4.2 and described in Fig. 4.3, where the SHS should be allocated in the shadowing area. The difference of SHS selection scheme in method B compared with the scheme method A is that choices of SHS are limited by not only γ but also the distance from BS which selects SHSs from FUs in the area dependent on α and β in method B.

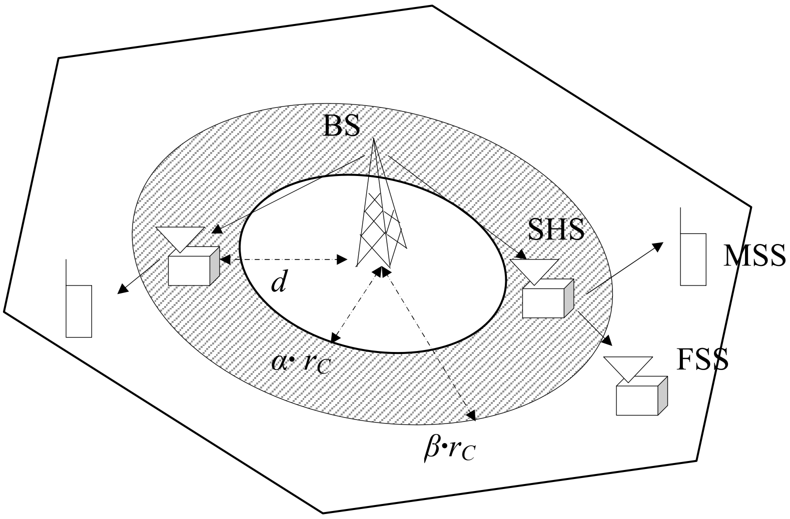


Figure 4.3 Distance dependent SHS selection scheme.

A user, which can be either FSS or MSS selects BS or SHS for connection by monitoring the pilot signals broadcasted by BS or SHS periodically.

When FSSs or MSSs connect to the network, they measure the received power of the pilot signals from BS and SHSs to select the connection with the strongest pilot power. The BS and SHSs can update the information for routing packets to end stations. Therefore, the users can change the connection if the received pilot power becomes weaker than other broadcasted pilot power in different time frames. Note that, less pilot transmission would keep the connection of users longer, while data traffic would not be sent to different SHSs. On the other hand, frequent pilot transmission would give more diversity in the time varying channel, however it would cause too much pilot traffic and waste of transmission power. In this chapter, we consider a practical system, in which BS and SHSs would send their pilot signals periodically. Channel condition is assumed to keep stable in one time frame which includes half uplink time slots and half downlink time slots.

A random generator of uniform distribution are used to allocate X coordinate and Y coordinate of user within cellular. Here, the density of users is a constant value, which means the distance from BS, d^2_i obeys the uniform distribution. The user distribution is shown as in Fig. 4.4.

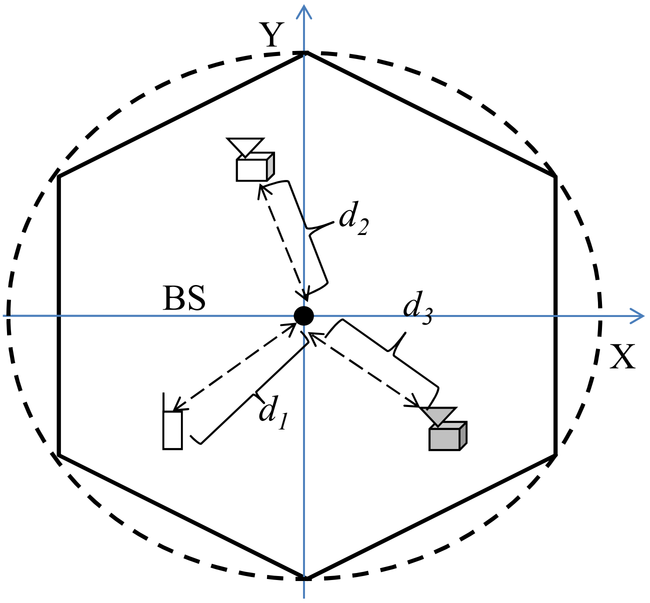
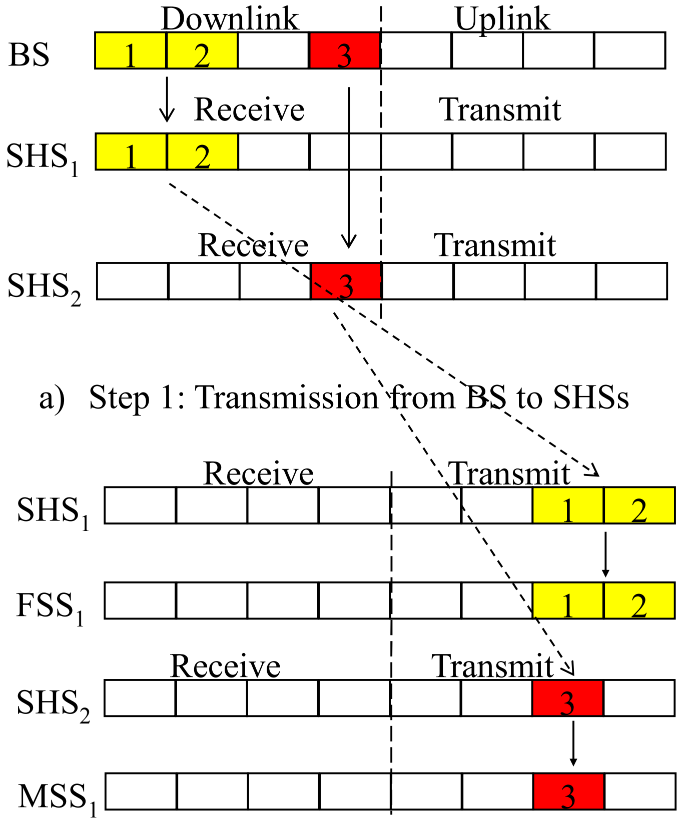


Figure 4.4 User distribution.

The random generator firstly generates the distance from the BS. Then, it gives the angle also to generate X and Y coordinates. Since multi cell condition is considered, the cells should be hexagons. By using uniform distribution, there might be several users allocated outside the cell. In this case, the random generators allocate these users again until positions of all users are in the cell.

4.2.2 Time Slot Allocation



a) Step 1: Transmission from BS to SHSs

b) Step 2: Transmission from SHS to FSS/MSS

Figure 4.5 Time slot allocation in the proposed TDD CDMA multihop network.

Fig. 4.5 shows the proposed time slot allocation scheme with the usage of fixed hopping stations compared to the conventional single hop TDD CDMA networks. For the conventional system, the time slots are divided into two parts: uplink time slots and downlink time slots from the BS. In each uplink time slot, the BS receives if there is a data packet from the user. In each downlink time slot, the BS serves the data packet if there is packet in the data queue.

As compared to the conventional system, time slot allocation is performed by BS for SHSs and the FSSs / MSSs which connect directly with the BS in the proposed system. BS also allocates a certain number of time slots to SHSs, while SHSs allocate time slots for the users which are connected with the SHSs in the certain slots. Assume all cells are frame synchronized. A station can only transmit or receive in one time slot. One time frame is divided into two parts for downlink and uplink transmission. In SHSs' receiving time slots, BS, FSSs and MSSs connected to SHSs can transmit. In SHS's transmitting time slots, only SHSs, FSSs and MSSs connected to BS can transmit. As shown in the part a) of Fig. 4.5, we take one FSS and one MSS connecting to two SHSs for example. Spreading codes are assigned for stations to decrease the interference in the same time slot. In one time slot each code is used for only one station. By receiving the time slot allocation information from BS, SHSs, FSSs and MSSs can share all the spreading codes.

4.3 System Performance Analysis

4.3.1 Propagation Model

Let *L(R)* be denoted as the pass loss (*L* in dBs) with the distance (*R* in kilometers). Assume that propagation between BS and SHS / FSS and between SHS and FSS is regarded as a line of sight model i.e. the propagation loss is the free space loss. The propagation model in [4.9] is used to calculate the path loss between BS and FSS / MSS, SHS and FSS / MSS.

Total path loss in decibels is expressed as the summation of three independent terms: free space loss L_{fs}, diffraction loss from rooftop to street L_{rts}, and reduction due to plane wave multiple diffraction past rows of buildings L_{md}.

The following equation is used for calculation of path loss.

$$L(R) = L_{fs} + L_{rts} + L_{md} \tag{4.1}$$

With the parameters of propagation model and antenna shown in Table

4.1 and Table 4.2, propagation losses are calculated as following:

The propagation loss between BS and FSS is expressed as

$$L(R) = 91.4 + 20\log R \tag{4.2}$$

The propagation loss between BS and MSS is

$$L(R) = 126.6 + 38\log R \tag{4.3}$$

The propagation loss between SHS and FSS is

$$L(R) = 96.4 + 20\log R \tag{4.4}$$

And the propagation loss between SHS and MSS is

$$L(R) = 145.6 + 40\log R \tag{4.5}$$

Table 4.1: Propagation parameters

Carrier frequency	5 GHz
Rooftop level	12 m
Distance between the rows of buildings	80 m
Street width	30 m

Table 4.2: Margin specifications

	Gain (dBi)	**Antenna Height (m)**
BS	10	30
SHS	5	15
FSS	5	15
MSS	0	1.5

4.3.2 Interference Analysis

A 19-cell model is considered as shown in Fig. 4.2. Central cell is considered as cell 0. Because of time slot allocation which divides time frame into uplink and downlink, it is assumed that other cells use the same uplink and downlink time frame to reduce the inter cell interference. The received signal power P_r can be expressed as

$$P_r = P_t \cdot 10^{-L(R,f,G)/10} \cdot 10^{(\eta/10)} \tag{4.6}$$

where P_t is the transmitted signal power, $L(R, f, G)$ is the function that stands for propagation path loss depending on distance R, carrier frequency f, and antenna gain G. η is a normally distributed random variable with a mean of 0. The two parts after the transmitted power represent the distance attenuation and shadowing, respectively.

Because one time frame is divided into uplink and downlink for BS and FSSs / MSSs, it is necessary to consider the *SIR* of in both transmitting and receiving time slots for SHSs. In BS uplink time slots, only SHSs and FSSs / MSSs directly connecting to BSs can transmit. FSSs and MSSs connecting to BS and SHS are denoted as subscriber stations (SSs) connected to BS and SHS (SS^B and SS^H, respectively). Since CDMA is interference limited system, interferences from BSs, SHSs and transmitting users are considered. Signal power of $SS^H_{0,i}$ in cell *0* received from $SHS_{0,j}$ in cell *0* is expressed as,

$$\begin{aligned} S^H_{0,i} &= P\left(SS^H_{0,i}, SHS_{0,j}\right) \\ &= P(SHS_{0,j}) \cdot 10^{-L[R(0i,0j),f,G]/10} \cdot 10^{(\eta/10)} \end{aligned} \tag{4.7}$$

Interference power received by $SS^H_{0,i}$ in the central cell is expressed as,

$$I_{SS} = \sum_{k=0}^{19} \left[\sum_{p=1}^{N_{SHS}} P\left(SS^H_{0,i}, SHS_{k,p}\right) + \sum_{q=1}^{N^B_{SS}} P\left(SS^H_{0,i}, SS^B_{k,q}\right) \right] \tag{4.8}$$

where N_{SHS} denotes the number of SHSs in the cell, N^B_{SS} denotes the SSs connecting to BS. Since the FUs are allocated in the cell with a uniform distribution, the number of FUs allocated in the area for selection of SHSs can be calculated with the value of α and β. On the other hand, the parameter γ which is denoted as the ratio for number of SHSs over number of FUs also limits the number of SHSs. There would be optimized value for α, β and γ for the system, however, it is complicated to calculate for three variables to get the optimization. Thus, we fix the value of γ by changing the values of α and β to get relationships between N_{SHS} and these values. With fixed value of γ the maximum number of SHSs is expressed as,

$$N_{SHS}^{\gamma} = \gamma\, N_{FU} \tag{4.9}$$

where N_{FU} is denoted as total number of FUs allocated in the cell. Because the FU is uniformly distributed in the cell, by considering the values of α and β, we can get another maximum number of SHSs which is denoted as,

$$N_{SHS}^{\alpha,\beta} = \left(\beta^2 - \alpha^2\right) N_{FU} \tag{4.10}$$

where N_{FU} is denoted as the number of FUs in the cellular. Therefore, we have the N_{SHS} calculated as,

$$N_{SHS} = \min\left\{N_{SHS}^{\gamma},\, N_{SHS}^{\alpha,\beta}\right\} \tag{4.11}$$

Thus, received SIR is calculated as,

$$SIR_{SS} = \frac{S_{0,i}^{H}}{I_{SS}} = \frac{P\left(SS_{0,i}^{H}, SHS_{0,j}\right)}{\sum_{k=0}^{19}\left[\sum_{p=1}^{N_{SHS}} P\left(SS_{0,i}^{H}, SHS_{k,p}\right) + \sum_{q=1}^{N_{SS}^{B}} P\left(SS_{0,i}^{H}, SS_{k,q}^{B}\right)\right]} \tag{4.12}$$

In the BS downlink time slots, SHSs and FSSs /MSSs directly connecting to BS can receive. The calculation of *SIR* is the same as that for the single hop cellular system. Most of the interference power comes from other BSs. Other interference power comes from the FSSs / MSSs transmitting to their SHSs. All SHSs and FSSs / MSSs need to get there *SIR* larger than SIR_{req} to satisfy the required signal quality.

4.4 Performance Evaluation

4.4.1 System Assumptions

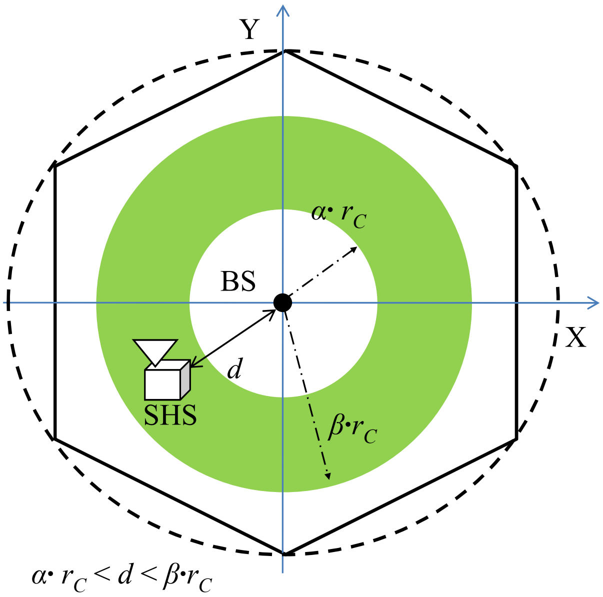
The system parameters are shown in Table 4.3. It is assumed that the conventional network is a single hop TDD CDMA network operating at 5 GHz with fixed time slot allocation (half of the time slots for downlink and the other half for uplink). In order to compare the proposed network to the conventional network, the total power in one cell is set to be the same. Therefore, the BS power for the conventional network equals to the BS power with the power of all the SHSs to make sure that power transmitted in each cell is the same.

For simplicity, both the conventional and proposed networks have sufficient number of spreading codes. In the proposed network, all cells are assumed to be synchronized and they use the same time slot allocation scheme. Therefore, the downlink time slots for FSSs and MSSs are allocated in the BS downlink time slots for the users connecting to BS or in the BS uplink time slots for the users connecting to SHSs. In this case, compared to reverse time slot allocation, the inter cell interference could be reduced.

Shadowing is taken into account only for MSS's propagation model, while the power control is used for BSs. Since the capacity of CDMA networks depends on the total interference, the worst case is considered, where BSs and SHSs transmit at their maximum power. In order to analyze the downlink traffic, in the proposed time slot allocation scheme, the downlink traffic occurs for FSSs / MSSs directly connecting to BS in the BS's uplink time slots, while for others connecting to SHSs in the BS's uplink time slots. Therefore, in the BS's uplink time slots, SHSs cause interference when transmitting to their connected users. In the BS's downlink time slots, the interference is from BSs of other cells. Pilot power of both BS and SHS are assumed to be the same although they have different maximum transmission power. Note that, according to propagation models for FU and MSS (see equation 4.2 - 4.5), BS still has larger coverage, where users receive the signal from BS have 5dB gain more than from SHS [4.9]. γ is considered as a system input parameter, for practicality the values are assumed as 0.1, 0.2 and 0.3 in the simulation. Users are allocated in the cell by using the uniform distribution.

Table 4.3: System parameters

	Symbol	**Quantity**
Carrier Frequency	F_C	5 GHz
Number of BSs (Cells)	n_{BS}	19
Number of users (FU and MSS) per cell	N_u	Maximum 300 in total
Radius of the cell	r_C	1 km
Max number of hops	Max_H	2
Max power of BS	P_{BS}	10 W
Max power of SHS	P_{SHS}	1.5 W
Allocation variables	α, β	$0 < \alpha < \beta < 0.87$
SHS ratio (Number of SHSs to Number of FUs)	γ	0.1, 0.2, 0.3
Required *SIR*	SIR_{req}	5 dB
Pilot power of BS	P_{BS_Pilot}	0.25 W
Pilot power of SHS	P_{SHS_Pilot}	0.25 W
Spreading factor	SF	128



$\alpha \cdot r_C < d < \beta \cdot r_C$

$0 < \alpha < \beta < 0.87$

Figure 4.6 SHS allocation for distance dependent scheme.

In order to find a sub-optimal solution for distance dependent scheme we use the simulation to compare the performance for each allocation parameter, as shown in Fig. 4.6. By changing the value of β we can find an optimal value for a fixing α. SHS should be allocated in the shadow area in the figure. Due to the shape of the cell in multi cell simulation, β should be less than 0.86 which might make some SHSs to be allocated in the edge of the cell.

4.4.2 Performance Results

As the two SHS selection schemes are introduced, the system is simulated with different SHS ratio and values of α, β and γ for the distance dependent selection scheme. Since the CDMA system is an interference limited system, transmission power control (TPC) is adopted. All the FSSs and MSSs connected to SHSs get their traffic from the SHSs. In order to get the required *SIR*, each user should receive a minimum power which is the required power from BS or SHS. If a user could not get its required power, the user is considered to be the outage user. So, outage probability is expressed as the ratio of number of unsuccessful users out of total users.

The choices of SHS are limited by not only γ but also the distance from BS which selects SHSs from FUs in the area dependent on α and β in method B. Fig. 4.7 shows the simulation to find a sub-optimized result for method B by fixing the value of γ when changing the values of α and β, where γ is considered as a system input value which indicates the number of SHSs allocated in each cell. α and β are simulated with a step 0.1 for each γ equal to 0.1, 0.2, and 0.3 respectively, where α and β are between 0.1 and 0.8 (since the shape of cell is assumed as a hexagonal, both the values should be less than 0.9).

By choosing $\alpha = 0.5$ and $\beta = 0.7$, method B can perform the best connectivity, when the users near the cell border can connect with SHSs in the BS uplink time slots. The result shows that SHSs allocated in the area close to the cell edge however not too far from BS could provide the best performance, as shown in Fig. 4.8. According to the allocation of the SHSs, more FSS/MSS could connect to SHSs in the area.

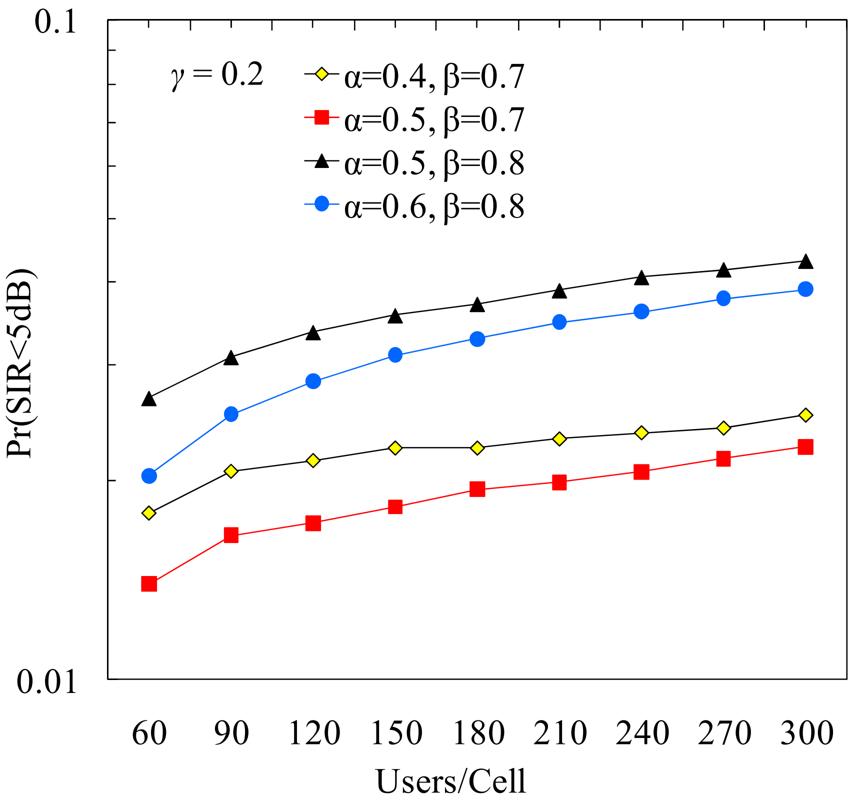


Figure 4.7 Optimization for distance dependent SHS selection scheme.

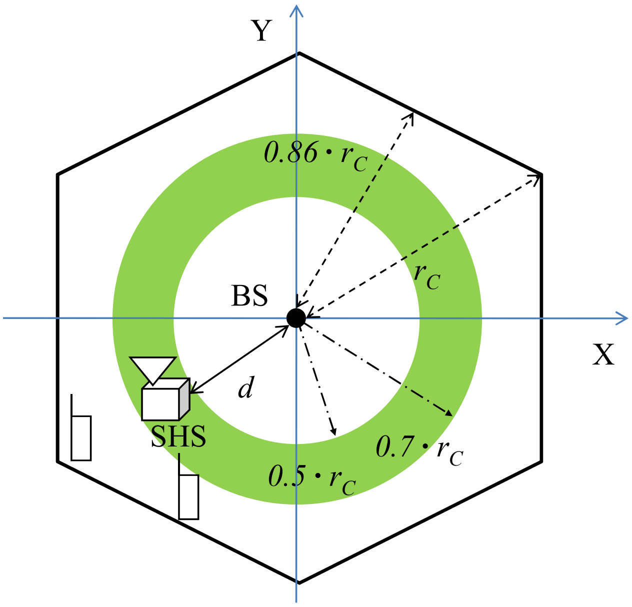
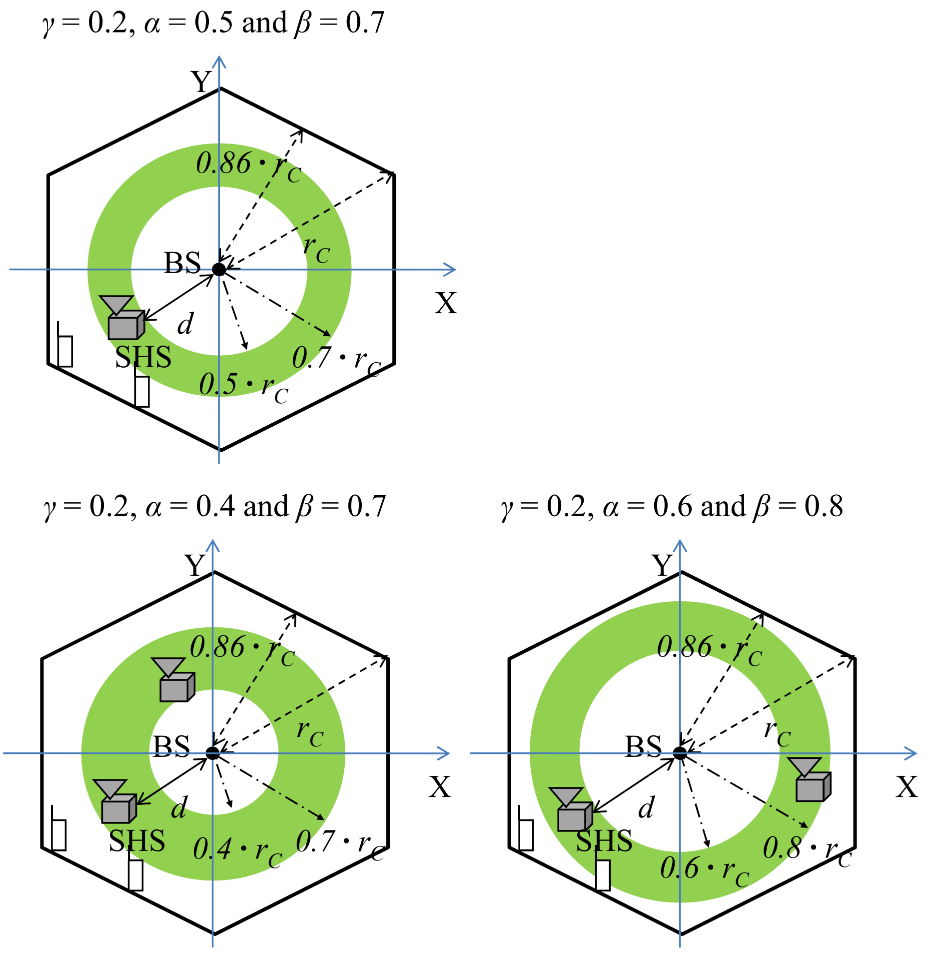


Figure 4.8 Allocation of SHSs for the best outage performance.



$\gamma = 0.2$, $\alpha = 0.5$ and $\beta = 0.7$

$\gamma = 0.2$, $\alpha = 0.4$ and $\beta = 0.7$

$\gamma = 0.2$, $\alpha = 0.6$ and $\beta = 0.8$

Some SHSs are too close to BS

Some SHSs are too far from BS

Figure 4.9 Comparisons of SHSs for the best outage performance.

Fig. 4.9 shows the comparisons for different allocation parameters. In case $\gamma = 0.2$, $\alpha = 0.5$ and $\beta = 0.7$ perform the best outage probability. SHS should be selected between half of the radius and the distance not so closed to the cell edge

Fig. 4.10 shows the outage probability of the random SHS selection and distance dependent SHS selection compared to single hop (conventional) system. The number of MSSs is twice as that of FUs with different values of γ. When the number of users is small, the single hop system is better, because the SHSs cause interference to their neighbor FSSs/MSSs. However, when there are more than 120 users in each cell, the fixed relay network provides better performance. We can see in the figure that the proposed schemes can achieve the outage probabilities less than 0.03 even the number of users reaches 300. By choosing values of α and β with γ equal to 0.1, 0.2 and 0.3 respectively, the distance dependent SHS selection scheme could be better than random scheme. Since the outage probability can be reduced by connection with the FSS / MSS far away from the BS. Further, with high density of users, the distance dependent SHS selection can provide the connection more fairly, especially for the FSSs and MSSs which are far from the BS.

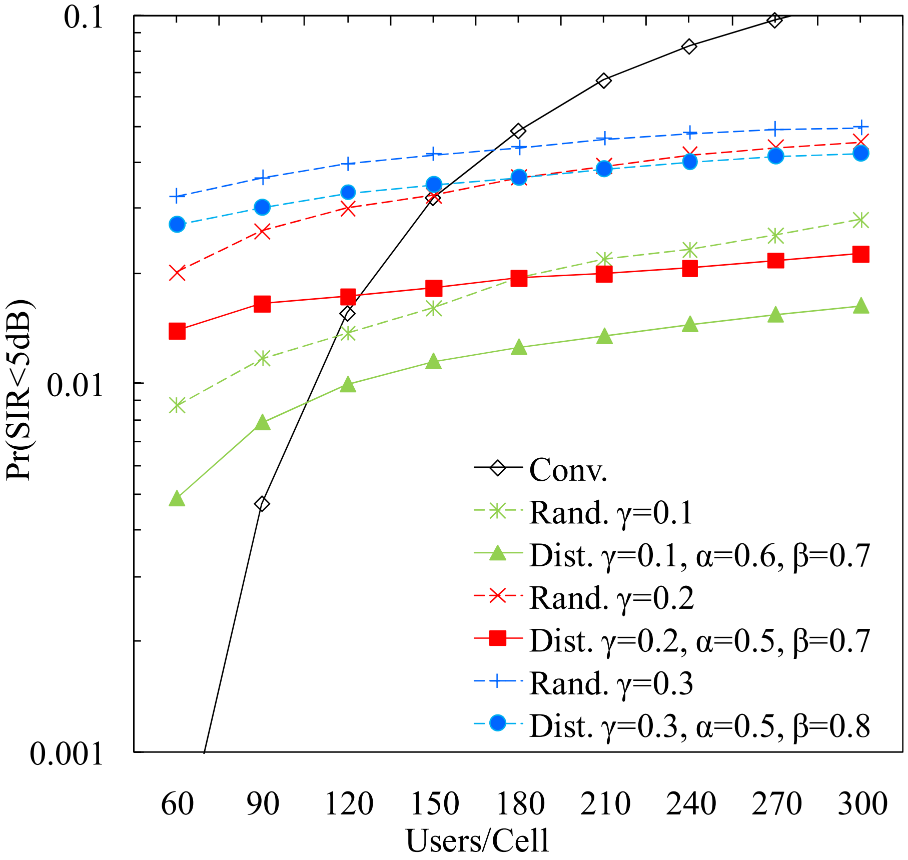


Figure 4.10 Outage probability when number of MSSs is twice as that of FSSs with SHSs with different values of γ.

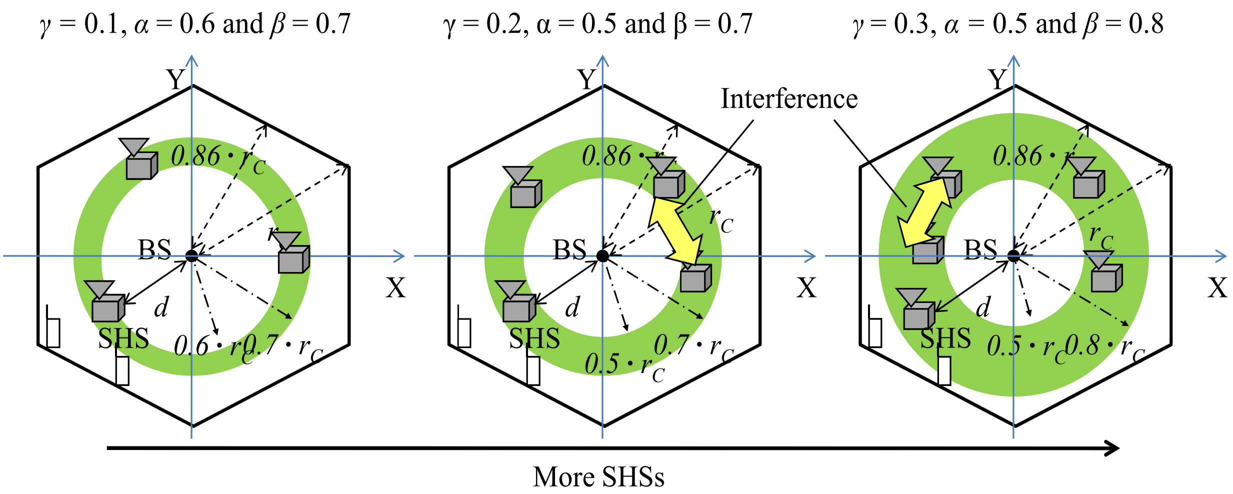
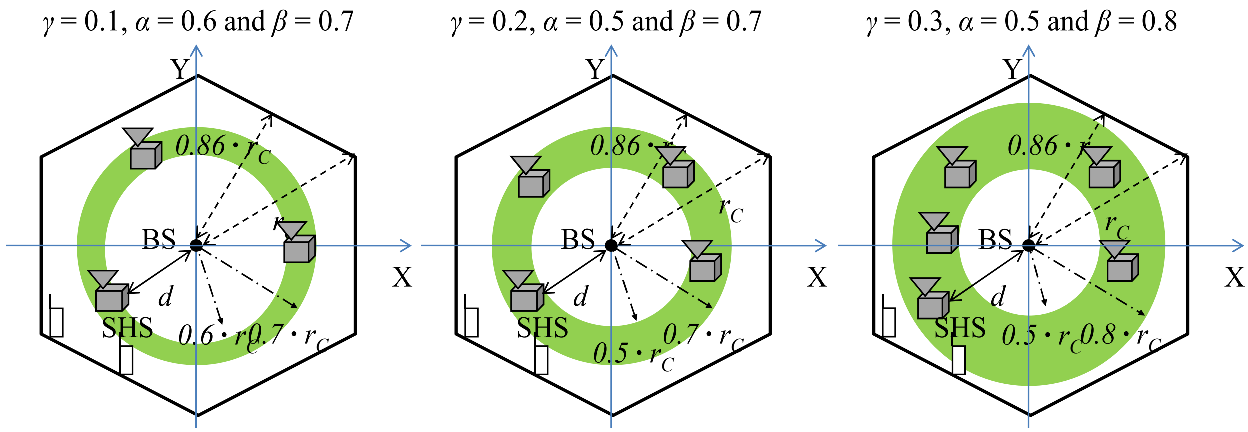


Figure 4.11 Comparisons of SHS selections.



Ratio of FUs: $(\beta^2 - \alpha^2) = 0.13$
SHS ratio: γ / 0.13 = 77%

Ratio of FUs: $(\beta^2 - \alpha^2) = 0.24$
SHS ratio: γ / 0.24 = 83%

Ratio of FUs: $(\beta^2 - \alpha^2) = 0.39$
SHS ratio: γ / 0.39 = 77%

Figure 4.12 The Relation between γ and SHS Selection.

Fig. 4.11 shows the comparison of allocation schemes. In the simulation γ = 0.1, α = 0.6 and β = 0.7 perform the best outage probability. Fig. 4.12 shows the relation between and SHS selection. When fixing α and β, the sub optimal value of γ could be found by simulating from 0 to (β2 - α2) due to the constant user density. Therefore, we could calculate the ratio of SHS in the selected area.

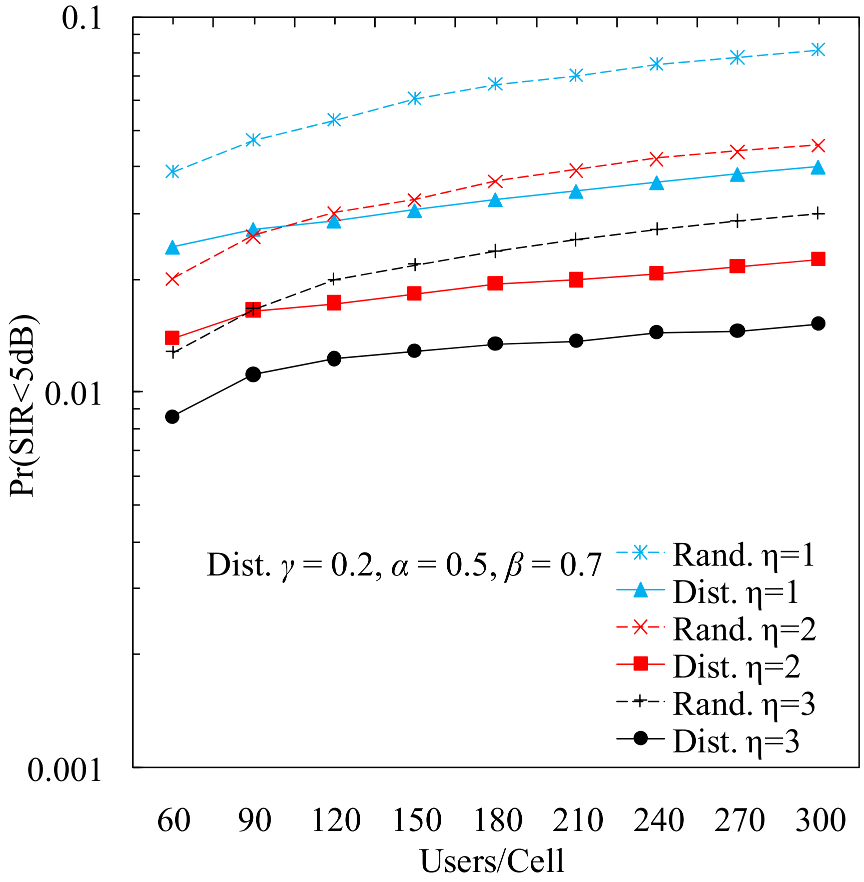


Figure 4.13 Outage probability under various ratios of MSSs.

Fig. 4.13 shows the outage probability with different ratios of MSSs with $\gamma = 0.2$. We denote the ratio for the number of MSSs to the number of fixed stations as η, which changes as 1, 2 and 3 respectively. According to the sub-optimized results we get from Fig. 4.7, α and β equal to 0.5 and 0.7 respectively. In the BS uplink time slot, SHSs act as relays by transmitting data to the users connected with. As the number of MSS increasing the outage probability is reduced, since less SHSs cause less interference while more MSSs can connect to SHSs successfully instead of BS. Thus, in the BS downlink time slot SHSs and the rest FSSs / MSSs could connect with BS with higher transmission power.

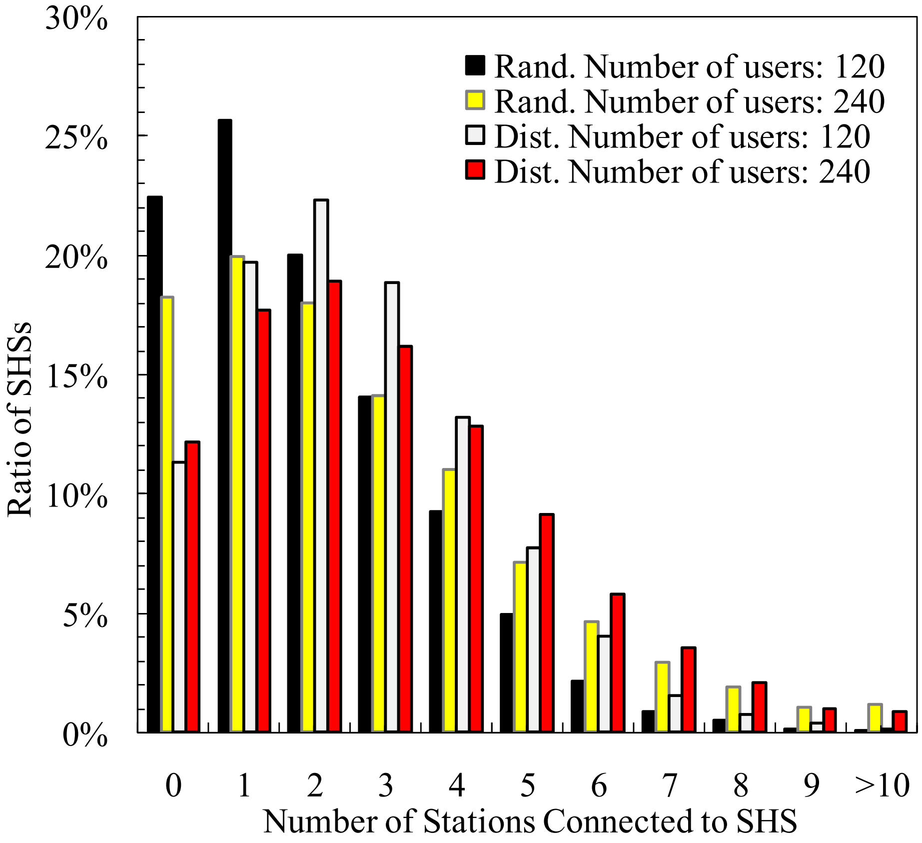


Figure 4.14 Ratio of SHSs vs. number of connections for two hopping station selection schemes.

We assume that when several FSSs/MSSs connecting to one SHS, SHS transmit for one user at a single time slot, where all the users have packets for transmission.

Fig. 4.14 shows the Ratio of SHSs under different number of connections for comparison of two hopping station selection schemes, where the number of users are 120 and 240, respectively. Note that ratio of SHSs is denoted as the ratio of the number of SHSs whose connection with FSS / MSS equals to 0, 1, 2, 3… or more than 10, respectively. We can find that most of the SHSs allocated by the distance dependent scheme connect 1, 2 or 3 FSSs and MSSs, on the other hand, most of the SHSs allocated by random selection schemes do not connect any user or only connect to 1 user. Thus, more hopping stations are used in the distance dependent hopping station selection scheme and the number of the connection for each hopping station is about 3 or 4 connections, while some hopping stations connecting with many users or very few in the random hopping station selection scheme. Since TPC is adopted in CDMA system, too many users cause high outage due to limitation of SHS transmission power. If locations of SHSs are too near or too far from BS, no FSS or MSS can receive higher SIR from these SHSs compared to BS, whose power are weaker than that BS can provide. Therefore, the distance dependent SHS selection is more efficient to use hopping stations.

In this section we simulate the different parameters such as α, β and γ for both random and distance dependent SHS selection schemes by comparing with the conventional single hop system. Considering γ as a system input value, simulation results show that by carefully choose the range of SHS allocation system could get much better performance than random SHS allocation. System designer should also consider the number of FSSs and MSSs to decide the allocation values.

4.5 Conclusions

In order to improve system capacity in the TDD CDMA cellular network with hopping station, we propose the scheme by combining the time slot allocation and selection of hopping stations. By exploiting time slot allocation scheme for different connection types of users, connecting to BS or hopping stations, the proposed scheme for the system is able to achieve lower outage probability, i.e. more users can connect to the networks with a required SIR. A sub-optimized allocation distance dependent SHS allocation scheme is described by using computer simulations. The results show that the proposed multi hop network architecture can achieve less outage probability compared to the conventional single hop TDD CDMA network, especially there are more mobile users and high user density. The comparison of two SHS selection schemes shows that the distance dependent SHS selection scheme gains more efficiency than random SHS selection scheme.

References

[4.1] R. Pabst, B. H. Walke, D. C. Schultz and P. Herhold, "Relay-Based Deployment Concepts for Wireless and Mobile Broadband Radio," *IEEE Commun. Mag*., pp. 80-89, Sep. 2004.

[4.2] N. Esseling, B. H. Walke and R. Pabst, "Performance Evaluation of a Fixed Relay Concept for Next Generation Wireless Systems," *IEEE PIMRC*, Barcelona, Spain, pp. 744-751, Sep. 2004.

[4.3] B. Liu, Z. Liu and D. Towsley, "On the Capacity of Hybrid Wireless Networks," *IEEE Infocom*, San Francisco, USA, pp: 1543-1552, Mar. 2003.

[4.4] Y. Lin and Y. Hsu, "Multihop Cellular: A New Architecture for Wireless Communications," *IEEE Infocom*, Tel Aviv, Israel, pp. 1273-1282, Mar. 2000.

[4.5] D. Zhao and T. D. Todd, "Cellular CDMA Capacity Improvement Using Ad Hoc Relaying," *IEEE PIMRC*, Barcelona, Spain, pp. 719-723, Sep. 2004.

[4.6] H. Wei, S. Ganguly and R. Izmailov, "Ad Hoc Relay Network Planning for Improving Cellular Data Coverage," *IEEE PIMRC 2004*, Barcelona, Spain, pp: 769-773.

[4.7] A. Fujiwara, S. Takeda, H. Yoshino and N. Umeda, "Evaluation of Cell Coverage and Throughput in the Multihop CDMA Cellular Network," *IEEE VTC*, Milan, Italy, pp. 2375-2378, May 2004.

[4.8] T. Rouse, S. McLaughlin and I. Band, "Congestion-Based Routing Strategies in Multihop TDD-CDMA Networks," *IEEE J. on Selected Areas in Commun.,* Vol. 23, pp. 668-681, Mar. 2005.

[4.9] H. H. Xia, "A Simplified Analytical Model for Predicting Path Loss in Urban and Suburban Environments," *IEEE Trans. on Vehicular Technology*, Vol. 46, pp. 1040-1046, Nov. 1997.

Chapter 5

Packet Scheduling for Cellular Relay Networks

In this chapter, we propose a packet scheduling algorithm for cellular relay networks by considering relay selection, variation of channel quality and packet delay. In the networks, mobile users are equipped with not only cellular but also user relaying radio interfaces, where the base station (BS) exploits adaptive high speed downlink channel. Our proposed algorithm selects a user with good cellular channel condition as a relay station for other users with bad cellular channel condition but can get access to relay link with good quality. This can achieve flexible packet scheduling by adjusting transmission rates of cellular link. Packets are scheduled for transmission depending on scheduling indexes which are calculated based on user's achieved transmission rate, packet utility and proportional fairness of their throughput. The performance results obtained by using computer simulation show that the proposed scheduling algorithm is able to achieve high network capacity, low packet loss and good fairness in terms of received throughput of mobile users.

5.1 Introduction

Providing quality of service (QoS) is one of the crucial requirements in wireless high speed data networks which exploit adaptive multi-rate shared channels, such as beyond third generation (B3G) wireless networks and IEEE 802.16 wireless metropolitan area networks (WirelessMAN). In order to achieve user fairness, Round Robin (RR) scheduling algorithm is proposed. On the other hand, maximum carrier to interference ratio (MCIR) scheduling algorithm can be used to achieve high system throughput. However, as the wireless channel condition is varying, existing scheduling algorithms do not utilize channel resources efficiently [5.1] [5.2].

Recently, opportunistic scheduling has drawn much research interests due to the efficient usage of channel resources, by developing rate adaptation schemes to increase data transmissions selectively on a link when it offers good channel quality [5.1]. In contrast, opportunistic manner always causes unfair to users who experience poor channel quality. The modified largest delay weight algorithm [5.3] is considered as a throughput optimal proportional fairness scheduling, which provides packets with long waiting time higher priority to be served. Furthermore, to provide QoS requirement for different traffic classes (delay sensitive traffic and delay tolerant traffic) [5.4], the proportional fairness based scheduling algorithms have been proposed in [5.5] - [5.8], where different traffic classes are distinguished, and delay bounded packet scheduling algorithms are provided. However, in these studies, high priority is given to delay sensitive packets, whereas a lot of delay tolerant packets would suffer long delay. More seriously, compared with users having good channel condition, the users with poor channel condition have to suffer from low priority. Thus, the low performance of such users becomes the bottleneck of scheduling design for system throughput enhancement.

In contrast to the conventional cellular systems, which use base stations (BSs) to transmit packets to mobile stations (MSs) directly, wireless relaying cellular network architecture has been proposed [5.9], by taking the advantages from the multi-hop networks, where the throughput-optimal scheduling strategies are considered with the queuing systems and routing for time varying channels [5.10] [5.11]. In the architecture, a MS can access the core network by connecting to BS directly in cellular mode or via other terminals, which operate as relays forwarding packets of MSs [5.12] [5.13]. A unified cellular and ad-hoc is proposed in [5.14] by introducing a routing protocol and proportional fairness scheduling in extension of 3G cellular.

Since most of the previous works focus on the architecture of the relaying networks, there is little research considering the interaction between the relay selections and scheduling algorithms according to our knowledge. In high speed wireless networks, the scheduling decision should be made very quickly time slot by time slot, where the selection for scheduled user affects the system throughput significantly. Furthermore, the selection of the relay might be the bottleneck if the scheduled user has to receive its packets via a relay. Thus, in order to improve the system capacity and packet QoS support, more efficient packet scheduling algorithms are needed in relaying networks. In this chapter, we propose a packet scheduling algorithm for relaying cellular networks by considering relay selection where MSs can use cellular adaptive multi-rate and user relay channels. Nowadays, more cell phones, PDAs and laptops are equipped with several wireless interfaces. Although the utilization of more resources (e.g. energy, bandwidth) is required as compared to the conventional single hop, the cost of such utilization could be reduced by sharing the information (e.g. SNR, traffic) between the cellular channel and ad hoc channel. Since the relay selection information is only fed back to BS, there is no inter-MS transmission.

Our objective is to improve system throughput and guarantee user's QoS for different traffic classes. In order to improve user fairness in terms of received throughput, our algorithm also introduces user throughput as a parameter of the scheduling index by comparing it with the overall average throughput. The proposal can also be recognized as a cross-layer approach, where the signal to noise ratio (SNR) based multi-rate support at physical layer offers primitives in an agile manner to fluctuations in channel conditions and channel utilization. The proposed scheduling algorithm considers both short term information such as available transmission rate, and the long term information such as user received throughput and packet delay constraint. Since different delay bounds are given to different traffic classes as QoS requirements, scheduling priority of packets is given by considering not only transmission rate of their destination MSs but also their waiting time in the data queue. Compared with Round Robin and MCIR scheduling algorithms, performance results obtained by using computer simulation show that the proposed scheduling algorithm can achieve higher overall throughput, less packet loss and better user fairness.

5.2 System Description

We consider a 3G-like cellular system with high speed downlink shared cellular channel. Mobile users access the cellular channel in a time division multiple access (TDMA) fashion. Fig. 5.1 shows the system model, where MSs are dual-mode, having both cellular and ad hoc relaying radios (without loss of generality, only central cell in the multi-cell model is shown in the figure). Without confusions we denote MS as the mobile user in the network, and relay stations (RSs) as the MSs which act as relays for other MSs. In contrast, subscriber stations (SSs) are denoted as the MSs which are end users connecting directly to BS or RSs. Each cell consists of a BS, and a set of finite MSs. BS maintains the separate queues for each MS with different traffic classes. In addition, we assume that data rates achieved by the ad hoc relaying radio are assumed to be much higher than those achieved by the cellular radio. This is usually true because, for example, transmission rates up 54 Mb/s can be achieved for IEEE 802.11g.

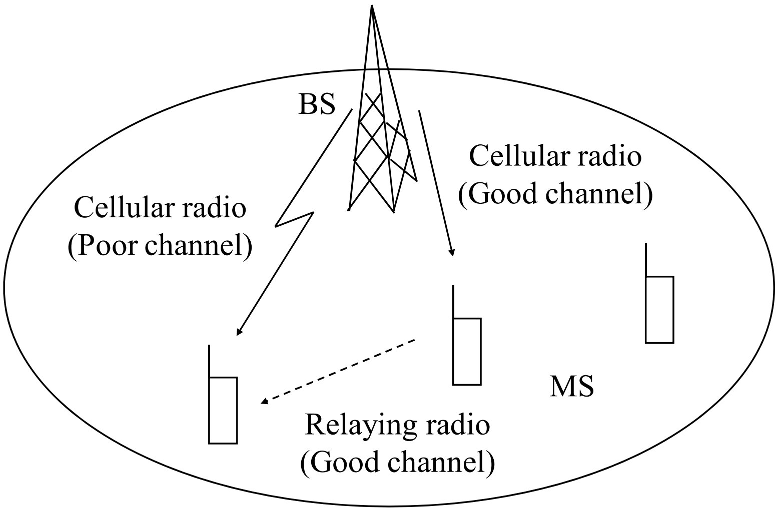


Figure 5.1 System model of relaying cellular networks.

Due to the symmetric channels we consider downlink without loss of generality in this section, since uplink case can be analyzed in a similar manner. In the cellular channel, time is divided into constant time slots, where MSs are sharing the multi rate adaptive channel. BS selects an available transmission rate level for a MS based on its received *SNR* (denoted with γ) when scheduling its packets. In case a packet is selected to transmit to *i*th MS, BS selects the appropriate transmission rate by following condition:

$$\gamma_i \geq \gamma_L \quad , \tag{5.1}$$

where γ_L denotes the required *SNR* corresponding to rate level *L*, *i* denotes the ID number of the MS. Thus, the transmission rate calculated by a SNR-rate function *f* for MS *i* at time slot *t* is expressed as,

$$r_i(t) = f(\gamma_i(t)) \quad . \tag{5.2}$$

where *f* compares the user SNR to the required SNR for each transmission rate level and selects the proper rate level for the user.

By exploiting dual mode terminal, an active MS is able to choose other MSs which are in its relaying radio range and have better channel quality as its RS. Communication links between RSs and MSs use frequency spectrum which is only available to relaying radio and does not consume the spectrum of cellular shared links. Assume that BS can transmit control messages including the decision of relay selection and scheduling signaling to all MSs in an individual control channel in the cell. By synchronizing and transmitting the control message in the cellular control channel, MSs connecting with RSs can also listen to this channel and feedback their SNR information. Received SNR is assumed to be constant during transmission of a single packet. By shifting some MSs having poor cellular channel condition to connect with others having good cellular channel condition when the ad hoc channel between them is good, BS can allocate the system resource more efficiently.

Since packets are transmitted in a high speed channel to RSs and MSs, BS and RS can be considered to keep stable to provide connections during the transmission, while the channel condition is considered to be constant. The objective of this chapter focuses on the BS scheduling decision and relay selection. For the ad hoc link, we assume that the packets can be managed to be served with interference free channel by different relays due to the high transmission performances. Different RSs do not interfere each other, while MSs could only be assigned to RSs within its relaying radio range. Due to mobility, the cellular channel quality of RS is varying. According to the feedback information which may report different choices of relay or no relay available, BS can reallocate relay or establish direct connection in next time slot.

We consider both delay sensitive and delay tolerant traffic, which are denoted as streaming packets and best effort packets, respectively. A streaming packet has to be transmitted within a delay bound, otherwise it is dropped. On the other hand, a best effort packet is set to have a virtual delay bound, while the system would fix its priority after its delay getting larger than the virtual delay bound instead of dropping the packet, although it is counted to have excessive delay. Thus, BS could select the destination MSs with poor cellular channel condition to connect with RSs with good cellular channel condition. We consider an independent traffic flow model in which for each MS independent sources generate data packets for transmission. For streaming packets, packet drop occurs not only due to the delay bound but also the buffer overflow in BS. In contrast, best effort packets would be dropped only due to the data queue overload.

In this chapter, we focus on the resource allocation problem in the relaying networks. Since MAC layer could be separated from physical layer, we consider the MAC layer could guarantee the error-free transmission with proper rates while the physical layer would provide retransmission or error recovery. In cellular relay networks, packet delay should be calculated with either the direct mode or the relay mode, where ω is denoted as waiting time in the data queue and σ is denoted as transmission delay. Here, packet transmission delay σ from BS is calculated by the packet size divided by the transmission rate. Although the relay has the advantages of throughput enhancement, extra delay might be caused by the relay due to the queuing delay and transmission delay. In order to evaluate the delay performance for the comparison between direct and relay transmission, we introduce a parameter τ for the delay of relay. The total delay is calculated as following,

$$d = \begin{cases} \omega + \sigma, & \text{direct connection} \\ \omega + \sigma + \tau, & \text{relaying connection} \end{cases}, \tag{5.3}$$

where the relay transmission delay τ is an average value of relay links for simplicity. Packets might be forwarded in different routes to their destination. Therefore, the packets sent directly or via different RSs would arrive in different order as compared to their original order due to different transmission rate and waiting time. In this case, those packets can be reordered in destination MSs after being received. According to (5.3), transmission delay σ of packet depends on the available transmission rate.

5.3 Packet Scheduling Algorithm

Compared to the conventional single hop cellular networks, relaying networks could benefit not only the users with poor cellular channel but also those with good channel. There are mainly two incentives for relay nodes to spend their resources to others. From the system’s point of view, distribution of traffic load to the relay nodes could improve the aggregated system throughput and reduce the loss of packets. On the other hand, the relay nodes could get more resources (e.g. time slots) from the BS since fewer resources are used for MSs with low transmission rates (compared to non-relay case). In this section, we propose a scheduling algorithm by considering relay selection which takes into account the user's variable transmission rate based on their received SNR, packet delay requirement of multi traffic classes, and user fairness constraints.

5.3.1 Scheduling Index

Maximum two hop relay connection is considered, since by trading off between a major portion of possible performance gains and implementation complexity, the limiting the number of hops to two is a good design choice [5.15]. Due to the assumption that relay radio exploits a high speed channel, the channel condition between a MS and its RS would be kept stable until the RS completes the transmission of packets to the MS. In the relaying channel, a MS periodically broadcasts a beacon signal containing its ID within relaying range. The contents of each beacon signal include the MS ID, SNR level in the cellular channel and a pilot signal. Each MS only selects the MSs which have better SNR level as its potential relays (maximum 3) and report these IDs to BS so that the BS can maintain the list of possible MSs which can become RSs of others. If a MS does not report its ID of beacon signal after a defined period e.g. 10s, BS would consider that this MS has moved out. Therefore, BS can select other MSs as RSs within the relaying range. Since all the scheduling decisions are made by BS and RS will forward the relaying packets after receiving them, the MS does not have to report its selection of potential relays to RSs but only to BS. Let N denote the total number of MSs in a cell. Several MSs act as RSs, thus, we use the $N * N$ matrix H = [hi,j] to denote the relay selection performed by BS, which satisfies,

$$h_{i,j} = \begin{cases} 1\,, & \text{if link } \overrightarrow{\text{ij}} \text{ is available} \\ 0\,, & \text{otherwise} \end{cases} . \tag{5.4}$$

By considering neighbor MSs within their relaying range, $h_{i,j}$ is set to 1 when MS j experiences the best channel quality among neighbors of MS i, while $i \neq j$. Note that if $h_{i,j} = 1$ and $i = j$, MS i directly connects to BS and can be selected as a RS. The value of the entity in the matrix is decided by BS to maximize the total performance of the networks. In order to improve the system throughput by using relays, BS would schedule the packet to RS for the MS which could connect to a RS with higher transmission rate. According to (5.4), for the MS i connected to RS, the available scheduling rate, εi(t), considered by BS is presented as,

$$\varepsilon_i(t) = \sum_{j=1}^{N} h_{i,j} r_j(t) \quad , \tag{5.5}$$

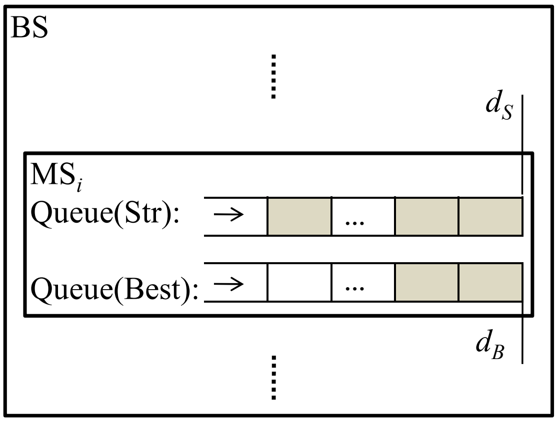
where r_j is the transmission rate of cellular link of MS j. For each i, $h_{i,j}$ has only one non-zero value. BS selects only one RS for a MS when the MS is chosen for scheduling, although one MS could have more than one potential RS. Note that, the SSs connected to RSs replace their available transmission rate by their RSs' transmission rate to increase their scheduling priority. BS performs the relay selection by comparing the available scheduling rate for each MS with its available relay and selects appropriate values for H.

The scheduling decision consists of three parts: rate opportunistic index, packet utility index, and user fairness index. For MS i connecting to BS via RS j, the SS's available scheduling rate is replaced by the RSs' achieved rates, i.e. $h_{i,j} = 1$. In contrast, for MS k connecting to BS directly, the scheduling rate is its own transmission rate of cellular link with $h_{k,k} = 1$. By comparing the available transmission rate with the average, giving high priority to the MSs with high transmission rate could gain larger system throughput. On the other hand, MSs with poor cellular channel conditions could get higher priority by cooperating with the relay selection. Therefore, we use transmission rate of MS i normalized to sum of all the MSs' as the rate opportunistic scheduling index, $R_i(t)$, which is expressed as,

$$R_i(t) = \frac{\varepsilon_i(t)}{\sum_{i}^{N} \varepsilon_i(t)} \quad . \tag{5.6}$$

The scheduler (BS) would use more resources for MSs who have better channel quality to increase the system throughput. In the rate opportunistic index, the scheduler prefers to serve MSs having high transmission rate, or SSs can connect to RSs with good channel quality although they have poor channel condition.

We depict the packet utility in terms of delay as shown in Fig. 5.2 to support QoS for different traffic classes with an example of data queue in BS, where queue delay is the waiting time for the packet in the head of queue. If packets are for streaming traffic, we can use a utility function that increases concavely and goes up near the delay bound. However, the utility would fall to zero after the delay getting larger than the delay bound, which refers to dropping loss of streaming packets. In the opposite, the utility increases convexly for best effort packets. Packet utility would keep the value 1 after the delay getting larger than the delay bound. Thus, the packet drop would be caused only by queuing drop in BS.



User data queue

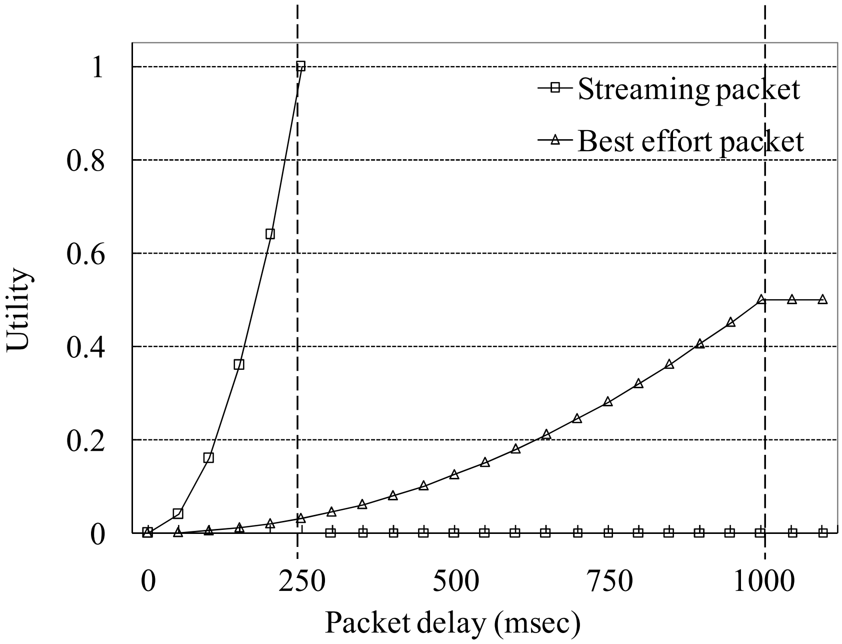


Figure 5.2 Utility function.

According to the packet utility function, the proposed scheduling algorithm assigns higher priority to streaming packets compared with best effort packets due to their urgency. In contrast, the priority of best effort packet is assigned with the delay bound. In the scheduler the larger the utility is, the faster the packet would be served. Consider the head packet in data queue of MS *i*, the packet utility scheduling index, $U_i(t)$, is shown as,

$$U_i(t)=\begin{cases} \left(\dfrac{d_i(t)}{D_S}\right)^2\cdot W_S\,, & t\le D_S\text{, stream} \\ \min\left(\left(\dfrac{d_i(t)}{D_B}\right)^2,1\right)\cdot W_B\,, & \text{best effort} \end{cases}, \qquad (5.7)$$

where $d_i(t)$ is denoted as the packet delay for the packet of MS *i*. Delay bound of streaming traffic DS is smaller than the delay bound of best effort traffic DB. WS and WD are denoted as weights for streaming and best effort traffic, respectively, which represent the priority for transmission. Practically, we set the value of WS larger than the value of WD to give the streaming packet higher priority. Packet delay depends on both available transmission rate and relaying selection, while packets would be dropped if queuing delay is higher than DS. In contrast, the utility would increase convexly until the bound for best effort packets. In order to guarantee packet delay performance, packets with longer delay utility should have higher priority for transmission. Since our proposal gives a virtual delay bound to best effort packets, the priority of them would not increase after their queuing delay become larger than their delay bound. We define utility to be a larger value when the packet is experiencing longer delay in Fig. 5.2. Our objective here is that BS would transmit the packet which has higher probability to be dropped as quickly as possible. Here, we have to make the tradeoff between the delay performance and user fairness in terms of individual user throughput.

We address the fairness issue to MS received throughput within a period. If the throughput of a MS in a certain period is less than the average received throughput, BS should increase the priority to be served. Ti(t) is the average of throughput received by MS i before time slot t in a certain period, which is denoted as the tracking time. Throughput of MS i, Ti(t), is updated as follows [5.16],

$$T_i(t+1)=\left(1-\frac{1}{t_w}\right)T_i(t)+\frac{1}{t_w}\phi_i(t) \quad , \tag{5.8}$$

where t_w is the window size of tracking time, while $\Phi_i(t)$ is the current scheduling rate of MS i at time slot t,

$$\phi_i(t)=\begin{cases}\varepsilon_i(t), & \text{user } i \text{ is scheduled}\\ 0\,, & \text{otherwise}\end{cases} \quad , \tag{5.9}$$

where the throughput of each MS is updated every time slot. Note that, BS schedules one packet in one time, where the transmission for one packet would occupy more than one time slot. In this case, (5.9) would keep updating until the transmission finished. By selecting the value of tracking time for throughput, the long term throughput constraint can be set to satisfy different fairness requirement. A MS is given high priority when it experiences a bad throughput. The throughput based fairness scheduling index of MS i, $F_i(t)$ is defined as,

$$F_i(t)=\exp\left(\overline{T}(t)-T_i(t)\right) \quad , \tag{5.10}$$

where $\overline{T}(t)$ is denoted as the average throughput of all MSs expressed as,

$$\overline{T}(t)=\frac{\sum_i T_i(t)}{N} \quad . \tag{5.11}$$

5.3.2 Packet Scheduling

Fig.5.3 shows the procedure of proposed scheduling algorithm. Our objective of scheduling design is to improve the system throughput while keeping the user fairness and packet QoS by using relay and adaptive channel. Hence, BS makes the decision of scheduling with the criteria given by,

$$I=\underset{1\le i\le N}{\arg\max} R_i(t)\cdot U_i(t)\cdot F_i(t) \quad . \tag{5.12}$$

BS would select the MS with the largest value of the scheduling index for transmission, by considering requirements for both MSs and their packets.

By multiplexing the transmission rate index with packet utility, we can see that the SSs using relay with higher transmission rate can also achieve higher utility value. BS always considers the index for the next time slot, thus, we have

- α is a normalized value, $0 <= \alpha <= 1$.
- U is a normalized value, $0 <= U < W_S / W_B$. Here, buffer weight could be changed by changing the value of W_S and W_B.
- β is not normalized, since the constraint of fairness could be controlled by changing the tracking window t_w. Small t_w (short term tracking) would make the weight for fairness larger. On the other hand, large t_w (long term tracking) would make the weight for fairness smaller

1. MS reports its *SNR* and ID of received beacon signals to BS.
2. BS compares each user's *SNR* with others in its relaying range and selects RSs for the SSs with poor cellular channel condition.
3. Transmission rate index is calculated cooperating with the relay selection.
4. For each user BS calculates utilities of the first packet for different traffic classes and selects the packet with the largest utility.
5. BS calculates the throughput index $T_i(t)$ (there is no packet drop in relaying link).
6. BS calculates the scheduling index for each MS, and selects the user with the largest value to serve.

Figure 5.3 Scheduling procedure.

5.4 Performance Simulation

5.4.1 Simulation Model and Assumptions

In this section, we carry out the computer simulation in terms of throughput, packet delay and user fairness by using the proposed scheduling algorithm. Our simulation is performed in a 9-cell model, where we focus on central cell. Each cell covers a square area with the range 800m × 800m.

We assume that there is no collision between relaying links. MSs could receive from a RS in the radio range of 150m. The variable rate channel experiences path loss, and follows the Rayleigh fading model for nomadic MSs.

We assume that BS uses 10% of its total power for signaling channel, which becomes the intra-cell interference for data transmission. In contrast, the inter-cell interference is caused by neighbor BSs. At the beginning of the simulation we allocate the mobile nodes randomly in the cellular range by using a uniform distribution. Since the mobile nodes are expected to move in a practical network, the most commonly mobility model called random waypoint model [5.17] is used in this chapter. For simplicity, the random waypoint model used in the simulation is assumed to keep the mobile nodes moving in the cellular range with the maximum speed of 5 meter per second.

The simulation is performed in a system level. The packet size and transmission rate used for simulation are assumed to be the real information bits. Packets with constant length are generated for each MS, equal for both streaming and best effort packets. Packet size is 900 bytes. We emulate the multi rate system, where we use 4 levels of transmission rates for simplification, although the system would have more transmission rate levels. The time slot duration is 1 msec. We emulate the multi rate system, where we use 4 levels of transmission rates for simplification, although the system would have more transmission rate levels [5.18]. Different SINR levels would be converted to the 4 levels of transmission rates, where the users with the SINR less than 0dB would be considered as outage users. The users with SINR between 0dB and 4dB, 4dB and 8dB, 8dB and 12dB would be assigned the transmission rates through level 1 to level 3 as shown in the table 1. In contrast, users with the SINR above 12dB would be transmitted with level 4 transmission rate. A bursty traffic model is simulated for best effort traffic. BS has finite separated data queues of both streaming and best effort packets for each MS. Thus, packet loss is occurred for streaming packets which could not be transmitted within delay bound. For best effort traffic, packets get dropped due to the data queue overloaded. Fig. 5.4 shows the simulation flow chat, where the information from both user side and carrier side are considered.

Table 5.1: Simulation parameters

Symbol	Quantity	Value
R_B	Cell range (square)	800 by 800 m
R_A	Relaying range	150 m
D_S	Delay bound for streaming packets	250 msec
D_B	Delay bound for best effort packets	1000 msec
W_S	Weight for streaming packets	1.0
W_B	Weight for best effort packets	0.5
D_R	Delay caused by relaying (buffering and propagation)	20 msec
t_w	Tracking window for MS throughput	5000 msec
σ	BS transmission delay	1, 2, 4, 8 msec
τ	Transmission delay of relay	20 msec
P	BS transmitting power	2 W
SH	Shadowing attenuation Mean: Standard deviation:	 0 dB 8 dB
L	Available rate level: Level 1: Level 2: Level 3: Level 4:	Transmission rate: 0.9 Mbps 1.8 Mbps 3.6 Mbps 7.2 Mbps
TR_S	Arrival streaming traffic (constant)	12 kbps / User
TR_B	Arrival best effort traffic Mean (on time): Mean (off time):	16 kbps / User 3 sec 15 sec
B	Buffer size (BS)	100 kb / User
T_S	Simulation duration	3 hours
PL	Pathloss Attenuation (R = distance from BS)	(in dB) 98.6+38.0*log(R)
Sh	Shadowing Attenuation (Gaussian variable) Mean Standard deviation	(in dB) 0 8

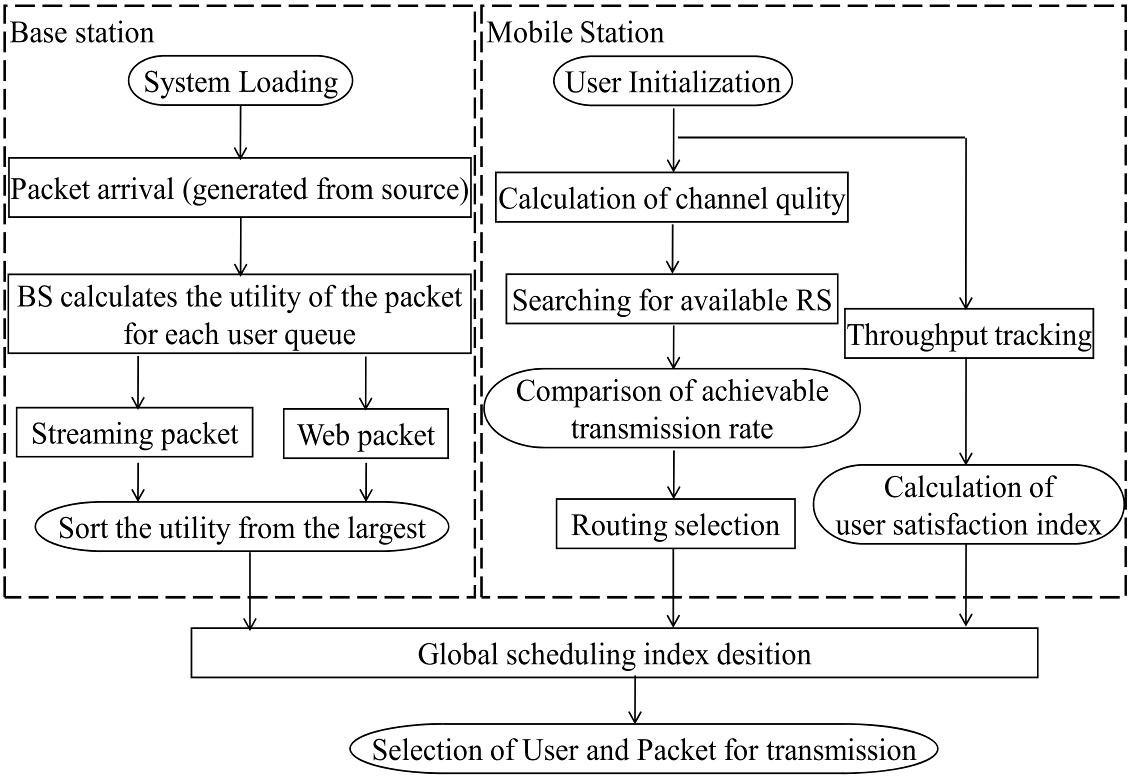


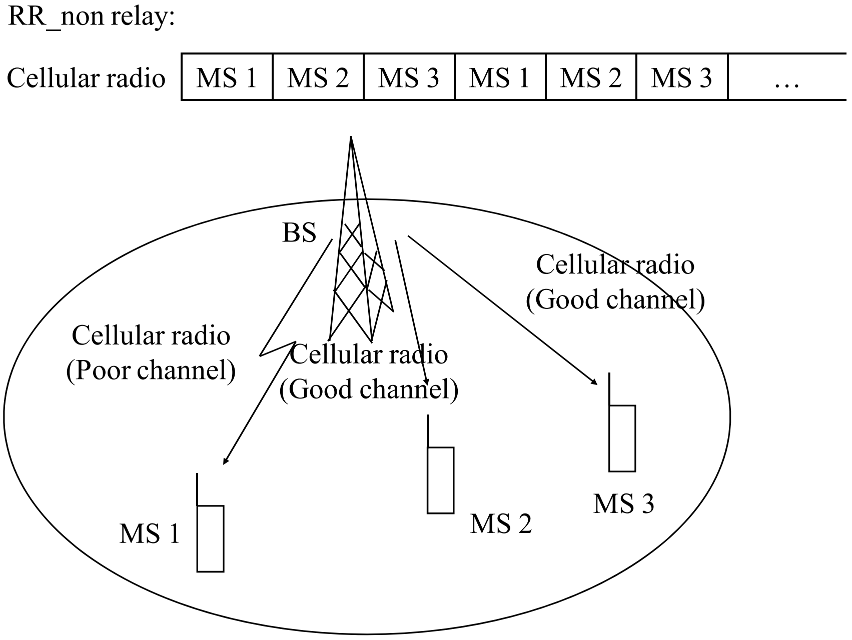
Figure 5.4 Simulation flow chat.

Since there is no communications between MSs to select a relay, the overhead would not be so much even the number of MSs is increasing. Here, the overhead of selecting the relay is only the report of the potential relays to BSs in the cellular channel. Each MS only reports not more than 3 potential relays, the overhead in selecting relay is acceptable. On the other hand, the overhead in the ad hoc channel is only the broadcast of beacon signals. Since we use a slow mobility model in the simulation, the MS would only broadcast the beacon signal periodically (e.g. once 10s). Thus, the overhead would not affect the network performance.

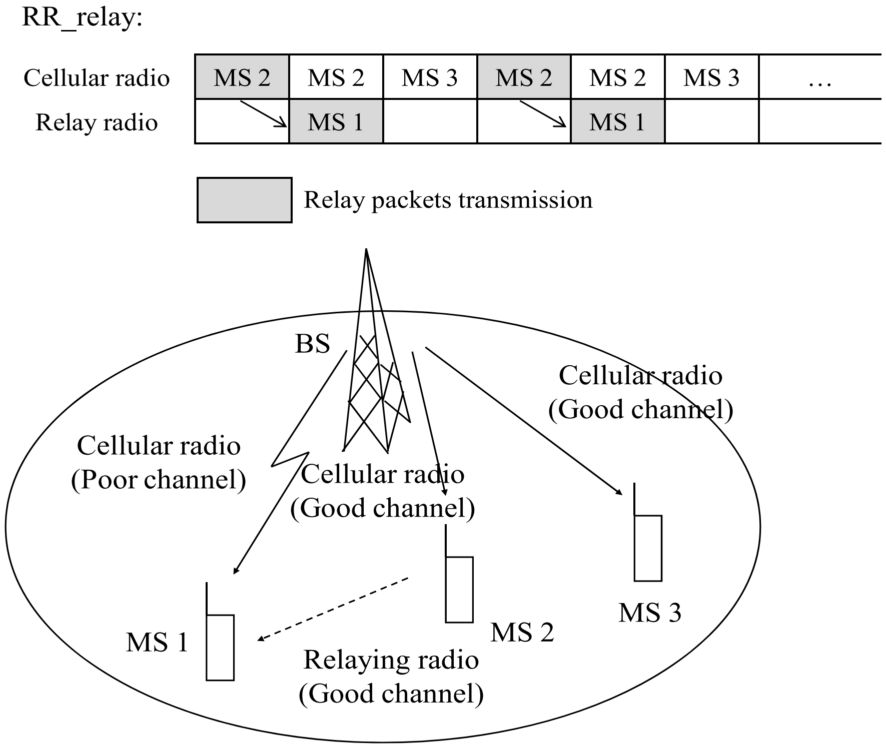
In our proposed algorithm, SS could connect to RSs who have better channel gain with relaying radio instead of direct connection with BS in a poor cellular channel as shown in Fig. 5.1. Each MS can feed back its received SNR and ID of received beacon signals to BS with the dedicated control channel. The simulation results are obtained considering received SNR levels and adaptive transmission rates shown in Table 1. We consider fixed numbers of MSs from 60 to 210 and compare our proposed algorithm with different scheduling algorithms: i) RR: Round Robin scheduling in a relay case, where BS schedules for each MS in a round robin fashion one after another. ii) MCIR: Maximum CIR scheduling with relaying, BS selects the MS with best transmission rate for every scheduling decision. iii) Proposal without realy: Proposed scheduling algorithm without relaying, where the available transmission rate of the MS depends only on received SNR. iv) Proposal with relay: Proposed scheduling algorithm with relaying. For comparison, RR and MCIR algorithms are performed in a relaying fashion by using the proposed relay selection scheme. That is the BS compares both direct path and relay path for each MS and chooses the path with higher transmission rate for scheduling. Table 5.2 compares the differences among these schemes, where Fig. 5.5 describes the detail of each scheduling scheme.

Table 5.2 Differences between the schemes in simulation

Schemes	Scheduling Index Used	Description
RR_non relay	Non	No relay is available BS serves the users one by one
RR_relay	Non	Relay is available (relay is selected if relay improves the throughput) BS serves the users one by one
MCIR_non relay	Opportunistic index: R	No relay is available BS serves the user with maximum R
MCIR_relay	Opportunistic index: R	Relay is available (relay is selected if relay improves the value of R) BS serves the user with maximum R
Proposal_non relay	Global index: I	No relay is available BS serves the user with maximum I
Proposal_relay	Global index: I	Relay is available (relay is selected if relay improves the value of I) BS serves the user with maximum I



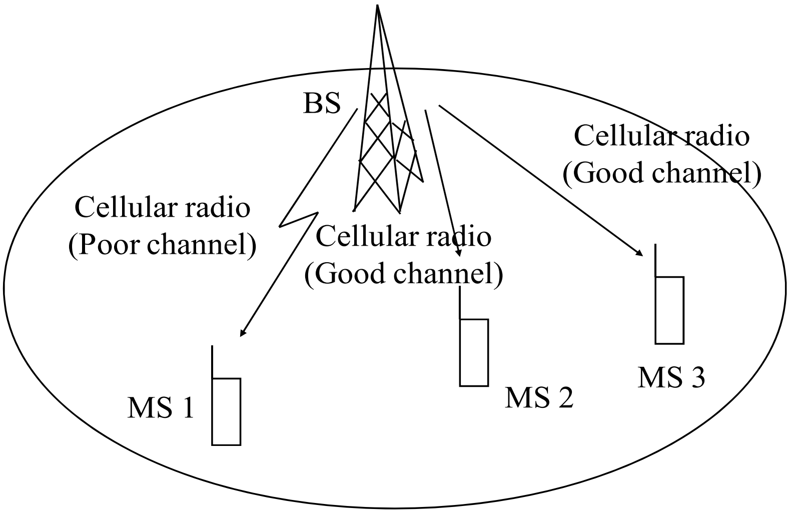
a) Round robin without relay.



b) Round robin with relay

MCIR_non relay:

Cellular radio	MS 2	MS 2	MS 3	MS 3	MS 1	MS 1	…

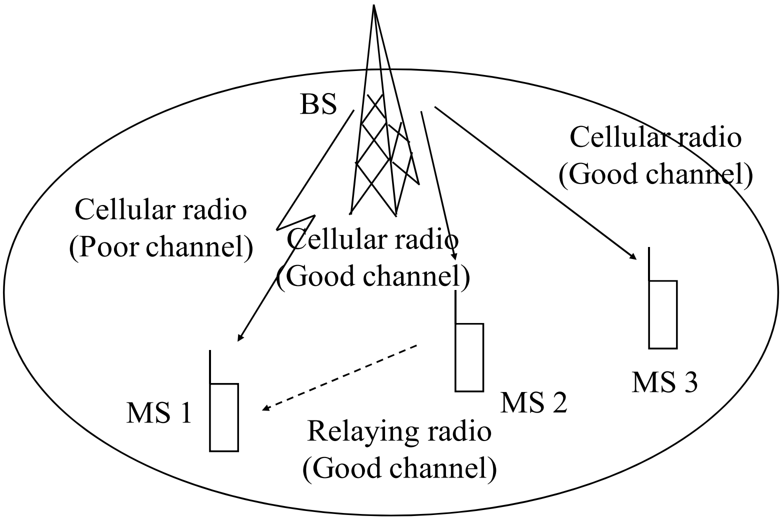


c) Maximum CIR without relay.

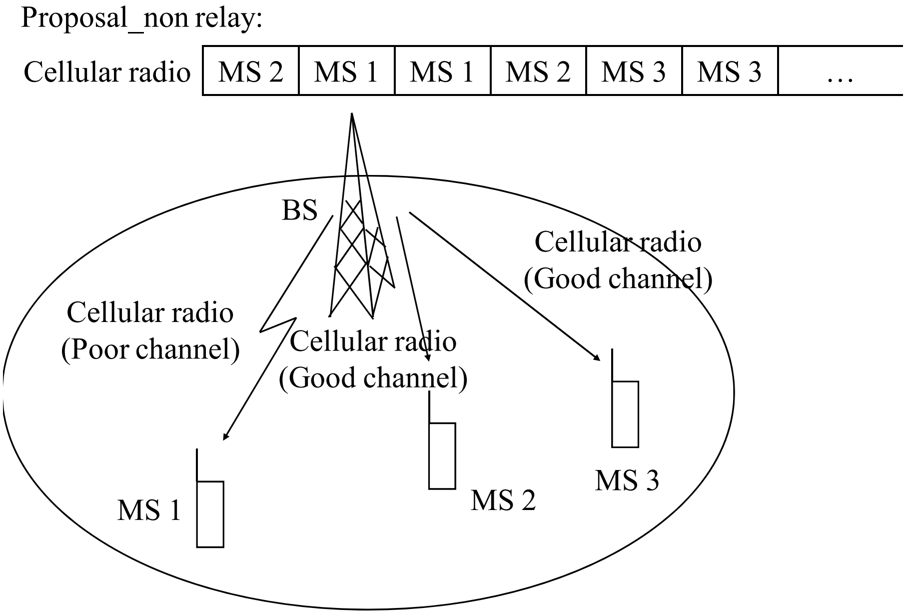
MCIR_relay:

Cellular radio	MS 2	MS 2	MS 2	MS 2	MS 3	MS 3	…
Relay radio				MS 1	MS 1		

▨ Relay packets transmission

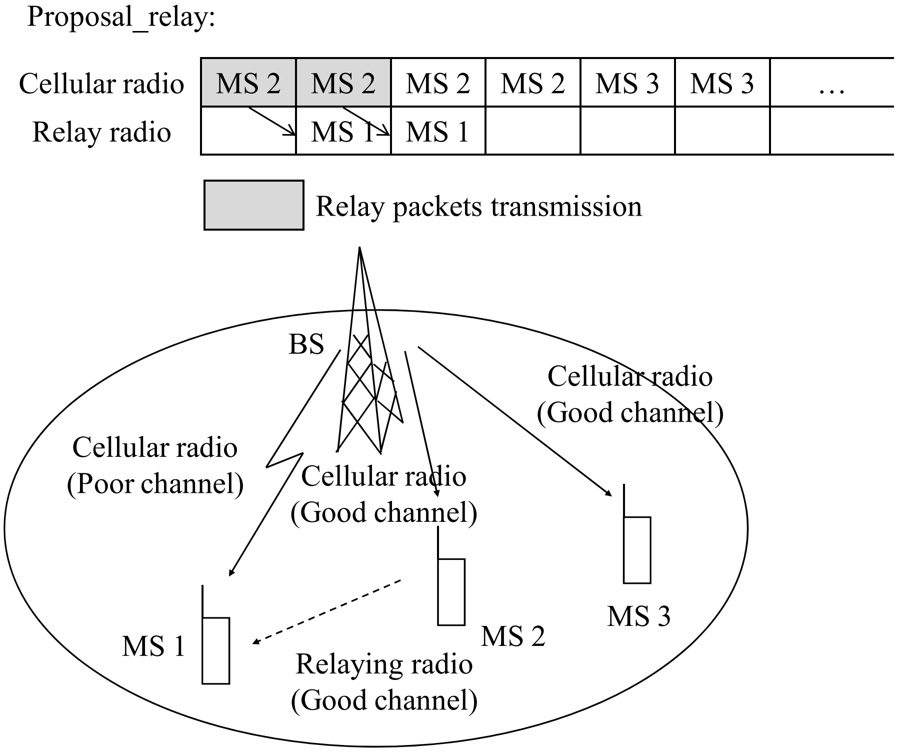


d) Maximum CIR with relay.


Proposal_non relay:

Cellular radio	MS 2	MS 1	MS 1	MS 2	MS 3	MS 3	…

e) Proposal without relay.


Proposal_relay:

Cellular radio	MS 2	MS 2	MS 2	MS 2	MS 3	MS 3	…
Relay radio		MS 1	MS 1				

▨ Relay packets transmission

f) Proposal with relay.

Figure 5.5 Details of different scheduling schemes.

5.4.2 Performance Results

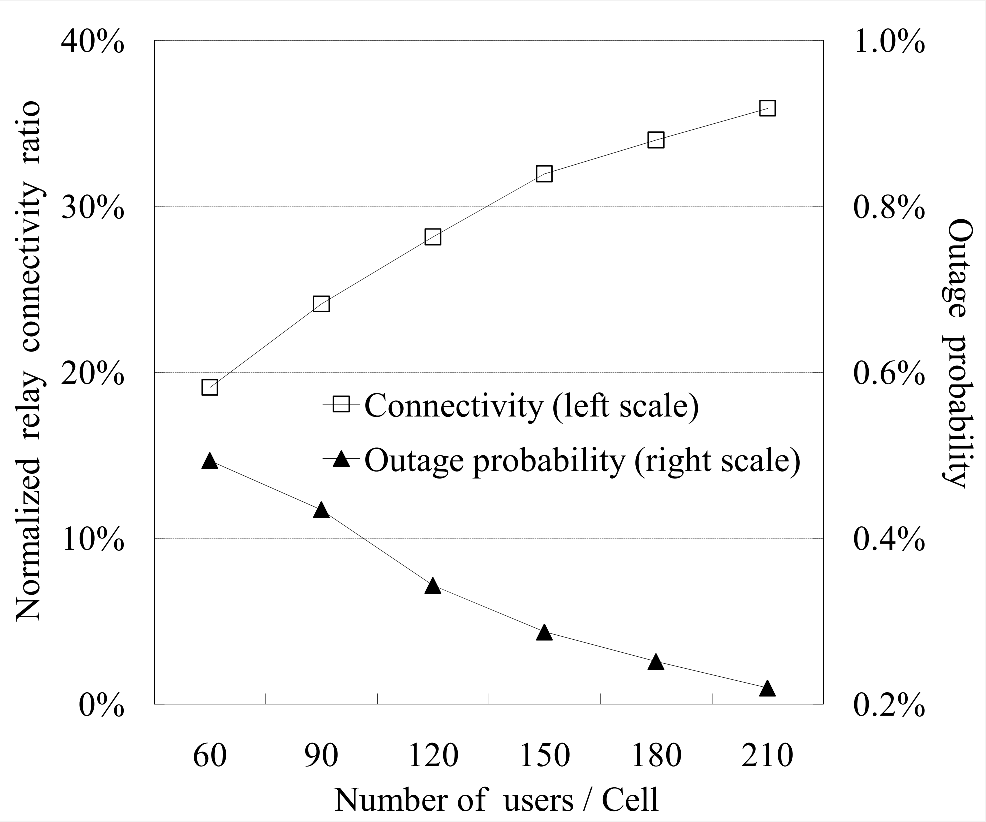


Figure 5.6 Performance of relay connectivity.

Fig. 5.6 shows the user relay connectivity ratio and outage probability. Since there are 4 levels of transmission modes in the simulation, while the SNR of the user could satisfy the lowest transmission level and the location of the user could not find another user as a relay in its relay range, the user is considered as an outage user. The relay connectivity refers to the normalized probability for MS to connect with a relay. As the user density increases, a SS has more chances to connect a RS whose channel is good. Higher user density can also reduce the user outage probability.

Fig. 5.7 shows the aggregated cell throughput of different scheduling algorithms. We assume that no error occurs in the transmission and the relay could send the relaying packet as soon as possible. Here, the relay will not cause any packet loss due to delay, since we already consider the delay in the packet utility index. Therefore, the throughput is calculated as the packets sent by BS successfully.

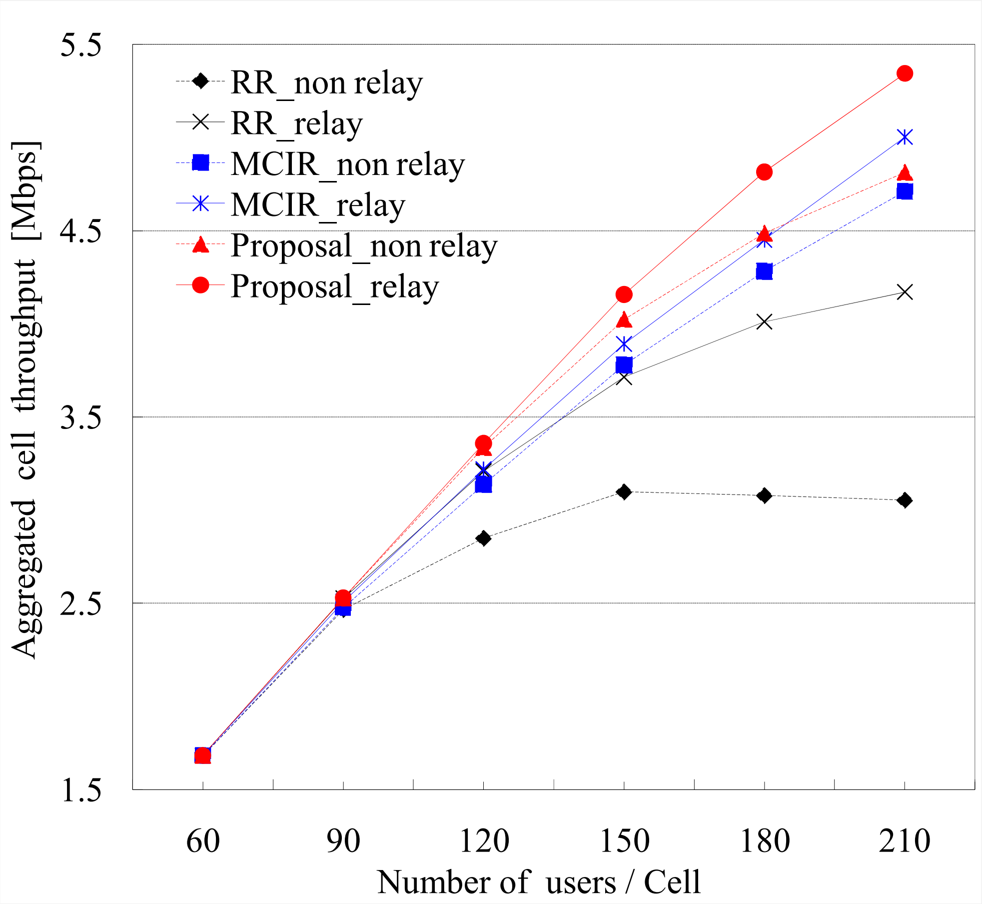


Figure 5.7 Performance of aggregated system throughput.

In order to show the relaying gain we also compare the RR and MCIR algorithms without relaying, which is clear that relaying systems could gain higher throughput when the number of users increases. Packets can be transmitted to MSs via the RSs with much higher transmission rates. The overhead in the cellular channel is only the reporting of potential relays. Here, we assume that these IDs are reporting in the signaling channel with the feedback of SNR, which would not make significant impact to the aggregated throughput. The total improvement of the proposed algorithm is gained from two components: best effort packets enhancement and streaming packets which could be sent before their delay bound. In contrast, RR with relaying still suffers low throughput because of the inefficient channel usage, where it serves user by user. On the other hand, MCIR with relaying could not have the best performance, since it only selects the MSs who have good channel quality or whose RSs have good channel quality, while streaming packets for other MSs are dropped.

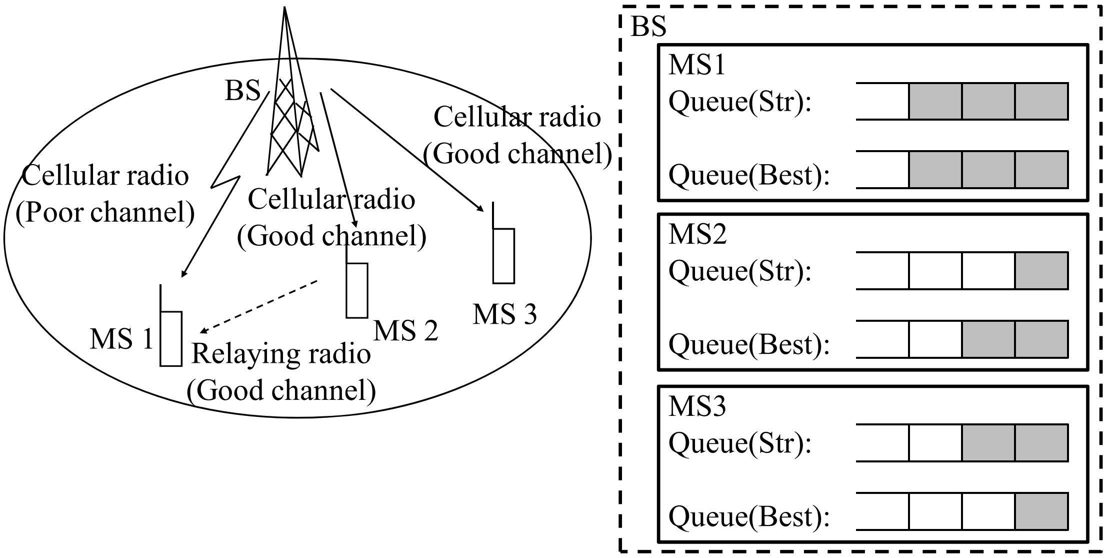
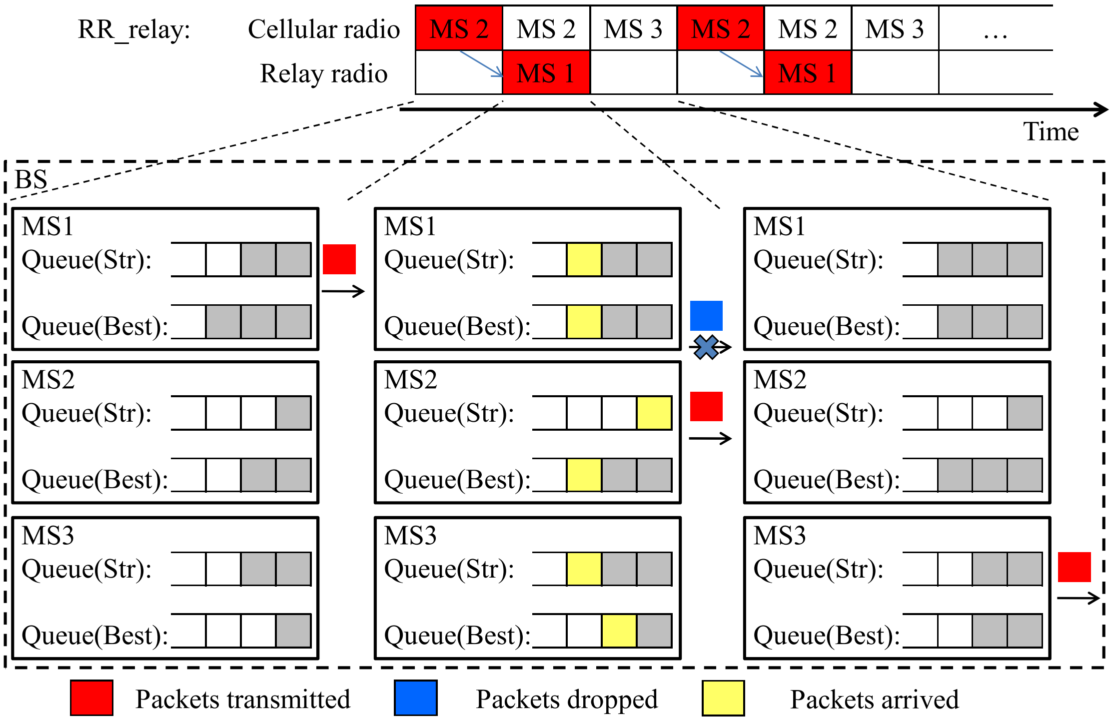
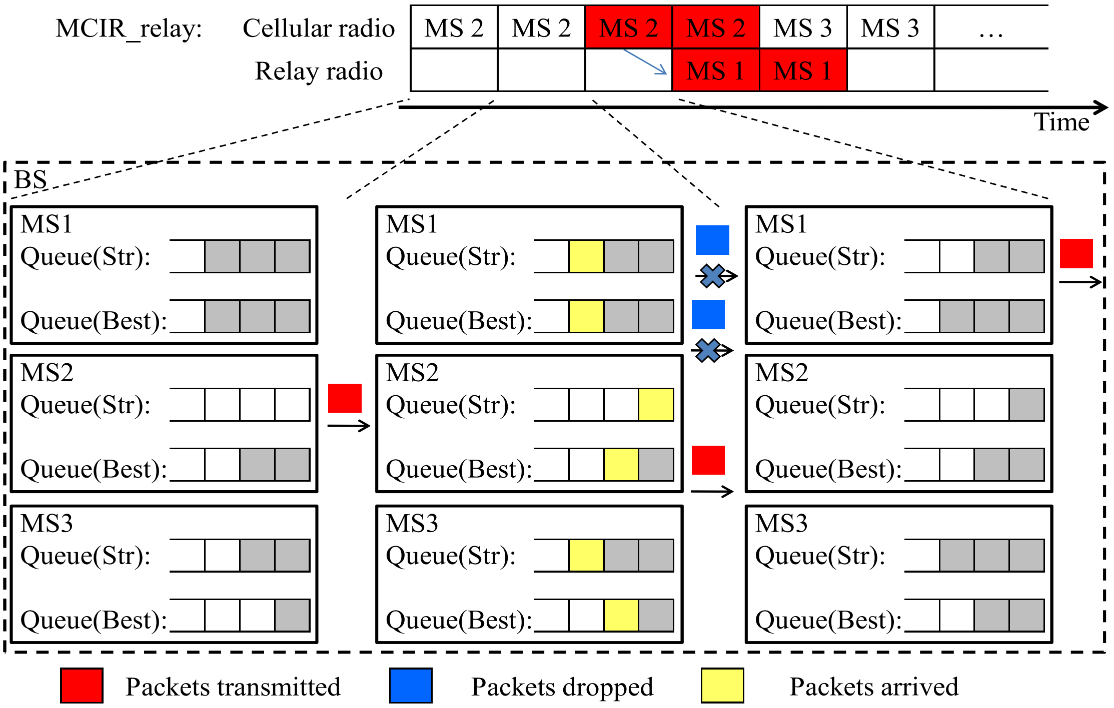


Figure 5.8 An example of user status.

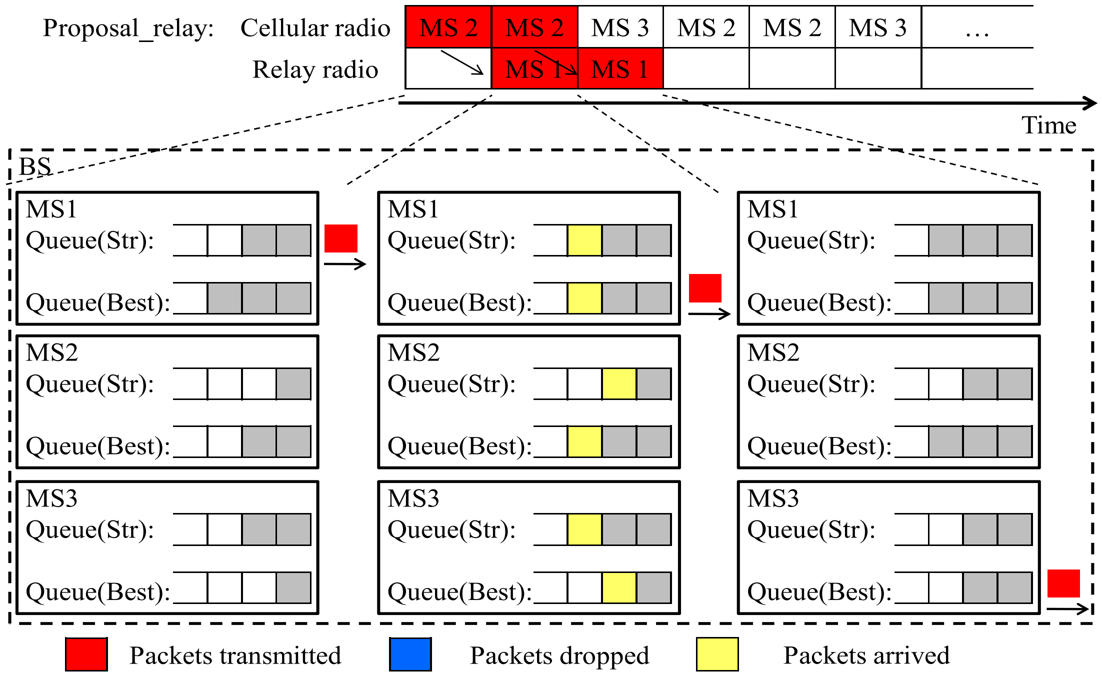
Fig. 5.8 gives an example to analyze the differences on throughput performance, where we assume 3 users and the initial data queue as in the figure. Fig. 5.9 shows the comparisons of packet transmission for each scheduling scheme with relay. Due to the streaming packet deadline and packet congestion the proposed scheduling scheme outperforms in the drop of packets.



a) Round robin with relay.



b) Maximum CIR with relay.



c) Proposal with relay.

Figure 5.9 Comparison of packet transmission.

We assume that BS would decide the user to serve in the next time slot between MS1 and MS3 and the opportunistic index *R* for MS3 is better than that for MS1. If we use the MCIR scheme, BS would prefer to serve MS3 all the time while there are packets in the queue. Thus, the loss of the streaming packets (due to the delay) and best effort packets (due to the size of the queue) would be increased for MS1. By using the proposed scheme, MS1 could achieve higher priority. Therefore, there would be less packet loss for MS1 according to the global index *I*.

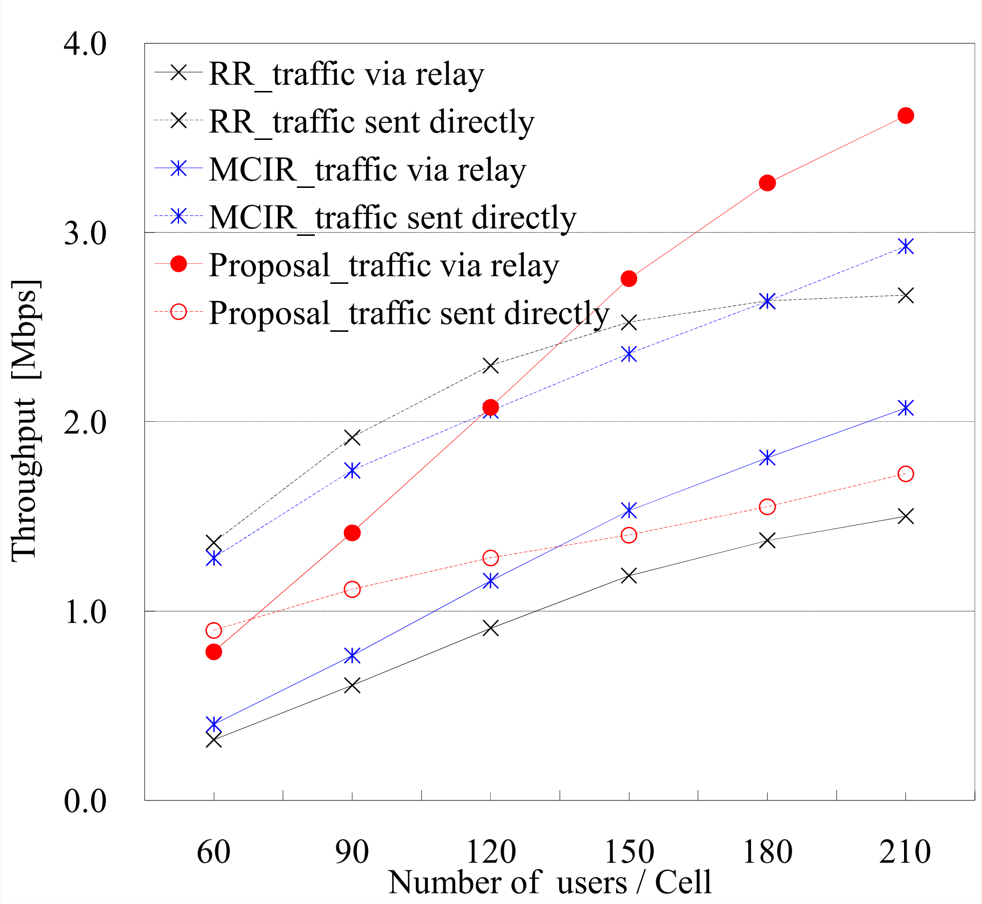


Figure 5.10 Performance of packet travel through relaying.

Fig.5.10 provides a detailed explanation for Fig.5.4, which shows the throughput comparison of scheduling algorithms with packets transmitted via relay and directly from BS. 'RR traffic sent directly' means the throughput directly sent by BS. The aggregate throughput is the summation of 'RR non relay traffic' and 'RR relay traffic', thus, in total the throughput provided by RR is less than the throughput provided by MCIR. In this figure we want to show the imbalance between the traffic sent directly and sent via relay. Only the traffic received via relay in the proposed algorithm increases significantly with the number of users, since the scheduling decision encourages the SS with poor channel quality to connect to a relay. In contrast, MCIR algorithm only selects a certain number of MSs to transmit, no matter the SS connects to a relay or has the good channel itself.

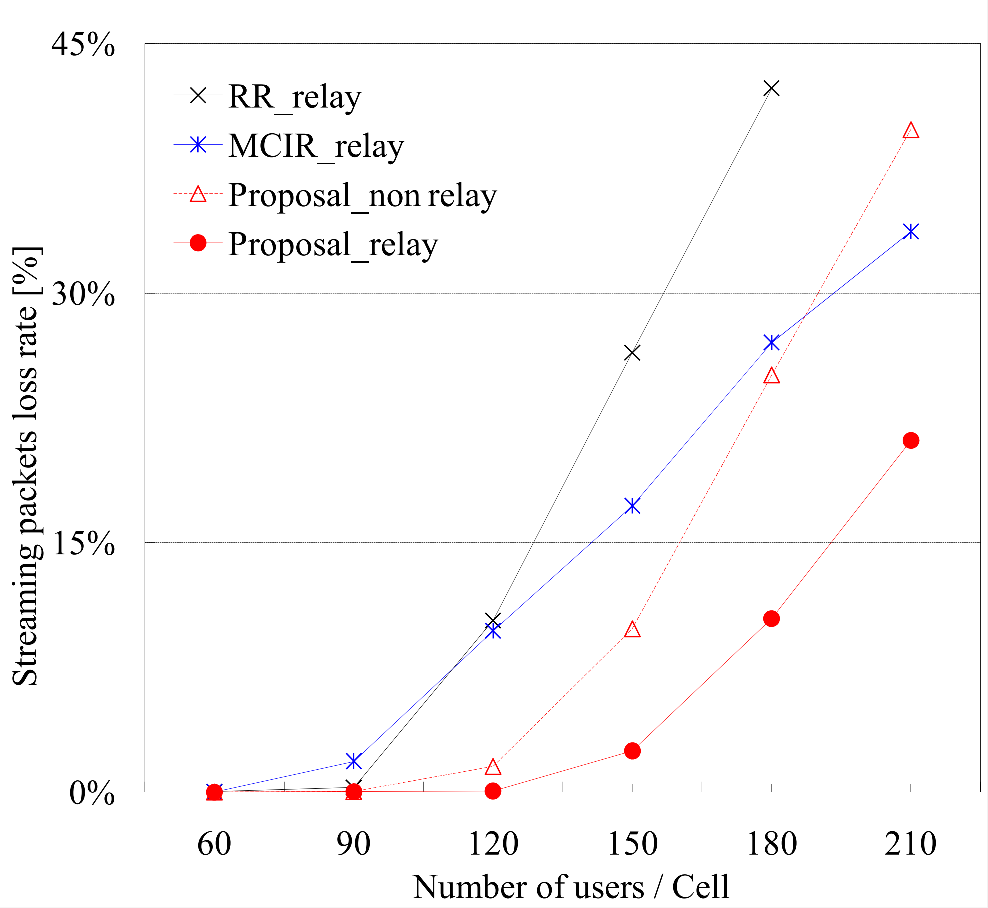


Figure 5.11 Performance of streaming packet loss.

Fig. 5.11 shows the packet loss rate of streaming packets. Packet loss is caused by streaming packets which could not be transmitted within the delay bound. Without relaying, BS should transmit all packets directly to MSs. Thus, data packet delays for streaming packets increase quickly. If best effort packets have higher scheduling rates and higher packet priority, more best effort packets would be transmitted rather than streaming packets. In contrast, the relaying algorithm shows advantages of separating the traffic to different RSs. Thus, streaming packets do not have to wait for the channel to be released. Relay can improve both the throughput and packet loss performance for the whole system. However, RR could not take the differences among users, where packet loss becomes seriously as the number of users increases.

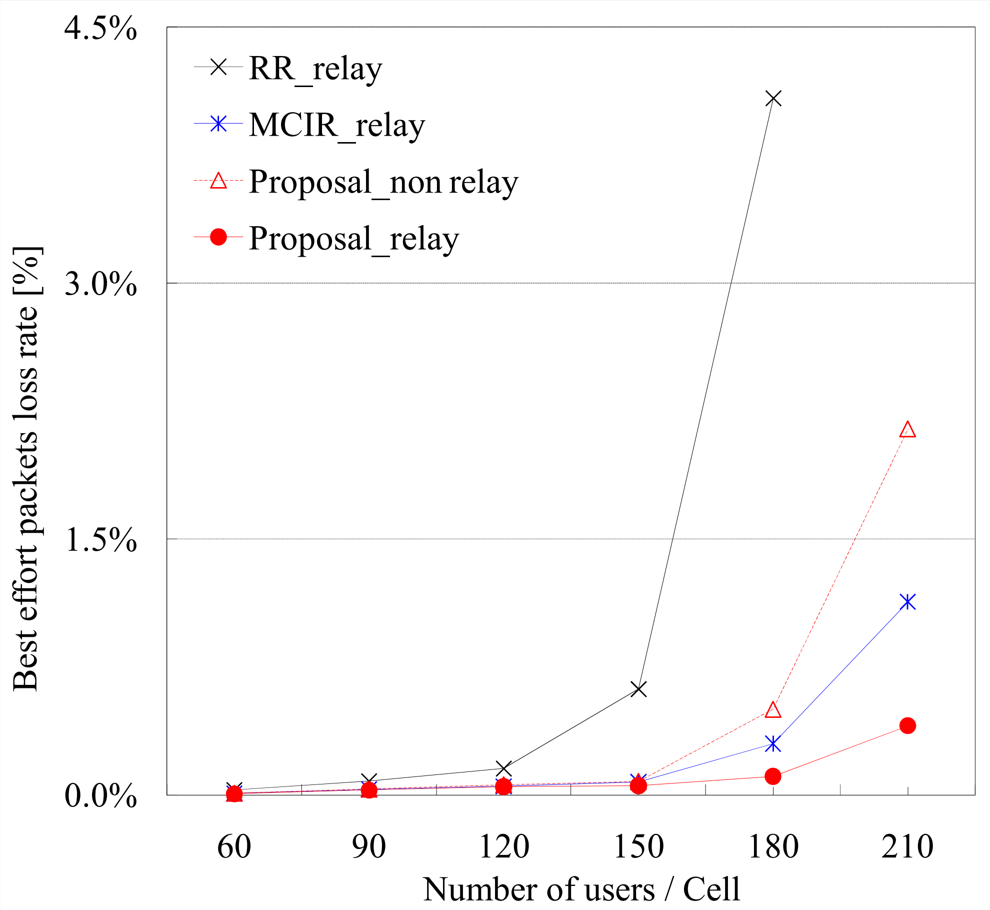


Figure 5.12 Performance of best effort packet loss.

Fig. 5.12 shows the packet loss of best effort traffic. In general, best effort packet loss is caused by overloaded data queue in BS. The proposed algorithm can achieve much less packet loss due to the consideration of both packet utility and user throughput. In contrast, MCIR serves only some MSs with good channel, thus, best effort packets would be dropped for the rest MSs. On the other hand, RR suffers the low capacity, which could not satisfy high rate data traffic. In this chapter, two types of the traffic are assumed which would be dropped due to their waiting time or queue status, shown in Fig. 5.10 and Fig. 5.11. For MCIR, both streaming traffic and web traffic get larger loss ratio than the proposed scheme due to the packets for the users suffering long waiting time or queue drop. Although BS can always selects the highest transmission rate users to transmit more packets for these users in MCIR scheme, the proposed scheme could also serve such users by delaying their transmission for other poor users.

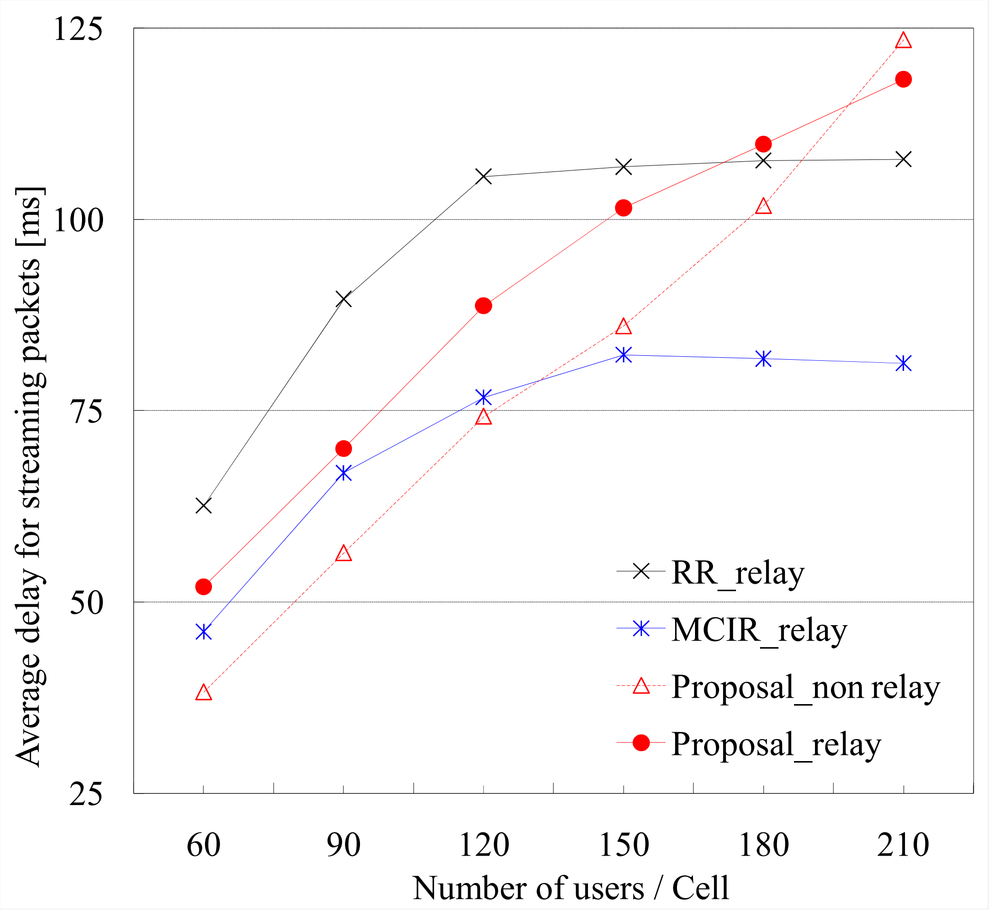


Figure 5.13 Performance of average delay for streaming packets.

Fig. 5.13 shows average streaming packet delay for different algorithms, while Fig. 5.14 compares that of best effort packets. Since streaming packets are dropped after their delay getting larger than their bound, the RR algorithm provides better delay performance for streaming traffic. However, best effort traffic suffers high delay. MCIR algorithm has good results for both traffic classes due to the reason that packets transmitted belong to MSs with good channel. Relaying algorithm can get better performance compared with no relaying case, although it does not perform short delay. However, most of streaming packets are transmitted within delay bound.

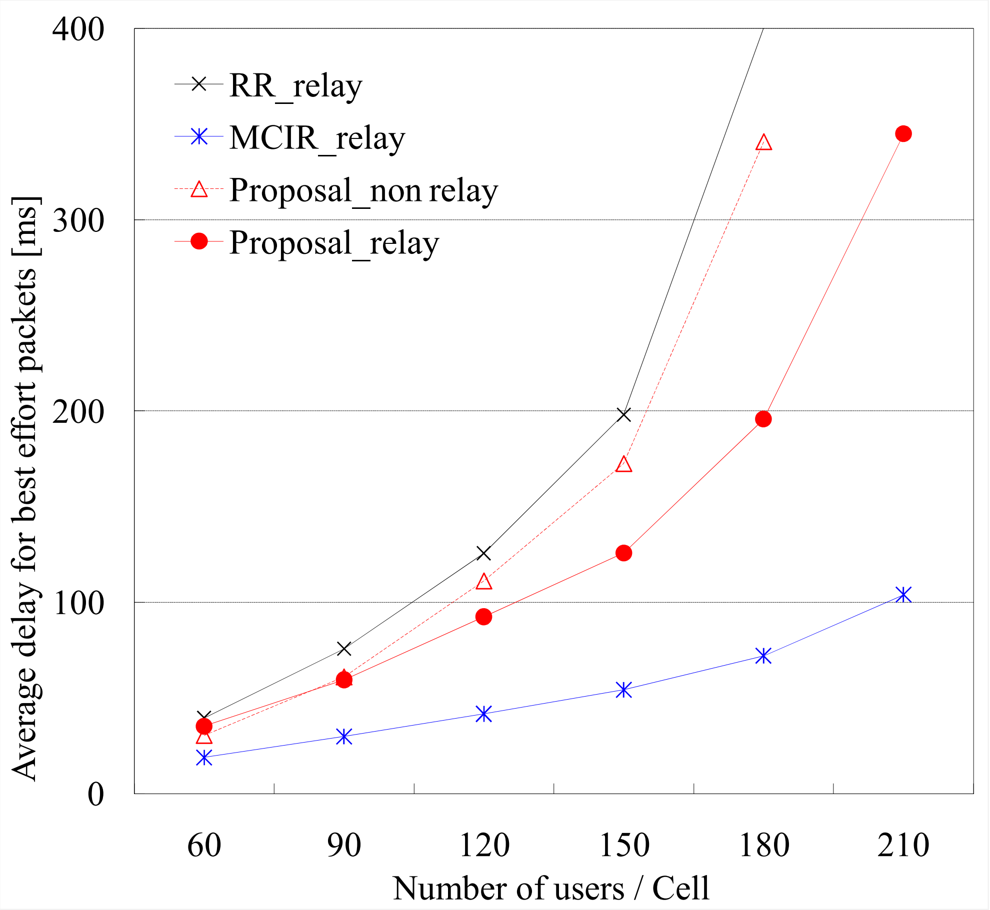


Figure 5.14　Performance of average delay for best effort packets.

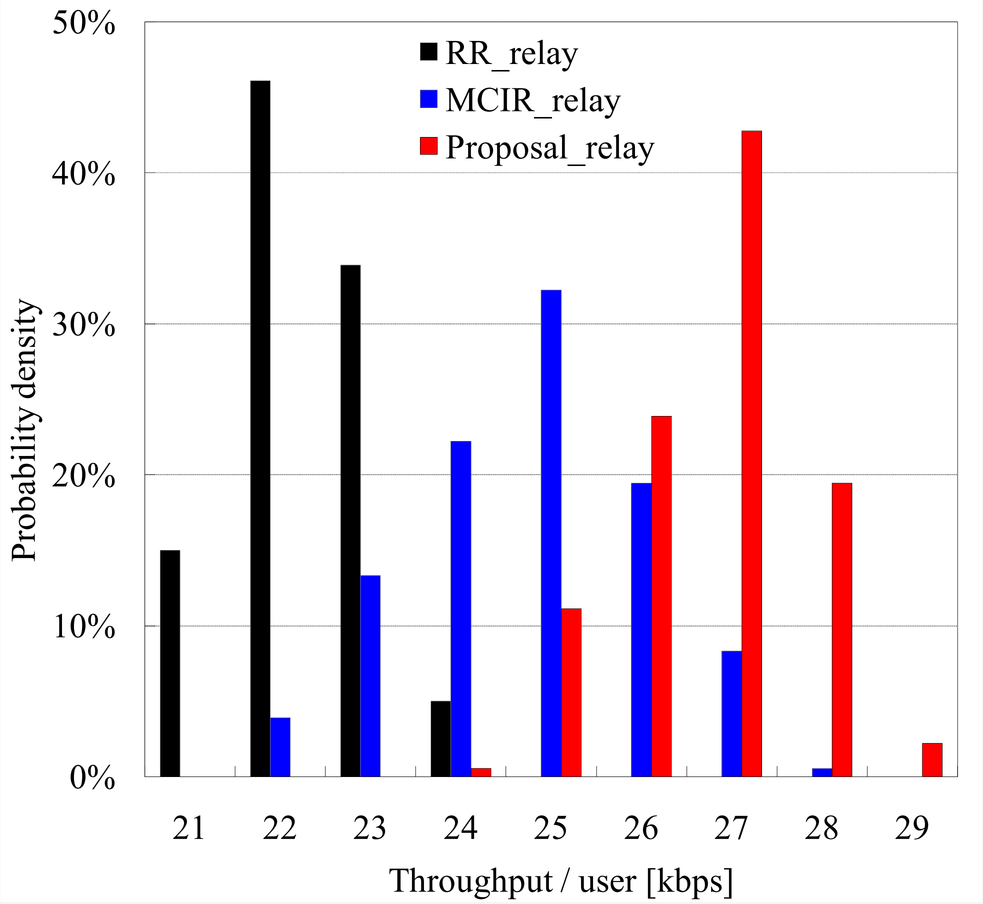


Figure 5.15 Comparison of user fairness.

Fig. 5.15 shows the comparison of fairness among three scheduling algorithms. RR algorithm has the best user throughput distribution which means good fairness performance by treating MSs one by one. In contrast, MCIR only takes care of MSs with good channel condition so that it has the worst throughput distribution due to bad fairness performance. Taking the trade-off between fairness and throughput performances, the proposal can get better fairness performance than MCIR while gaining the largest throughput. We address the fairness issue from a throughput point of view. In order to get a similar throughput among the users, RSs may spend more resources for MSs with poor cellular channel. However, in contrast to the resource utilization the aggregated throughput has been improved.

5.5 Conclusion

We have proposed a packet scheduling algorithm considering relay selection for relaying cellular networks which exploit adaptive channels as well as constraints of user transmission rate, user throughput, and packet QoS. We take into account both relay selection and adaptive high speed channel to improve the overall system performance, where BS could switch the destination MSs with poor cellular channel by connecting to other MSs with good cellular channel within their relay range. By selecting users who get high transmission rates as relays, the proposed scheduling algorithm can provide high throughput, users' fairness and guaranteed packet QoS. Simulation results show the improvement of the total system throughput performance, less packet loss and delay. In this chapter, we focus on the throughput enhancement and delay performance, thus, we assume the mobile nodes would have resource utilization for relaying. Further evaluation of the channel efficiency and improvement of the resource utilization would be considered as our future works.

Reference

[5.1] H. Fattah and C. Leung, “An Overview of Scheduling Algorithms in Wireless Multimedia Networks,” *IEEE Wireless Commun.*, pp. 76-83, Oct. 2002.

[5.2] Y. Ofuji, A. Morimoto, S. Abeta and M. Sawahashi, “Comparison of Packet Scheduling Algorithms Focusing on User Throughput in High Speed Downlink Packet Access,” *IEEE PIMRC*, Lisboa, Portugal, Sep. 2002.

[5.3] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R. Vijayakumar, “Providing Quality of Service over a Shared wireless Link,” *IEEE Commun. Magazine*, pp. 150-154, Feb. 2001.

[5.4] D. Zhao, X. Shen and J. W. Mark, “Radio Resource Management for Cellular CDMA Systems Supporting Heterogeneous Services,” *IEEE Trans. on Mobile Comp.*, Vol. 2, April-June 2003.

[5.5] M. Andrews and L. Zhang, “Scheduling over a Time-Varying User-Dependent Channel with Applications to High-Speed Wireless Data,” *J. of the ACM*, Vol.52, pp. 809-834, Sep. 2005.

[5.6] Q. Liu, S. Zhou and G. B. Giannakis, “Cross-Layer Scheduling with Prescribed QoS Guarantees in Adaptive Wireless Networks,” *IEEE J. on Selected Areas in Commun.*, Vol. 23, pp. 1056-1066, May 2005.

[5.7] H. Jiang, W. Zhuang, and X. Shen, “Cross-Layer Design for Resource Allocation in 3G Wireless Networks and Beyond,” *IEEE Commun. Mag.*, pp. 120-126, Dec. 2005.

[5.8] Flavio De Angelis, Ibrahim Habib, Giovanni Giambene and Samuele Giannetti, “Scheduling for Differentiated Traffic Types in HSDPA Cellular Systems,” *IEEE Globecomm*, Dec. 2005.

[5.9] H. Wu, C. Qiao, S. De and O. Tonguz, “Integrated Cellular and Ad Hoc Relaying Systems: iCAR,” *IEEE J. of Selected Areas in Commun.*, Vol. 19, pp. 1105-2115, Oct. 2001.

[5.10] L. Tassiulas and A. Ephremides, “Stability Properties of Constrained Queueing Systems and Scheduling Policies for Maximum Throughput in Multihop Radio Networks,” *IEEE Trans. on Automatic Control*, Vol. 37, pp. 1936-1948, Dec. 1992.

[5.11] M.J. Neely, E. Modiano and C.E. Rohrs, “Dynamic Power Allocation and Routing for Time Varying Wireless Networks,” *IEEE Infocom*, Vol. 1, pp. 745-755, San Francisco, USA, Mar. 2003.

[5.12] D. Cavalcanti, D. Agrawal, C. Cordeiro, B. Xie and A. Kumar, “Issues in Integrating Cellular Networks, WLANs, and MANETs: A Futuristic Heterogeneous Wireless Network,” *IEEE Wireless Commun.*, pp. 30-41, June 2005.

[5.13] D. Zhao and T. D. Todd, “Cellular CDMA Capacity with Out-of-Band Multihop Relaying”, *IEEE Trans. on Mobile Comp.*, Vol. 5, pp. 170-178, Feb. 2006.

[5.14] Haiyun Luo, et. al, “UCAN: A Unified Cellular and Ad-Hoc Network Architecture,” *ACM MobiCom*, San Diego, USA, pp. 353-367, Sep. 2003.

[5.15] J. Cho and Z. J. Haas, “On the Throughput Enhancement of the Down-Stream Channel in Cellular Radio Networks through Multihop Relaying,” *IEEE J. on Selected Areas in Commun.*, Vol.22, pp. 1206-1219, Sep. 2004.

[5.16] A. Jalali, R. Padovani and R. Pankaj, “Data Throughput of CDMA HDR: a High Efficiency High Data Rate Personal Communication Wireless System,” *IEEE VTC*, Tokyo, Japan, Vol. 3, pp. 1854-1858, May 2000.

[5.17] “The network simulator ns-2. http://www.isi.edu/nsnam/ns2,”

[5.18] 3GPP TS 25.306 V5.7.0 (2003-12): “UE Radio Access Capabilities.”

Chapter 6　Overall Conclusions

This dissertation proposes a number of resource allocation schemes and analyzes the performance enhancement for the cellular relay networks. Analysis and simulation results show the improvement of throughput, packet loss rate by using the scheduling schemes.

Chapter 1 gives an overview of the wireless networks and some main technologies for the next generation wireless communication systems.

Chapter 2 introduces key concepts of wireless architectures and resource allocation technologies as a liquid background for the research. In contrast to infrastructure base cellular networks, fixed relay network and ad hoc network are introduced due to their flexibility. However, the routing, scheduling problems limit their performance. Furthermore, we provide an overview of the resource allocation schemes.

Chapter 3 describes the previous works and problems of resource allocation in cellular relay networks. Since the time slot allocations and packet scheduling schemes have been studied in only a single hop fashion. In order to improve and evaluate the performance for cellular relay networks, we discuss the problem by exploiting time slot allocation and scheduling schemes into cellular relay networks.

Chapter 4 proposes a joint hopping station selection and time slot allocation scheme to improve downlink performance for TDD CDMA cellular relay networks. In the network, a number of fixed subscriber stations act as hopping stations between base stations and far-away subscriber stations, by combining of cellular and ad hoc mobile network architectures. The proposed system is able to provide lower outage probability (i.e. more users can connect to the networks with required SIR). The computer simulation results show that the proposed networks can provide better outage probability compared to the conventional single hop networks.

Chapter 5 proposes a packet scheduling algorithm for cellular relay networks by considering relay selection, variation of channel quality and packet delay. In the networks, mobile users are equipped with not only cellular but also user relaying radio interfaces, where base station exploits adaptive high speed downlink channel. Our proposed algorithm selects a user with good cellular channel condition as a relay station for other users with bad cellular channel condition but can get access to relay link with good quality. This can achieve flexible packet scheduling by adjusting transmission rates of cellular link. Packets are scheduled for transmission depending on scheduling indexes which are calculated based on user’s achieved transmission rate, packet utility and proportional fairness of their throughput. The performance results obtained by using computer simulation show that the proposed scheduling algorithm is able to achieve high network capacity, low packet loss and good fairness in terms of received throughput of mobile users.

Chapter 6 concludes the dissertation.

Acknowledgements

This thesis comes from several researches in Sasase Laboratory at Keio University, which has studied the resource management in the wireless multihop networks to improve the system performance and efficiency. I would like to thank many people who contributed to this thesis.

My sincere gratitude should be first given to my supervisor Prof. Dr. Iwao Sasase of Keio University, for his valuable advices. I would also like to thank Prof. Dr. Masao Nakagawa, Prof. Dr. Tomoaki Ohtsuki, Prof. Dr. Yukitoshi Sanada and Prof. Dr. Naoaki Yamanaka, all of whom are with Keio University, for their great comments improving this thesis. I also have to express my gratitude to Dr. Hoang Nam Nguyen and Dr. Riaz Esmailzadeh, since they give many valuable advices and help me to master the simulation program for my research.

Finally, and most importantly, I would like to express my sincere gratitude to my parents, Kongxiang Zhou and Zhenyu Zhang and my wife Dan Li, for their encouragement and all kinds of support to my education.

Rui Zhou

School of Open and Environmental System

Graduate School of Science and Technology

Keio University