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Performance Evaluation of a WiMAX System with Relay-assisted Scheduling

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Abstract

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Abstract:

An IEEE 802.16j based system with relay-assisted scheduling performance is evaluated in terms of the requirements set by the standard. We focus on the non-real-time (NRT) services in the downlink of a cellular network with two-hop relay transmission. Mobile stations (MSs) are grouped into the base station (BS) region and the relay station (RS) region according to their mean path losses. MSs in the BS region are connected directly to BS while MSs in the RS region receive packet from BS directly or indirectly via RS based on the CSI (Channel State Information). The RS operates in either the amplify-and-forward (AF) mode or decode-and-forward (DF) mode. We propose two relay-assisted scheduling schemes, in which the RS assists the BS in its scheduling decision and therefore we make it possible for the BS to exploit CSI on the access links without those of the relay links from all the users directly. A large amount of feedback overhead is avoided. Our objective is to explore the performance of DF and AF relays in these two different scheduling schemes. Moreover, we consider a friendly graphical user interface to realize user interaction and facilitate the investigation of the effect of different parameters to the system performance.

Keywords: WiMAX , Scheduling , Relay

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Työssä tutkitaan IEEE 802.16j standardin määrittelemän järjestelmän suorituskykyä ja keskitytään ei-raaliaikaisiin palveluihin ja verkkoon, jossa verkon topologiaan kuuluu tukiasemien lisäksi välittimiä. Päätelaitteet ryhmitellään kahteen luokkaan sen mukaan, ovatko ne suoraan yhteydessä tukiasemaan, vai onko yhteys muodostettu välittimen avulla. Tukiasemassa toimiva skedulointialgoritmi jakaa lähetysresursseja eri käyttäjien kesken hetkellisen kanavatiedon perusteella. Työssä on rakennettu simulaattori, jonka avulla voidaan tutkia erilaisten järjestelmäparametrien, skedulointialgoritmien ja välittimien vaikutusta järjestelmän suorituskykyyn.

Avainsanat:

WiMAX , Skedulointi, Välitin

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Gui Fang
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List of Abbreviations

AF	Amplify-and-Forward
ART	Above Roof Top
BRT	Below Roof Top
BS	Base Station
BS-RS	Base Station-Relay Station
BS-MS	Base Station-Mobile Station
BW	Bandwidth
BWS	Broadband Wireless Systems
CDF	Cumulative Distribution Function
CSI	Channel State Information
DF	Decode-and-Forward
DL	Downlink
DSL	Digital Subscriber Line
DS-TDMA	Direct Sequence-Time Division Multiple Access
FCFS	First-Come-First-Serve
GHz	Gigahertz
GPF	Generalized Proportional Fair
GPF+RR	Generalized Proportional Fair and Round Robin
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
LOS	Line-of-Sight
MAC	Medium Access Control
MAN	Metropolitan Area Network
MaxSNR	Maximum SNR
MaxSNR+RR	Maximal SNR and Round Robin

MMR	Mobile Multi-hop Relay
MS	Mobile Station
MR	Max Rate
NLOS	None- Line-of-Sight
NRT	Non Real Time
PAR	Project Authorization Request
PMP	Point-to-Multipoint
QoS	Quality of Service
RL	Relay Link
RS	Relay Station
RS-MS	Relay Station-Mobile Station
RR	Round Robin
RX	Receiver
SINR	Signal-to-Interference-and-Noise-Ratio
SNR	Signal-to-Noise-Ratio
SS	Subscriber Station
SUI	Stanford University Interim
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TX	Transmitter
UL	Uplink
WiMAX	Worldwide Interoperability for Microwave Access

Chapter 1

1. Introduction

1.1 Background

As one of the most important broadband wireless technologies, WiMAX (Worldwide Interoperability for Microwave Access) is anticipated to be a viable alternative to traditional wired broadband techniques due to its cost efficiency. Relaying technique allows multiple wireless hops for data to reach its destination in cellular networks. It has been conceived to improve data throughput and coverage area. Recently relay links are expected to play a critical role in the design of wireless networks. IEEE 802.16's Relay Task Group is developing a draft under the P802.16j PAR, which was approved by the IEEE-SA Standards Board on 2006-03-30. The PAR addresses "Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Multihop Relay Specification."[23]

Scheduling algorithms are playing a key role in overall system performance of broadband wireless systems (BWS). As relay station (RS) is introduced between base station (BS) and mobile station (MS), modifications in the specification are required to support scheduling service. The WiMAX standard provides signaling messages for both centralized and distributed scheduling, but leaves the scheduling algorithms open for the vendor’s implementation. We concern the centralized scheduling service and in our proposed scheduling schemes, BS neither makes all scheduling decisions nor manages all the resource over both relay links and access links. In our work, there is a proposed relay-assisted scheduling, in which the RS assists the BS in its scheduling decision, thereby making it possible for the BS to exploit channel state information(CSI) on the access links without having to obtain the information from all the MSs and hence avoiding the large feedback overhead. It is possible for the RS to estimate the CSI for each of the MS served by it and the feedback information from the RS to the BS contains only the CSI information of the selected MS.

We expand this proposed relay-assisted scheduling into two specific system scheduling schemes, MaxSNR+RR (BS applies Maximum SNR and RS applies Round Robin) and GPF+RR (BS applies Generalized Proportional Fair and RS applies Round Robin). The relay terminal operates in either the Amplify-and-Forward (AF) protocol or Decode-and-Forward (DF) protocol. Our objective is to explore the performance of the two relay-assisted scheduling schemes with the assistance of DF and AF relay.

1.2 Structure of the thesis

This thesis is organized as follows:

Chapter 2 gives some background information about WiMAX. We first provide a brief review of WiMAX and IEEE 802.16 standards and amendments and compare the network architecture for IEEE 802.16j MMR and Conventional WiMAX. This is then followed by a presentation of usage model and channel model in IEEE802.16j MMR.

Chapter 3 describes three widely adopted scheduling techniques, Round Robin (RR), Maximum SNR (MaxSNR) and Generalized Proportional Fair (GPF) in wireless networks, respectively. Based on the above three scheduling algorithms, we propose two centralized scheduling schemes.

Chapter 4 explains our simulation system. The first three sections outline the system model, channel model and Media Access Control (MAC) Layer Model. The following section then discusses different SNR and data-rate performances in three relay modes. At the end of this chapter, the focus then shifts to the implementation issues of scheduling and measurement model.

Chapter 5 illustrates the effects of different parameters on system packet delay, fairness and throughput of cellular networks with different relay protocols (AF/DF), different BS/RS schedulers through the simulation results.

The conclusions reached in this thesis and the possible directions for further investigation are discussed in Chapter 6.

Chapter 2

2. Overview of WiMAX

2.1 Introduction of WiMAX

WiMAX is a standard-based technology, interoperability of the IEEE 802.16 standard, officially known as WirelessMAN (Metropolitan Area Network). WiMAX enables the delivery of last mile wireless broadband access as an alternative to wired broadband like cable and DSL (Digital Subscriber Line). WiMAX provides fixed, nomadic, portable and, soon, mobile wireless broadband connectivity. The two driving forces of modern Internet are broadband, and wireless. The WiMAX standard combines the two, delivering high-speed broadband Internet access over a wireless connection.

2.2 IEEE 802.16 standards and Amendments

The IEEE 802.16 working group was set up by the IEEE in 1999 under IEEE 802 LAN/MAN (local Area Network / Metropolitan Area Network) Standards Committee. The first 802.16 standard was approved in December 2001. [1-3]

- IEEE 802.16: This is the basic 802.16 standard that was released in 2001. It provided for basic high data links at frequencies between 11 and 60 GHz.
- IEEE 802.16a: The standard specifies the operation from 2GHz to 11GHz, both licensed and license exempts. Because the signals at lower frequency can penetrate barriers and thus a line-of-sight connection between the transceiver and receiver is not required, most commercial interests have focused mainly on the lower frequency ranges. Under this premise, IEEE 802.16a standard was thus completed in January 2001. It enables the WiMAX implementations with better flexibility while maintaining the data rate and transmission range. IEEE 802.16a also supports mesh deployment, which can extend the network coverage and increase the overall throughput.
- IEEE 802.16b: This extension increases the spectrum to the 5 and a 6 GHz frequency band, which provides QoS (Quality of Service) guarantee to ensure

priority transmission for real-time applications and to differentiate service classes for different traffic types.

- IEEE 802.16c: As the Work Group's initial interest, IEEE 802.16c defines a 10 to 66 GHz system profile that standardizes more details of the technology. These high frequency bands have more available bandwidth, but the signals cannot diffract the obstacles and require line of sight deployment.
- IEEE 802.16d: Approved in June 2004, IEEE 802.16d upgrades the 802.16a standard. This extension aims to improve performance for 802.16 especially in the uplink traffic.
- IEEE 802.16e: This technology standardizes networking between fixed base stations and mobile stations, rather than just between base stations and fixed recipients. IEEE 802.16e enables the high-speed signal handoffs necessary for communications with users moving in vehicles. It promises to support mobility up to speeds of 70-80mi/h. The subscriber stations (SSs) could be personal communication devices such as mobile phones and laptops.
- IEEE 802.16f: Management Information Base.
- IEEE 802.16g - Management Plane Procedures and Services.
- IEEE 802.16h - Improved Coexistence Mechanisms for License-Exempt.
- IEEE 802.16i - Mobile Management Information Base.
- IEEE 802.16j - Multihop Relay Specification.
- IEEE 802.16k - Bridging of 802.16.
- IEEE 802.16m - Advanced Air Interface. Data rates of 100 Mbit/s for mobile applications and 1 Gbit/s for fixed applications, cellular, macro and micro cell coverage, with currently no restrictions on the RF bandwidth (which is expected to be 20 MHz or higher).

Among above IEEE802.16 standards, we only concentrate on IEEE802.16j.

2.3 802.16j Mobile Multi Hop

2.3.1 The Main Propose

This amendment provides specifications by a relay station for mobile multi hop relay features, functions and interoperable relay stations to enhance coverage, throughput and system capacity of 802.16 networks.

2.3.2 Network Architecture in 802.16j

Figure 2.1 compares the network architecture between MMR and conventional WiMAX. It is easy to find out that the biggest difference between them is that in MMR network, the system enables mobile stations to communicate with a base station through intermediate relay stations. In conventional WiMAX network architecture, signals are transferred between base station and mobile terminals. In MMR network architecture, the whole cell is divided into two regions: BS region and RS region. The users near the base station who belong to BS region are connected directly to BS while users in the relay region, out of BS region are connected to RS. Here, RS pretends to be a MS for BS and to be a BS for MS.

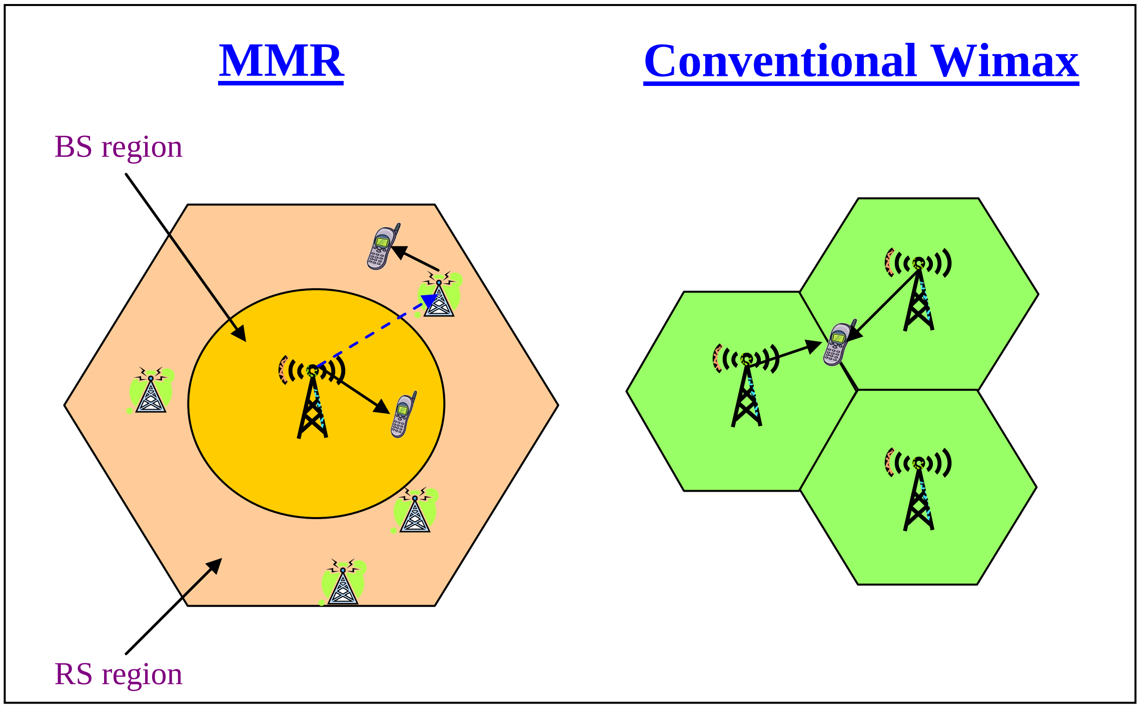


Figure 2.1: Network Architecture for MMR and Conventional WiMAX

In both network architectures of MMR and Conventional WiMAX, the role of users is the same, receiving or transmitting data from/to nearest BS or RS. The BS and RS have some new functions in MMR.

- Base Station

1. Add support for MMR links
2. Add support for aggregation of traffic from multiple RSs
3. MAC protocol to support multi-hop communication between BS and RS

- Relay Station
  1. Supports Point-to-Multipoint (PMP) & MMR links
  2. Supports aggregation of traffic from multiple RSs
  3. MAC protocol to support multi-hop communication between RSs

2.3.3 Usage Models in 802.16j

According to the different ways in which RSs are deployed and the diverse types of services and performance goals to be achieved, four major usage models are envisaged for 802.16j systems.

2.3.3.1 Fixed Infrastructure Usage Model

In this usage model, relay stations are fixed and owned by the infrastructure provider. RSs can range from simple to complex. In Figure 2.2, RSs are utilized to extend coverage at the edge of the cell, to provide coverage for indoor location, to provide coverage for users in coverage holes that exist due to shadowing and in valleys between buildings, and to provide access for clusters of users outside the coverage area of the BS. [5]

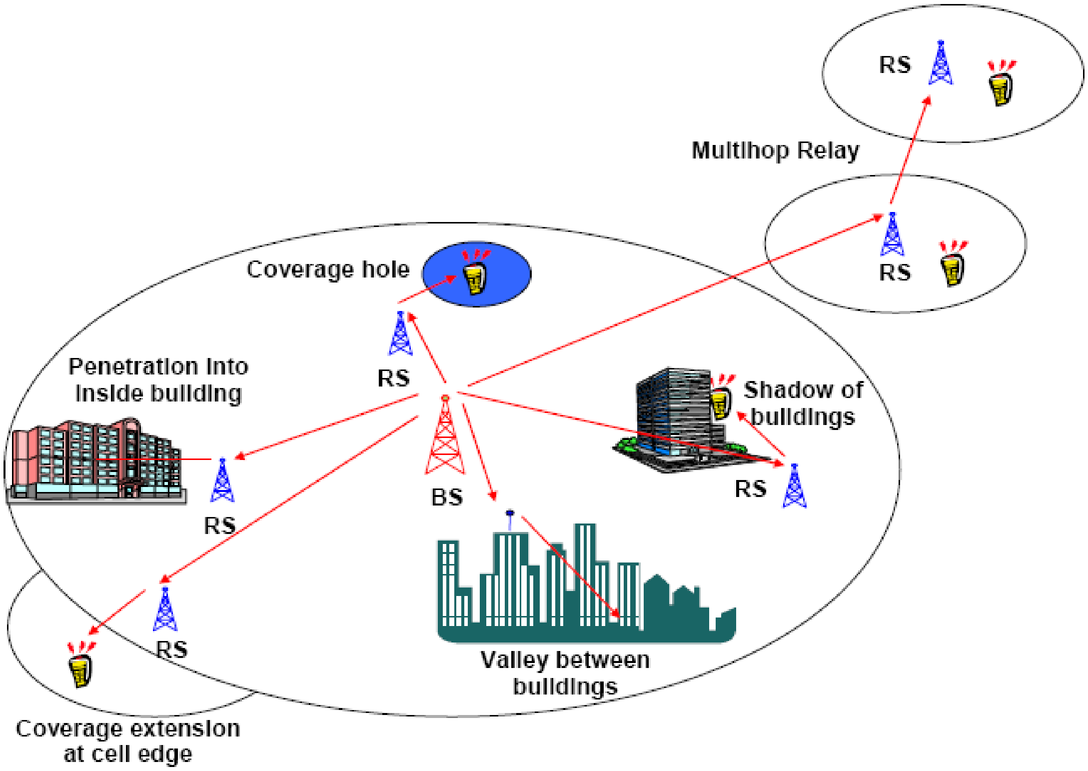


Figure 2.2: Example Use Cases from the Fixed Infrastructure Usage Model [5]

2.3.3.2 In-Building Coverage Usage Model

This usage faces to situation in a building, tunnel or underground such as on a subway platform. The RSs can be owned by the infrastructure provider or by the customer and will generally need to be simple and cheap [5]. In this usage model, relay stations can be fixed or portable. They can be moved to a location, positioned for operation and turned on. One example in in-building coverage usage model is that a nomadic RS placed indoor receives a single from BS and then sends it to subscribers within the room of building or data is relayed among several RSs in one big building such as a multi-tenant dwelling or office building.

2.3.3.3 Temporary Coverage Usage Model

In this usage model RSs are not fixed and are just deployed for temporary situation. For example, when a big sporting event or fair is held, sometimes we need other RSs to help

BS or fixed relays to provide sufficient coverage or capacity. Besides, temporary RSs can take place of the destroyed fixed relay in one area in emergency/disaster recovery.

2.3.3.4 Coverage on Mobile Vehicle Usage Model

In this usage model RSs are placed in a mobile vehicle, such as a bus or a train and it connects to an BS or RS via a mobile link. The RS provides a fixed access link to MS/SS devices riding on the platform. The RSs is mobile. The RSs can move in a predetermined trajectory or an arbitrary trajectory. RSs are also used when the train is traveling through a tunnel where coverage is provided by a series of RSs.

In this thesis work, we only concentrate on the first usage model- Fixed Infrastructure Usage Model, we utilize relay to improve the cell channel quality.

2.4 Channel Models in 802.16j

2.4.1 Path-Loss Model

2.4.1.1 Path-loss Types

The path loss for the IEEE802.16j system contains the basic models for the IEEE802.16-2004 and additional path-loss associated with RS nodes. The path-loss types are listed in Table 2.1.

Table 2.1: Summary Table of Path-loss Types for IEEE802.16j Relay System [6]

Category	Description	Reference
Type A	Hilly terrain with moderate-to-heavy tree densities (macro-cell suburban)	Section 2.1.2.1
Type B	Intermediate path-loss condition (macro-cell suburban)	
Type C	Flat terrain with light tree densities (macro-cell suburban)	

Type D	Both node-antennas are ART	LOS	Section 2.1.2.2
Type E	Only one node-antenna is ART	NLOS	Section 2.1.2.3
Type F	Both node-antennas are BRT	LOS/NLOS	Section 2.1.2.4
Type G	Indoor Office	LOS/NLOS	Section 2.1.2.5

Note: LOS (Line Of Sight), NLOS (Non Line Of Sight), ART (Above Roof Top), BRT (Below Roof Top)

2.4.1.2 The relationship path-loss models with the relay system usage models

Table 2.2: Relationship between path-loss and usage models [6]

Links	Path-loss Type	Applicable Usage Model	Note
BS-RS	Type A/B/C	Ⅰ, Ⅲ, Ⅳ	Suburban, RS antenna is BRT
	Type D	Ⅰ, Ⅲ	BS antenna is ART and RS antenna is ART
	Type E	Ⅰ, Ⅲ, Ⅳ	Urban, BS antenna is ART and RS antenna is BRT
BS-MS	Type A/B/C	Ⅰ, Ⅲ, Ⅳ	Suburban, BS antenna is ART
	Type E	Ⅰ, Ⅲ, Ⅳ	BS antenna is ART
RS-RS	Type A/B/C	Ⅰ, Ⅲ, Ⅳ	Suburban, one RS antenna is ART
	Type D	Ⅰ, Ⅲ	Both RS antennas are BRT
	Type E	Ⅰ, Ⅲ, Ⅳ	Urban, One RS antenna is ART and another one is BRT
	Type F	Ⅰ, Ⅲ, Ⅳ	Both RS antennas are BRT
	Type G	Ⅱ	Both RS antennas are inside building
RS-MS	Type A/B/C	Ⅰ, Ⅲ	Suburban, RS antenna is ART
	Type E	Ⅰ, Ⅲ	RS antenna is ART
	Type F	Ⅰ, Ⅲ, Ⅳ	RS antenna is BRT
	Type G	Ⅱ	Both RS and MS antennas are inside building

The usage models referenced from IEEE 802.16j-06/015 are:

Ⅰ. Fixed Infrastructure Usage Model
Ⅱ. In-Building Coverage Usage Model
Ⅲ. Temporary Coverage Usage Model
Ⅳ. Coverage on Mobile Vehicle Usage Model

2.4.1.3 Detailed Path-loss Models

Type-A/B/C (Suburban, ART-to-BRT)

The modified IEEE 802.16 path-loss model is recommended for these links where it is given in [7]

$$PL = A + 10 \cdot \gamma \cdot \log_{10}(d/d_0) + \Delta PL_f + \Delta PL_h \text{ dB} \tag{2.1}$$

where d0=100m and d>d0.

$$A = 20 \cdot \log_{10}(4\pi d_0/\lambda) \tag{2.2}$$

$$\lambda = (a - b \cdot h_b + c/h_b) \tag{2.3}$$

λ is the wavelength in meters and h_b is the BS antenna height, which is between 10m and 80m. Three propagation scenarios are categorized as

Terrain Type A: Hilly terrain with moderate-to-heavy tree densities
Terrain Type B: Intermediate path-loss condition
Terrain Type C: Flat terrain with light tree densities

The corresponding parameters for each propagation scenario are listed in the Table 2.3.

Table 2.3: Parameters for the Type A/B/C [7]

Model Parameter	Terrain Type A	Terrain Type B	Terrain Type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

Moreover, the correction factors for carrier frequency ΔPL_f and receive antenna height ΔPL_h are:

$$\Delta PL_f = 6 \cdot \log 10\ (f / 2000)\ \text{dB} \qquad (2.4)$$

where *f* is the carrier frequency in MHz

$$\Delta PL_h = -\ 10.8 \cdot \log 10\ (h / 2)\ \text{dB; for Terrain Type A and B} \qquad (2.5)$$

$$\Delta PL_h = -\ 20 \cdot \log 10\ (h / 2)\ \text{dB; for Terrain Type C} \qquad (2.6)$$

where *h* is the MS/RS receive antenna height between 2m and 10m.

Extended IEEE802.16 model [9]

$$PL(dB) = \begin{cases} 20\log\left(\dfrac{4\pi d}{\lambda}\right) & \text{for } \ d \le d_0^{'} \\ A + 10\lambda\log\left(\dfrac{d}{d_0}\right) + \Delta PL_f + \Delta PL_{ht} & \text{for } \ d > d_0^{'} \end{cases} \qquad (2.7)$$

where,

$$A = 20\log\left(\frac{4\pi d_0^{'}}{\lambda}\right)$$

$$d_0 = 100m$$

$$d_0^{'} = d_0 10^{-\left(\frac{\Delta PL_f + \Delta PL_{ht}}{10\gamma}\right)}$$

$$\gamma = a - bh_b + \frac{c}{h_b}$$

$$\Delta PL_f = 6\log\left(\frac{f(MHz)}{2000}\right)$$

$$\Delta PL_{ht} = \begin{cases} -10\log\left(\dfrac{h_t}{3}\right) & \text{for } \ h_t \le 3m \\ -20\log\left(\dfrac{h_t}{3}\right) & \text{for } \ h_t > 3m \end{cases}$$

$d =$ distance between BS and RS
$h_b =$ height of BS
$ht =$ height of RS

The model parameters for Type A, B and C are the same as those specified for the basic model, as provided in Table 2.3. We choose Type A as our main object.

2.4.2 Small Scale Fading Channel Model

Small scale fading is caused by interference between two or more versions of transmitted signal which arrive the receiver at slightly different times. Small scale fading has two types:

Type 1: Doppler spread —Frequency dispersion and time selective fading:

- Fast fading:
  - High Doppler spread, coherence time<<signal duration
  - Channel variations faster than baseband signal variations
- Slow fading:
  - Low Doppler spread, coherence time>>signal duration
  - Channel variations slower than baseband signal variations

Type 2: Delay spread —Time dispersion and frequency selective fading:

- Frequency non-selective fading(Flat fading):
  - BW of signal < BW of channel
  - Symbol period > Delay spread
- Frequency selective fading:
  - BW of signal > BW of channel
  - Symbol period < Delay spread

2.4.2.1 Fast Fading Model

Fast fading is due to reflections of local objects and the motion of the objects relative to those objects. Fast fading arises when the coherence time of the channel is small relative to the symbol period of the transmitted signal.

The coherence time of the channel is related to a quantity known as the Doppler spread of the channel. In general, coherence time is inversely related to Doppler spread, typically expressed as:

$$T_c = \frac{k}{D_s} \qquad (2.8)$$

where T_c is the coherence time, D_c is the Doppler spread, and k is a constant taking on values in the range of 0.25 to 0.5[25].

When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. This phenomenon is known as the Doppler shift. Signals travelling along different paths can have different Doppler shifts, corresponding to different rates of change in phase. The difference in Doppler shifts between different signal components contributing to a single fading channel tap is known as the Doppler spread. The change in frequency is given by:

$$\Delta f = \frac{fv\cos\theta}{c} = \frac{v\cos\theta}{\lambda} \tag{2.9}$$

where

f is the transmitted frequency

v is the velocity of the transmitter relative to the receiver in meters per second: positive when moving towards one another, negative when moving away

c is the speed of wave (3×10^8 m/s for electromagnetic waves travelling in air or a vacuum)

λ is the wavelength of the transmitted wave subject to change

θ is the angle the direction of motion makes with the path

2.4.2.2 Slow Fading Model

Slow fading is the result of shadowing by buildings, mountains, hills, and other objects. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The level of shadow fading (in dB) is usually simulated by dropping a normal distributed random variable that refers to typical log-normal shadow fading model.

In 802.16j MMR Channel model, a typical log-normal shadow fading model is applied. The typical values based on WINNER models of the standard deviation for lognormal shadowing is listed in Table 2.4.

Table 2.4: Standard Deviation Values [7]

	Type-A	Type-B	Type-C	Type-D	Type-E	Type-F		Type-G	
						LOS	NLOS	LOS	NLOS
Std(dB)	10.6	9.6	8.2	3.4	8.0	2.3	3.1	3.1	3.5

A model of correction factor for standard deviation of the shadowing is proposed where the lognormal standard deviation increases with excess path loss over free space loss [7] as below:

$$\sigma(r) = \sigma_u \left[1 - e^{\frac{-\left|P(r) - P_{fs}(r)\right|}{4}} \right] + 1.5 \tag{2.10}$$

Where,

σ_u is the maximum standard deviation

$P(r)$ is the mean path loss (dB)

$P_{fs}(r)$ is the free space path loss (dB)

2.4.2.3 Multipath Model

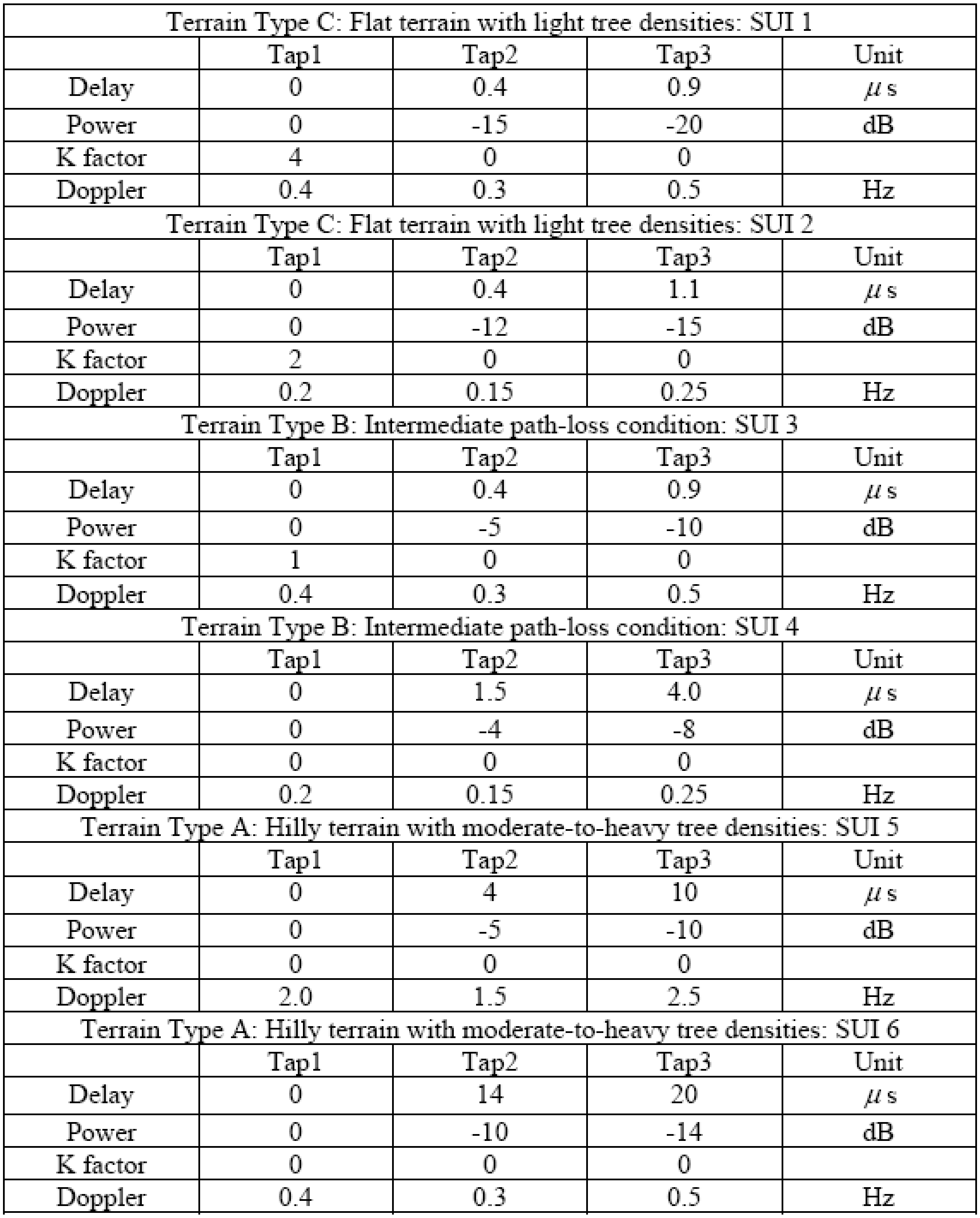
Multipath Fading occurs when there are obstacles and reflectors in the wireless propagation channel, the transmitted signal arrivals at the receiver from various directions over a multiplicity of paths. The multipath propagation is also called as NLOS propagation.

The radio channel of a wireless communication system is often described as being either LOS or NLOS.

- Line-of-sight (LOS): the direct connection between the transmitter (TX) and the receiver (RX).
- Non-line-of-sight (NLOS): the path arriving after reflection from reflectors.

A tap delay line is used to emulate the multipath fading channel. Depending on the K-factor, each tap coefficient is generated from either a Rician or Rayleigh random variables. 802.16 (derived from SUI) multipath fading model parameters are summarized in Table 2.5 and other details regarding the channel models can be found in [8]. The SUI-1, SUI-2 and SUI-3 modes are applicable for LOS condition, and SUI-4, SUI-5 and SUI-6 models are applicable for NLOS condition.

Table 2.5: 802.16 - SUI channel models [7]



Terrain Type C: Flat terrain with light tree densities: SUI 1				
	Tap1	Tap2	Tap3	Unit
Delay	0	0.4	0.9	μs
Power	0	-15	-20	dB
K factor	4	0	0	
Doppler	0.4	0.3	0.5	Hz
Terrain Type C: Flat terrain with light tree densities: SUI 2				
	Tap1	Tap2	Tap3	Unit
Delay	0	0.4	1.1	μs
Power	0	-12	-15	dB
K factor	2	0	0	
Doppler	0.2	0.15	0.25	Hz
Terrain Type B: Intermediate path-loss condition: SUI 3				
	Tap1	Tap2	Tap3	Unit
Delay	0	0.4	0.9	μs
Power	0	-5	-10	dB
K factor	1	0	0	
Doppler	0.4	0.3	0.5	Hz
Terrain Type B: Intermediate path-loss condition: SUI 4				
	Tap1	Tap2	Tap3	Unit
Delay	0	1.5	4.0	μs
Power	0	-4	-8	dB
K factor	0	0	0	
Doppler	0.2	0.15	0.25	Hz
Terrain Type A: Hilly terrain with moderate-to-heavy tree densities: SUI 5				
	Tap1	Tap2	Tap3	Unit
Delay	0	4	10	μs
Power	0	-5	-10	dB
K factor	0	0	0	
Doppler	2.0	1.5	2.5	Hz
Terrain Type A: Hilly terrain with moderate-to-heavy tree densities: SUI 6				
	Tap1	Tap2	Tap3	Unit
Delay	0	14	20	μs
Power	0	-10	-14	dB
K factor	0	0	0	
Doppler	0.4	0.3	0.5	Hz

Chapter 3

3. An Overview of Scheduling

3.1 Importance of scheduling

Scheduling is a key concept in computer multitasking and multiprocessing operating system design, and in real-time operating system design. It refers to the way in which processes are assigned priorities in a priority queue. This assignment is carried out by software known as a scheduler.

In real-time environment, such as mobile devices for automatic control in industry (for example robotics), the scheduler also must ensure that processes can meet deadlines; this is crucial for keeping the system stable. Scheduled tasks are sent to mobile devices and managed through an administrative back end. [9]

Scheduling algorithms provide mechanisms for bandwidth allocation and multiplexing at the packet level. Admission control and congestion control policies are all dependent on the specific scheduling disciplines.

Multi-user scheduling in a wireless context, where channel state information exploited at the base-station will result in large throughput gains to users. Hence, it has attracted a lot of interest over the past few years in characterizing the capacity as well as designing scheduling algorithms in this field. Such system consists of K mobile users, M relay stations and a central base-station. Packets arrive to the base-station from the Internet and are destined to the mobile users. Packets destined to various mobile users are temporarily buffered at the base station. The wireless access consists of a time-division system, i.e. time is divided into fixed size time-slots and users are allocated time-slots in a dynamic manner.

In a time division multiplexing (TDM) system that transmits to one user at a time, the overall throughput can always be maximized by transmitting to the user with the best channel. However, this approach can result in poor performance for users with poor channel quality. This problem is especially prominent in a low-tier mobility environment where channel conditions vary slowly with time. To address these considerations, various “fair” scheduling approaches have been considered, such as the proportional fair algorithm.

3.2 Scheduling Algorithms

Scheduling algorithm is playing a key role in overall system performance of broadband wireless systems. In this chapter, three widely adopted scheduling techniques in wireless networks are investigated: Round Robin, Maximum SNR and Generalized Proportional Fair. Maximum SNR and Round Robin emphasize efficiency and fairness respectively while Generalized Proportional Fair algorithm provides tradeoff between efficiency and fairness.

3.2.1 Round Robin Scheduling

RR is one of the fairest and most widely used scheduling algorithms, designed especially for time-sharing systems. The packet frame is equally divided into M non-overlapping slots. Then the M slots are assigned one at a time successively to each mobile user without priority. Clearly, this scheme provides a simple and fair sharing of transmission time, but results in loss in the throughput because RR is blind sequential scheduling which does not concern on the condition of channel; the data rate is much lower for users having very poor channel conditions.

3.2.2 Maximum SNR Scheduling

By exploiting the inherent channel variations in wireless systems, maximum SNR scheduling seeks to maximize the cell throughput by transmitting to the mobile user with the best channel in every time slot [10]. Let k* denotes the number of users in cell, Then, as above, by scheduling one user from each cell, user k* is selected if

$$k^* = \arg \max_{1 \le k \le K} SNR \tag{3.1}$$

The Properties of MaxSNR is that it could maximize the mean date rate of the whole system and it always tends to select close users. Some users which are far away from the BS or RS will hardly get the chance to transmit data. Cell could get the highest throughput while the user's delay will be a big problem.

3.2.3 Generalized Proportional Fair Scheduling

The essential goals of GPF packet scheduling scheme are to enhance the system throughput as well as to provide fairness among the queues under consideration. Comparing Round-Robin scheduling, where users are cyclically scheduled irrespective of the channel condition, this increases the system throughput while maintaining the long-term allocation fairness between users. The GPF scheduler allocates the user *k** who maximizes the ratio of achievable instantaneous data-rate over average received data-rate. This approach can be broadened to GPF by introducing weighting factors $\alpha \in [0;\infty)$ and $\beta \in [0;\infty)$ as follows [11]

$$P_k(n) = \frac{[DRC_k(n)]^{\alpha}}{[R_k(n)]^{\beta}} \tag{3.2}$$

$$k^* = \arg\max_k \{P_k(n)\} \tag{3.3}$$

Where $DRC_k(n)$ denotes the achievable instantaneous data-rate of user k at time n. $R_k(n)$ denotes the low-pass filtered average data-rate user k has received up to time n according to the following equation:

$$R_k(n) = \left(1 - \frac{1}{N_T}\right) R_k(n-1) + \frac{1}{N_T} DRC_k^{'}(n-1) \tag{3.4}$$

with $DRC_k^{'}(n-1)$ denoting the actual received data-rate of user m at time n-1 and N_T denoting exponential filtering factor and takes value around 100 slots, or 1.667 second for the high data rate system. If user *k* at time *n*-1 is not selected to receive data, $DRC_k^{'}(n-1)$ = 0.

For a parameter setting of $\alpha = \beta$ =1 conventional GPF scheduling is achieved, which provides a good trade-off between allocation fairness and system throughput by utilizing the multiuser diversity. Tuning parameters α and β in equation (3.2), the trade-off between fairness and system throughput can be changed. Increasing α will increase the influence of the achievable instantaneous data-rate $DRC_k(n)$, which enhances the probability of a user in currently good condition to be scheduled and it results in higher system throughput, but less allocation fairness and less data-rate fairness. Increasing β will increase the influence of the average data-rate $R_k(n)$, which increases the probability of a user with a low average data-rate being scheduled. This results in higher data-rate fairness, but lower system throughput [11].

The effects described above can be identified by the following two settings for α and β [11]:

- $\alpha \neq 0$ (e.g. $\alpha = 1$) and $\beta = 0$ is equal to the Max Rate (MR) scheduler, where the user with the highest achievable instantaneous data-rate at time *n* is scheduled, since the denominator in equation (3.2) is equal for all users. The maximum system throughput is obtained at low fairness.
- $\alpha = 0$ and $\beta \neq 0$ (e.g. $\beta = 1$) schedules the user with the lowest average data-rate up to at time *n*, i.e. equalizes the average data-rates of the users, since the numerator in equation (3.2) is equal for all users. This results in maximum data-rate fairness, but in low system throughput.

3.3 Relay-Assisted Scheduling

As RSs are introduced between BS and MS, modifications in the specification are required to support scheduling service. The following scheduling models could be used in 802.16j system [21].

- - Centralized, where BS make centralized control of the resource over both relay links and access links.
- - Distributed, where the resource over the relay or access link is managed by the associated RS. Two modes of the distributed scheduling service can be used.
    - Distributed with BS coordination on bandwidth grants, termed as Coordination mode
    - Distributed without BS coordination on bandwidth grants, termed as Non-coordination mode

Centralized scheduling services let BS take responsibility for all the resource control and The RSs are assumed to be simplified in terms of their functionality and all scheduling decisions are made at the BS [22]. This makes RS simple but since CSI reporting from all the MS are required, it needs a lot of feedback overhead.

In our proposed scheduling, the BS does not manage all the resources over both relay links and access links. And all scheduling decisions are not only made at the BS.

BS has user queues (buffers) for the MS in BS region instead of each of the MS in its cell. The RS has per-user queues and is allowed to perform scheduling on its own. Each RS runs its own scheduling algorithm to select the highest priority user as candidate MS and send this MS CSI to BS. BS collects all CSI from MSs in its BS region and some MSs selected from RSs by RS schedulers.

We propose a relay-assisted scheduling, whereby the RS assists the BS in its scheduling decision, thereby making it possible for the BS to exploit CSI on the access links without having to obtain the information from all the MS and hence to avoid the large feedback overhead. It is possible for the RS to estimate the CSI of each of the MS served by it. The RS applies its own scheduler to select only one MS with the highest priority and it just needs to send back the CSI of selected MS to BS. This incurs a significant reduction of feedback overhead.

Chapter 4

4. Scheduler Design

4.1 System Model

We consider a set of K mobile users, uniformly distributed in a cell, served by a single base station with M relay stations, in which each mobile device intends to receive its NRT (Non Real Time) data from the BS, possibly by multi-hop routing. We focus on downlink traffic (from the base station to the users) in a cellular radio network for the discussion below. Each user perfectly (without error or delay) predicts its own downlink channel state information and feedback information, combined with the knowledge of the quality of service(e.g. throughput and delay) that each user has achieved so far , is used to calculate the priorities by certain scheduling algorithm at the BS side[12]. For each time slot, either a mobile terminal or a relay terminal with the highest priority is selected by BS for the transmission of the data packets.

Assume that K mobile users are divided into BS region and RS region according to their mean path loss, and denote the number of users in the two regions by K1 and K2, respectively. K MSs are uniformly distributed in a cell and each MS is assigned to the BS or one of the RSs according to its geometric position. While a user located in the BS region is served by the BS directly; a user in the RS region could be served in two alternative ways: it is either connected to the BS directly or is connected to the BS by a two-hop transmission scheme through the RS. The transmission mode will be determined by a channel capacity based direct/relay link criterion developed according to some information-theoretic results. The transmission mode with better instantaneous transmission capacity will be selected. The details will be presented in Chapter 4.4 Relay mode.

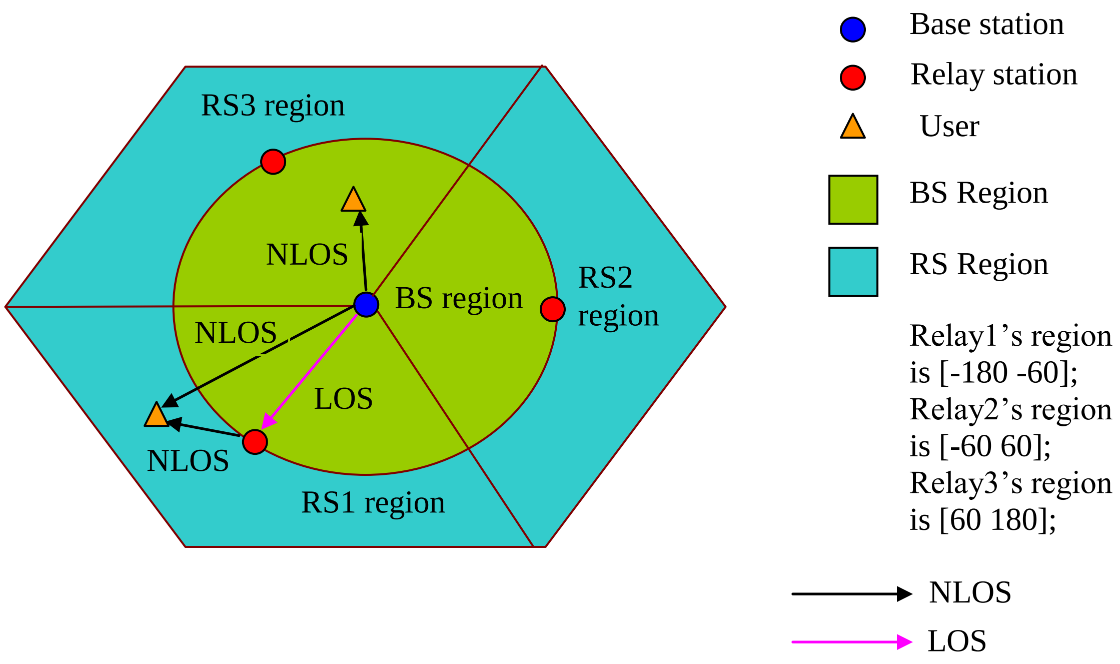


Figure 4.1: Simulation Model

Figure 4.1 illustrates the simulation model. As shown, there are three RSs in a single cell. The green circle is BS Region, the users located in this BS region is served directly by the BS. The blue area is RS regions. The users in the RS region are divided into 3 sub-regions: RS1, RS2, RS3 regions. The users in each of the 3 sub-regions can be served by the BS directly or indirectly through the corresponding RS.

We assume that BS-RS link is error-free and this can be justified, e.g., by saying that the link uses directional antennas in both ends. Furthermore, BS-RS and RS-MS links use the same frequency band, and BS-RS and RS-MS transmissions follow TDMA protocol. We further assume that transmission within the sector is synchronized so that there is no intrasector interference. Multiuser interference from other sectors and cells is ignored to simplify the implementation of the scenario.

The traffic model we considered is the full queue model. In the full queue user traffic model, all the users in the system always have data to send or receive [7]. In other words, there is always a constant amount of data that needs to be transferred, in contrast to bursts of data that follow an arrival process. This model allows the assessment of the spectral efficiency of the system independent of actual user traffic distribution type.

In this thesis, we concerned with relay-assisted scheduling, which has been described briefly in Chapter 3.3. Here, we give a detailed illustration about this relay-assisted scheduling.

Packet scheduler structure is illustrated in Figure 4.2. In a single cell with a set of K mobile users served by a single base station with M relay stations, for each time slot, every mobile terminal tries to receive data packet which are assumed to have fixed size from BS. The K1 users in the BS region are taken as the transmission candidates and their CSI are feedback to the BS. However, only M out of the K2 users in the RS region will be taken as the transmission candidates and be asked to feedback their CSI to the BS. All of the K2 users are first stored in the RSs scheduling queues of infinite length waiting to be served by their corresponding RS. Each RS runs its own scheduling algorithm over the MSs that are assigned to it and select one user according to the output of the scheduling algorithm. The CSI of the selected user of the RS is feedback to the BS in a particular time slot. Therefore, there will be M additional transmission candidates in the BS and each of the M candidates is selected by one of the M RSs and the total user number of the final candidate set in every time slot is K1+M. BS then runs its own scheduling algorithm over the candidate set of users to determine the final user who will be scheduled for the current time slot.

There are two different transmission sets in the BS: direct transmission set and relay transmission set. The users in direct transmission set selected by BS scheduler receive the packet in direct link from BS. The users selected from relay transmission set receive the information from BS via relay station in relay transmission mode which includes relay link from BS to RS and access link from RS to MS. See Figure 4.2. We suppose the relay link (between BS and RS) is a line-of-sight (LOS) link while the direct link between BS and MS and the access link between RS and MS are non-line-of-sight (NLOS) links.

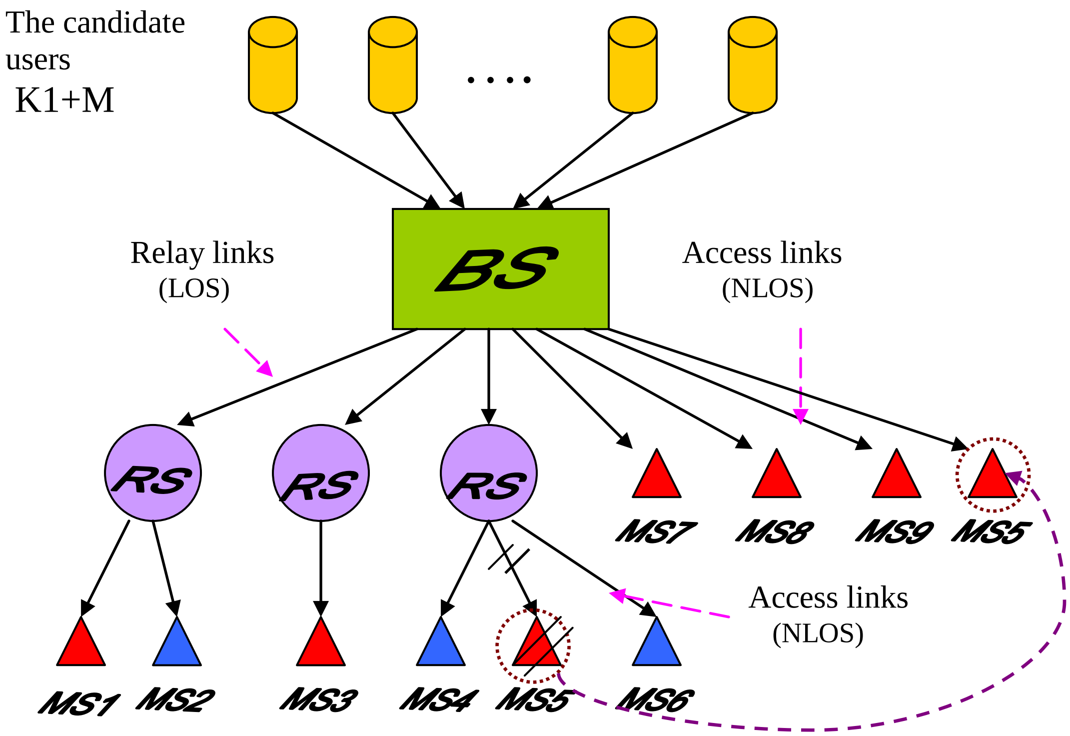


Figure 4.2: Packet Scheduler Structure

The total number of candidate users is K1+M. K1 users in BS region are always classified in the direct transmission set. The M candidates selected by M RSs are assumed to be in the relay transmission set initially but may be classified to direct transmission set by BS based on their own CSI feedback information later, which includes the user instantaneous transmission capacity of both the direct mode and relay mode. If its direct mode instantaneous transmission capacity is higher, BS will transfer this user from the relay transmission set into the direct transmission set. Refer to Figure 4.2, the user 5 which is selected by RS starts by sitting in the relay transmission set but is moved into the direct transmission set later. Although user 5 is located in the Relay region geometrically, it is classified in the direct transmission set in the BS because its user instantaneous transmission capacity of the direct mode is higher than that of the relay mode.

Some other characteristic assumption is displayed in Table 4.1.

Table 4.1: Some Characteristic Assumption

Link Types: • BS to MS NLOS • RS to MS NLOS • BS to RS LOS Number of Hops • 1 most prevalent Types of Routes • DL and UL can be asymmetric • Multiple Routes possible	RS Characteristics • Mobility – Fixed • Ownership – Provider-owned • Antenna Usage – No restrictions on antenna type were identified – Antenna heights may vary depending on the scenario

4.2 Channel Model

In this thesis work, we concentrate on the terrain type B as shown in Table 2.1: Intermediate path-loss condition, Suburban, BS antenna is ART in Fixed Infrastructure Usage Model in 802.16j MMR. We assume that the time-varying fading is caused by the superposition of the distance-related attenuation, log-normal shadowing, and Rician fading.

4.2.1 Path Loss Model

The path loss model is the one that has been describe in equation (2.7) in Chapter 2 .4.

In terrain type B model, the values of a, b, c, according to Table 2.3, are:
a=4.0
b=0.0065
c=17.1

The antenna height of the BS and the MS is set as follows:
h_b=30m
h_t=1.5m

Figure 4.3 gives the distance-dependent path loss in dB at 2.5GHz with the distance between 10m and 1000m.

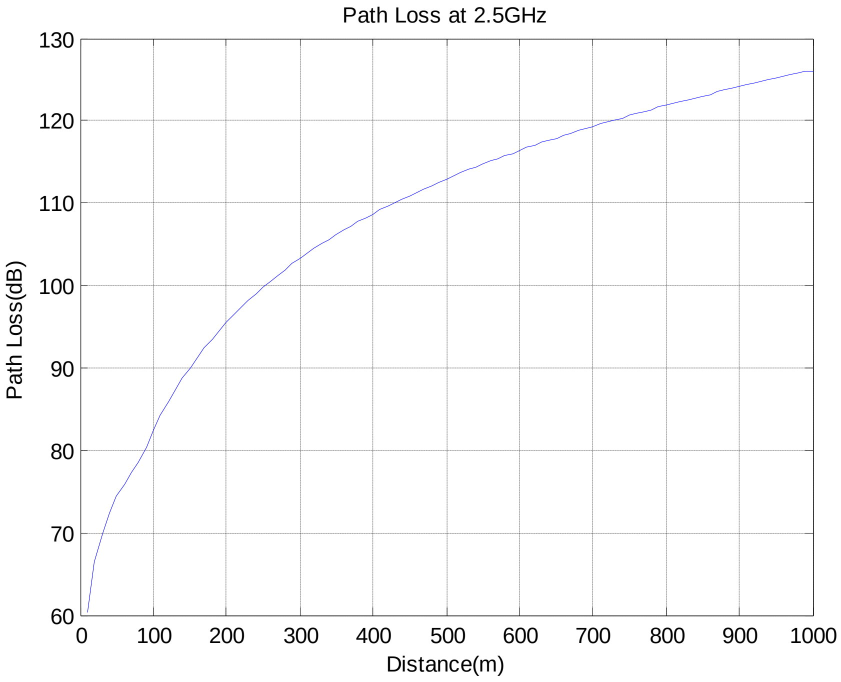


Figure 4.3: Path Loss at 2.5GHz

4.2.2 Log-normal Shadowing Model

The variation of the variance of the lognormal shadowing with respect to the frequency is also taken into account and the expression given by Okumura is used [17]:

$$\sigma = 0.65[\log(f)]^2 - 1.3\log(f) + A \qquad (4.1)$$

with f in MHZ,
A=5.2dB (urban) or 6.6dB (suburban)

There is no uniform globally licensed spectrum for WiMAX, although the WiMAX Forum has published three licensed spectrum profiles: 2.3GHz, 2.5GHz and 3.5GHz. In our model, we use the one at 2.5GHZ. Substituting this frequency value and the A value of 6.6dB into equation (4.1), we have: $\sigma = 9.6876$.

Compare $\sigma = 9.6876$ with the standard deviation value of terrain type B channel model in Table 2.4, we have justified the use of this Lognormal Shadowing in this simulation.

4.2.3 Rician Fading Model

In this simulation, the multipath fading is characterized as Rician distributed fading. Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

The Rician Probability Density Function (PDF) with variable *x* is expressed by:

$$f(x|v,\sigma) = \frac{x}{\sigma^2}\exp\left(\frac{-(x^2+v^2)}{2\sigma^2}\right)I_0\left(\frac{xv}{\sigma^2}\right) \qquad (4.2)$$

where $v \geq 0$ and $\sigma \geq 0$ are the parameters, $x \in [0;\infty)$ is the sample from the Rician process . $I_0(z)$ is the modified Bessel function of the first kind with order zero. When $v = 0$ the distribution degrades to a Rayleigh distribution.

Mean: $\sigma\sqrt{\pi/2}L_{1/2}(-v^2/2\sigma^2)$ (4.3)

Variance: $2\sigma^2 + v^2 - \frac{\pi\sigma^2}{2}L_{1/2}\left(\frac{-v^2}{2\sigma^2}\right)$ (4.4)

Figure 4.4 gives the Rician PDF with different parameter values of s and v. Here, the s in the figure is the σ in equations (4.2)-(4.4).

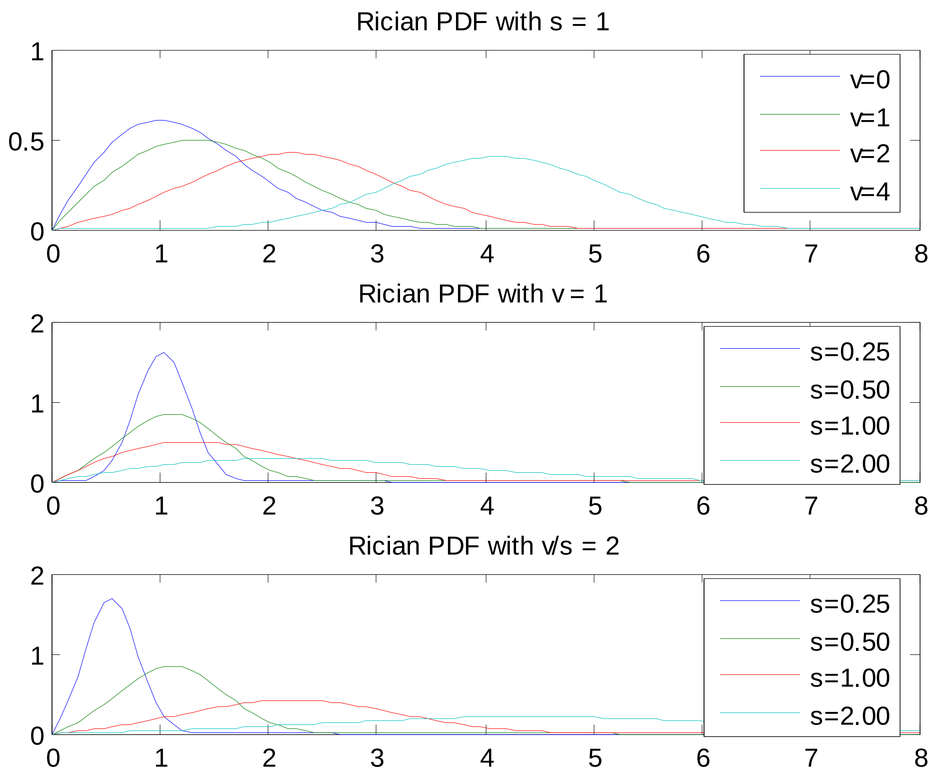


Figure 4.4: The Rician PDF with different parameter values

4.2.4 Channel Model for NLOS and LOS

The channel gain (attenuation and phase shift) h reflects the effects of several physical phenomena including scattering, obstacles, and multipath propagation.

The relay link between BS and RS is defined to be a LOS link, in which a signal travels over a direct and unobstructed path from the transmitter to the receiver. The channel gain $h_{r,k}$ in relay link can be expressed as

$$h_{r,k} = \sqrt{cp_k} \tag{4.5}$$

where *c* is a constant incorporating the transmission and receiving antenna gains, p_k is the path loss for user k.

The access link between BS and MS and between RS and MS are NLOS links. In a NLOS link, a signal reaches the receiver through reflections, scattering, and diffractions. The signals arriving at the receiver consists of components from the direct path, multiple reflected paths, scattered energy, and diffracted propagation paths [24]. The channel gain $h_{a,k}$ in access link can be written as

$$h_{a,k} = \sqrt{cp_k S_k m_k} \tag{4.6}$$

where c is a constant incorporating the transmission and receiving antenna gains, p_k is the path loss for user k , S_k is a random variable for the shadow fading effect, which is known to follow the log-normal distribution with zero-mean and variance σ_s^2 (dB) in the log-scale. The multipath fading effect m_k is modeled as an exponential random variable with a mean 4.0, which represents the Rician fading channel.

4.3 MAC Layer Model

The protocol stack of the access point is illustrated in Figure 4.5. A pair of variable-rate adaptive physical layers connects a particular client user to the access point. Above the physical layer, there is the channel-adaptive MAC layer. The operation of the MAC layer at the access point is divided into two sublayers, namely, request collection and resource scheduling. In the request-collection phase, mobile users will send their request for bandwidth allocation through contention in the minislots of the system frame. The base station collects all the requests from the active mobiles, and passes the CSI to the resource-scheduling. Specifically, the scheduling algorithm has to determine which user(s) should be scheduled for transmission, the corresponding transmit power, and the transmission rate. The base station broadcasts the scheduling results through in the downlink slot before payload transmission. [13]

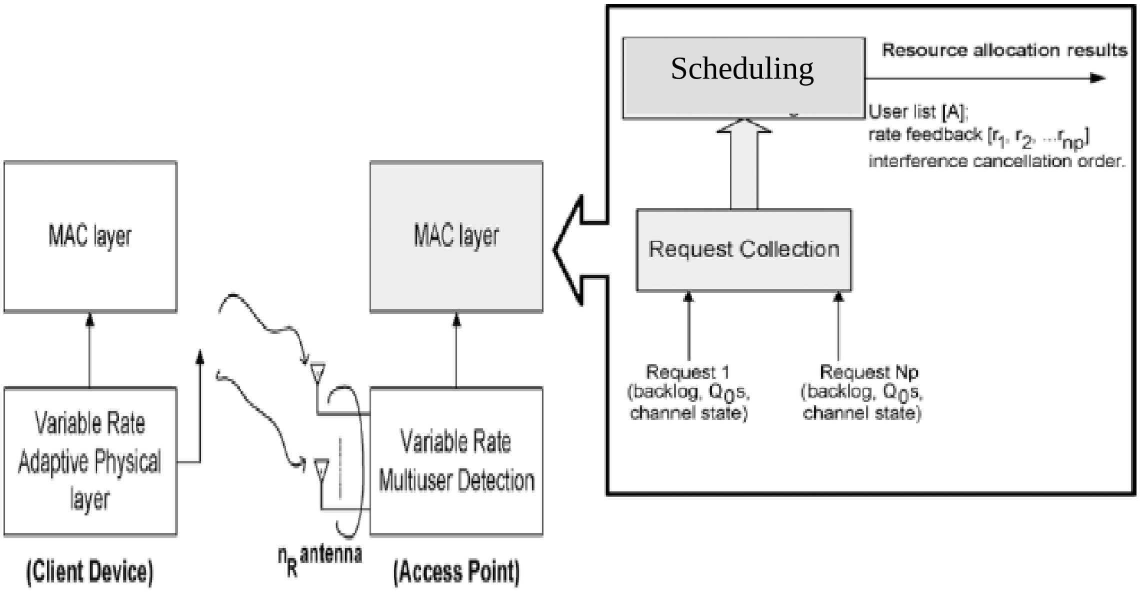


Figure 4.5: Protocol stack of the wireless access system [13]

4.4 Relay modes

In all usage models, RSs are deployed to provide 2 performance objectives. One is per-user throughput and/or capacity and/or reliability enhancement. A single low SINR (Signal-to-Interference-and-Noise-Ratio) link could be replaced with multiple high SINR links and RSs also could be deployed in dense topology (small cells) to improve the capacity. The other aim is coverage and/or range extension. RSs could extend coverage to users in a coverage hole, users in isolated areas that are outside the reach of any BS due to shadowing and in valleys between buildings, users riding on mobile vehicles or even to the users out of cell.

Assuming that the relaying stations operated in a centralized packet cellular system based on orthogonal access (TDMA) has been considered in this work. In the relay assisted scenario the best instantaneous channel depends not only on the channel state of the BS-MS link but also on the selection of a suitable RS to provide a good enough relay link. Consider, for instance, the TDMA in downlink transmission. Some time slots are assigned to send data to MS directly and others are assigned to RS first. The MS in RS region either connected to BS directly or indirectly. Figure 4.6 gives one example of DL time slot. There is a user MS1 in RS2 region, it is connected to BS directly in the first time slot and served via RS2 in the third time slot.

BS-MS1	BS-RS1-MS2	BS-RS2-MS1	BS-MS4	BS-RS1-MS5

Figure 4.6: Example of DL time slot

Two relay protocols are considered: amplify-and-forward and decode-and-forward. The former one simply amplifies the signal and forwards it and the latter one decodes the information, re-encodes it, and then forwards it.

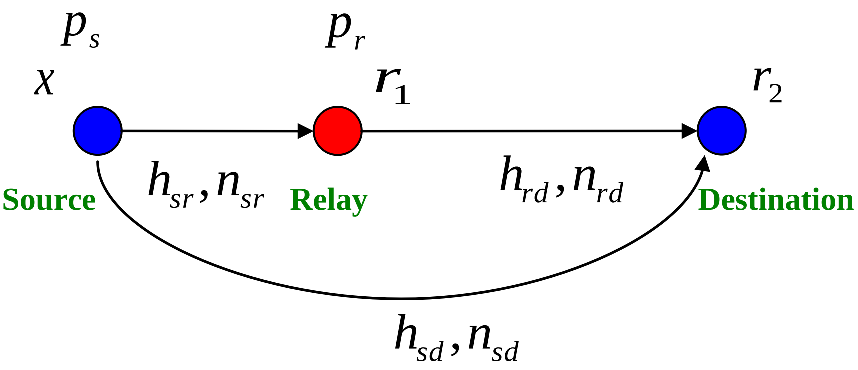


Figure 4.7: Sample Topology of source, relay and destination

Where:

x is the source signal,

r_1 is RS received signal

r_2 is the destination received signal,

p_s is the transmit power of the source (base station)

p_r is the transmit power of relay station

h_{ij} is the channel gain in link ij

n_{ij} is noise contribution in link ij and are modeled as mutually independent complex Gaussian random processes with zero means and variance N_{ij}.

The subscript $ij \in \{sd, sr, rd\}$ denotes the source-destination source-relay and relay-destination links, respectively.

4.4.1 No relay mode

In no relay mode (the direct transmission mode) as shown in Figure 4.7, the source end transmits the message to the destination without the assistance of a relay. The signal observed at the destination is expressed as,

$$r_2 = P_S h_{sd} x + n_{sd} \tag{4.7}$$

The channel link between BS and MS is defined as a NLOS access link, so the channel gain h_{sd} in BS-MS access link in no relay mode is calculated by equation (4.6),

$$h_{sd} = \sqrt{cpSm} \tag{4.8}$$

where c is a constant incorporating the transmission and receiving antenna gains, p is the path loss , S is a random variable for the shadow fading effect, m is a random variable for the multipath fading effect.

The instantaneous signal-to-noise ratio (SNR) of user in no relay mode is:

$$SNR_{sd} = \frac{|h_{sd}|^2 P_s}{N_{sd}} \tag{4.9}$$

The transmission capacity $\overline{C}_{s,d}$ of user in no relay mode is:

$$\overline{C}_{sd} = W \log_2(1 + SNR_{sd}) \tag{4.10}$$

4.4.2 Amplify-and-Forward Mode

The amplify-and-forward relay in AF mode is an intermediate terminal that amplifies the received signal from immediately preceding terminal and forwards it on. This leads to low-complexity relay transceivers and lower power consumption since there is no signal processing for decoding procedures. The relay nodes amplify both the signal and noise received and send them together to the destination.

When the data is transmitted via relay from source (BS) to Destination (user), see Figure 4.7, the received signal of the relay is:

$$r_1 = P_s h_{sr} x + n_{sr} \tag{4.11}$$

The RS amplifies the source information and noise together and takes them as the signal to pass through the relay-to-destination link. The received signal at the destination can be written as:

$$r_2 = P_r D h_{rd} r_1 + n_{rd} = P_r D(P_s h_{sr} x + n_{sr}) h_{rd} + n_{rd} \tag{4.12}$$

The relay link between BS and RS is a LOS link, and the channel gain h_{sr} is obtained by equation (4.5) while the access link between RS and MS is a NLOS link, and the channel gain h_{rd} in RS-MS access link is calculated by equation (4.6). Hence, we have:

$$h_{sr} = \sqrt{cp} \tag{4.13}$$

$$h_{rd} = \sqrt{cpSm} \tag{4.14}$$

where *c* is a constant incorporating the transmission and receiving antenna gains, p is the path loss , S is a random variable for the shadow fading effect, m is a random variable for the multipath fading effect.

The instantaneous signal-to-noise ratio (SNR) of AF-relay transmission is:

$$SNR_{srd} = \frac{|h_{sr}|^2 |h_{rd}|^2 P_s P_r D}{|h_{rd}|^2 N_{sr} P_r D + N_{rd}} \tag{4.15}$$

Where D is relay amplification factor .Several different choices of amplification factor D have been proposed in the literature, such as

$$D_1 = \sqrt{\frac{P_r}{\mathrm{E}\left[|r_1|^2\right]}} = \sqrt{\frac{P_r}{P_s N_{sr} + N_{rd}}} \tag{4.16}$$

And

$$D_2 = \sqrt{\frac{P_r}{P_r |h_{sr}|^2 + N_{rd}}} \tag{4.17}$$

in [18] and [19], respectively. Here, E[·] is the statistical expectation operator .The amplification factor D1 in (4.16) requires the knowledge of the average power received by the relay while the amplification factor D2 in (4.17) requires the relay to have instantaneous channel knowledge h_{sr}. The relays with amplification factor D1 using a constant gain are called fixed gain relays, while relays using amplification factor D2 are called variable gain relays because they continuously adjust their gain depending on the instantaneous channel [20]. To reduce the analysis complexity, our subsequent analysis will concentrate on fixed gain relays.

The AF relay channel capacity of user in AF mode is expressed as:

$$\overline{C}_{r,AF} = W \log_2 (1 + SNR_{srd}) \tag{4.18}$$

4.4.3 Decode-and-Forward Mode

The decode-and-forward relays in DF mode decode the received data and re-encode it before it is forwarded by the relays. DF relay channel does not propagate noise along the channel but it introduces the possibility of decoding error and the experienced delay due to intermediate terminal decoding.

When the data is transmitted via relay from source (BS) to Destination (user), see Figure 4.7, the received signal of the DF mode is the same as in equation (4.11) in AF mode and the SNR value in the DF relay is expressed as:

$$SNR_{sr} = \frac{|h_{sr}|^2 p_s}{N_{sr}} \tag{4.19}$$

The channel gain h_{sr} in relay link between BS and RS in DF mode is obtained by equation $h_{sr} = \sqrt{cp}$ (4.13) as that in AF mode.

DF Relay avoids noise accumulation whenever the decoding process is done successfully and the information transmitted from the DF relay to the destination is simply the decoded version of the source signal x. Besides, it takes two time slots to transmit a packet from BS to MS via DF relay. In the latter time slots of DF relay transmission, BS sends a packet to a user or a relay station in the same cell as well when RS forwards the packet received from BS in the last time slot to the MS. Hence, the interference between 2 users should be taken into consideration.

The received signal at the destination is given by:

$$r_2 = P_r h_{rd} x + n_{rd} + I \tag{4.20}$$

I denotes the interference factor. In Figure 4.8, user b or RS b is scheduled in this time slot to get the packet from BS directly. At the same time Relay r decodes and forwards the information to user a. p_s is the transmit power of the source (base station) to user b or RS b, h_a is the channel link gain between BS and user a, h_{rb} is the channel link gain between BS and user b/relay b.

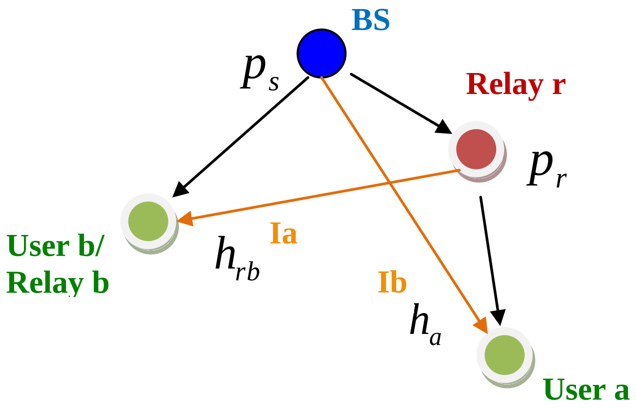


Figure 4.8: Sample of 2 transmissions at the same time slot in DF mode

The interference user b/RS b adds to user a is

$$I_a = |h_a|^2 P_s \tag{4.21}$$

The interference user a adds to user b/RS b is

$$I_b = |h_{rb}|^2 P_r \tag{4.22}$$

The SNR of the destination (mobile user) in DF mode which is affected by the interference I_a is:

$$SNR_{rd} = \frac{|h_{rd}|^2 p_r}{N_{rd} + |h_a|^2 P_s} \tag{4.23}$$

The channel gain h_{rd} in access link between BS and RS in DF mode is obtained by equation $h_{rd} = \sqrt{cpSm}$ (4.14) as that in AF mode.

The SNR of this cascade relay channel in DF mode is

$$SNR_{srd} = \min(SNR_{sr}, SNR_{rd}) \tag{4.24}$$

Once DF relay is used in the cell, the SNR should include the interference I_b when calculating channel quality in the next time slots.

Hence the SNR of user in the next time slots in direct transmission link is:

$$SNR_{sd} = \frac{|h_{sd}|^2 P_s}{N_{sd} + |h_{rb}|^2 P_r} \tag{4.25}$$

The SNR of user in the next time slots in relay transmission link between BS and RS is:

$$SNR_{sr} = \frac{|h_{sr}|^2 p_s}{N_{sr} + |h_{rb}|^2 P_r} \tag{4.26}$$

The channel capacity $\overline{C}_r$ in a specific time slot is the minimum value of channel capacity $\overline{C}_{sr}$ of the link between the source and relay station, and channel capacity $\overline{C}_{rd}$ between the relay station and destination, as expressed in (4.27).

$$\begin{aligned}\overline{C}_{r,DF} &= \frac{1}{2}\min(\overline{C}_{sr}, \overline{C}_{rd}) \\ &= \frac{1}{2}\min\{W\log_2(1+SNR_{sr}), W\log_2(1+SNR_{rd})\}\end{aligned} \tag{4.27}$$

We apply non-relay transmission in the BS region; user has a direct connection to the base station. In the relay region, we define the link type to be direct/relay link [16]. The user in relay region can either choose a direct transmission mode with the base station or a relay transmission mode to the base station via the relay station. The flexibility for a user in a relay region to switch between the direct and the relay transmission modes gives rise to the question of how to decide an appropriate criterion for the selection of transmission mode. In what follows, we employ some information-theoretic results and develop a channel capacity based direct/relay link criterion. The approach for deciding the transmission mode is to compare the relay channel capacity $\overline{C}_r$ with the direct transmission capacity $\overline{C}_{sd}$. If $\overline{C}_r > \overline{C}_{sd}$, user k selects the relay transmission mode; otherwise, user k uses the direct transmission mode, where $\overline{C}_r \in [\overline{C}_{r,AF}, \overline{C}_{r,DF}]$

4.5 Measurement Model

4.5.1 Delay Measurement

Since the data buffer for each user is assumed to be full all the time, it is difficult to define the instant when a packet arrives at the buffer. Here the delay for a packet (packet delay) is defined as the duration (in the number of slots) between the time when last packet is received by its target user, and the time when the current packet is received by that user (see Figure 4.8). The packet delay defined above is independent of packet arrival behavior and reveals the performance of the scheduling algorithm for physical layer. Note that in each slot only one packet is assumed to be transmitted without retransmission [14]. For example, if user k receives data packets at time slot 1, 2 5 respectively, then the packet delay for the second packet is 0 and the packet delay for the third packet is 3. The average packet delay of user k is defined as the mean of each received packet delay, which is expressed by:

$$\overline{D}_k = \sum_{m=1}^{M_k} D_{k,m} \Big/ M_k \tag{4.28}$$

where, $D_{k,m}$ denotes the packet delay of the m–th packet for user k ; M_k denotes the total number of packets transmitted to user k during the calculation.

The whole cell system packet delay is the average value of the total user average packet delay. For system with K mobile users in a single cell radio wireless network, the cell system packet delay can be written as below:

$$\overline{D} = \sum_{k=1}^{K} D_k \Big/ K \quad k \in [1,2,\dots,K] \tag{4.29}$$

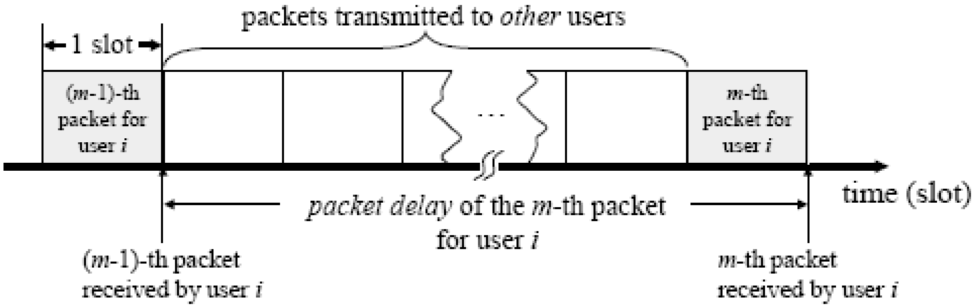


Figure 4.9: Definition of packet delay when there is no packet arrival process [14]

4.5.2 Fairness Measurement

The fairness criteria is a very important consideration, because an unfair scheduler could give a high system throughput, but lead to starvation of some mobile users in bad conditions.

A fairness index [15] is defined as

$$F = \frac{\left(\sum_{k=1}^{K} x_k(\Delta T)\right)^2}{K\sum_{k=1}^{K} x_k(\Delta T)^2} \tag{4.30}$$

where k denotes the index for different users, x_k denotes the per-user performance measure, such as the per-user time-fraction or per-user mean throughput. Correspondingly F is a (time) resource-based or (throughput) performance-based fairness index. It takes a continuous value between 1/K and 1. A larger F means better fairness: The value of 1 corresponds to a totally fair allocation (with all x_k 's equal) and a totally unfair allocation (with the chance of system access given to only one user) has a fairness of 1/K.

For this thesis we consider time resource-based allocation fairness F and x_k denotes the number of allocation time slots scheduled to user k in time interval ΔT .

4.5.3 Throughput Measurement

We assume that the data rate is ideally adapted to channel conditions, so that in every time slot, certain amount of information in the buffer is transmitted to the scheduled user in a way that the Shannon capacity is exploited. Meanwhile, the user's throughput (average data rate), is recorded and updated [6].Here, we define the total system throughput Th expressed as:

$$Th = \sum_{k=1}^{K} \overline{R}_k \tag{4.31}$$

Where $\overline{R}_k$ denotes the average system throughput of the kth user and is defined as

$$\overline{R}_k = \varepsilon[r_k] = \sum_{t=1}^{T} r_k(t) \Big/ T \qquad t \in [1,2,\dots,T] \tag{4.32}$$

where $r_k(t)$ is the instantaneous data rate assigned to user k at time t.

Obviously, the larger the total system capacity is, the better the scheduler performance.

The instantaneous data-rate of user k in time slot t in no relay mode is calculated by:

$$r_{k,sd}(t) = \log_2(1 + SNR_{k,sd}) \tag{4.33}$$

AF protocol does not require the relay to decode the source's transmission, which can be a major processing saving and does not cause much delay. Hence, we assume that when BS intends to send information to subscribers in the relay region via AF relay, the whole transmission time from BS to MS is within one time slot. Therefore, the instantaneous data rate of user k in time slot t is expressed as :

$$r_{k,AF}(t) = \log_2(1 + SNR_{srd}) \tag{4.34}$$

Since the source information should be decoded in the DF relay station before it is sent to the user, its arrival to the user takes 2 time slots instead of 1 time slot in the AF and non-relay transmission, assuming the process of decoding needs 1 time slot in DF relay. The source encodes the message and transmits it in the first time slot to the DF relay. In the second time slot, RS decodes and retransmits the message to the destination. The instantaneous data rate of user k at time slot t is the half of the data rate user k requires as below:

$$\begin{aligned} r_{k,DF}(t) &= \frac{1}{2}\log_2(1 + SNR_{srd}) \\ &= \min \frac{1}{2}\left\{\log_2(1 + SNR_{sr}), \log_2(1 + SNR_{rd})\right\} \end{aligned} \tag{4.35}$$

4.6 Scheduling Model

4.6.1 MaxSNR+ RR

In this setup, we assume that the BS uses Maximum SNR (MaxSNR) scheduling and RS uses Round Robin (RR) scheduling

1) Initially, according to the distance between BS position and user position, K users are divided into BS region and different RS regions by K1 and K2. M RSs use RR scheduler and FCFS(First-Come-First-Serve) criterion to serve the users in a RS region in a relay scheduling queue;

2) For users in BS region, calculate their SNRs(SNR_{sd})and record their SNRs and classifying these users into the direct transmission set, the length of the direct transmission set equals to the number of users in BS region, L_{direct}=K1. When relay type is AF , the SNRs(SNR_{sd}) could be calculated by equations (4.8)-(4.9);When relay type is DF, BS needs to first check whether other transmission also happens in this time slot from RS to MS. If it happens, the SNRs should be added interference factor so they are calculated by the equation (4.25), or the SNRs are calculated by equations (4.8)-(4.9);

3) For each of the RS regions, calculate the first user k's channel information (SNR) of its relay scheduling queue. The user's channel information includes the direct mode and the relay mode. Equation (4.5) and (4.8) give the first user's SNR of direct mode (SNR_{sd}). The SNR of relay mode (SNR_{srd}) for the first user k is obtained by using equations (4.13)-(4.16) when the relay type is AF, while by using equations (4.13)-(4.14),(4.19),(4.23),(4.24) when the relay type is DF. Change equation (4.19) to (4.26) if there is interference in DF mode.
The length of relay transmission set in this stage is the number of RSs since each RS selects one MS as a candidate, L_{relay}=M;

4) Compare the first user's SNR of direct mode (SNR_{sd}) with that of relay mode (SNR_{srd}). If its direct mode SNR_{sd} is higher, add this user into the direct transmission set and remove it from the relay transmission set;
If there are n users transferred from the relay transmission set to the direct transmission set, we have L_{direct}=K1+n and L_{relay}=M-n.
The direct transmission set and the relay transmission set constitute the candidates set. $L_{candidates}$= L_{direct}+L_{relay}=K1+M;

5) The BS scheduler picks user k with the highest priority in the candidates set, i.e. the one with the highest instantaneous SNR value in equation

$$k = \arg \max_{1 \le k \le K1+M} \log(1 + SNR) \tag{4.36}$$

6) Calculate user k's instantaneous data rate. If user k uses direct mode, calculate user k's instantaneous data rate $r_{k,sd}(t)$ by equation (4.33). If user k uses a relay mode, calculate user k's instantaneous data rate $r_{k,AF}(t)$ by equation (4.34) when the relay type is AF while $r_{k,DF}(t)$ by equation (4.35) when the relay type is DF. For DF mode, if there are 2 packets are transmitted in the same time slots, the system instantaneous data rate is the sum of these 2 packet instantaneous data rate;

7) Record the user k's number and user k's instantaneous data rate and update the user's use time slots number;

8) Empty the candidates set, direct transmission set and relay transmission set. Retain the relay scheduling queues and goto 1).

We note that the relay station can transmit data to their destination users, when they are not scheduled to communicate with the base station.

4.6.2 GPF + RR

In this scheduling scheme, BS uses Generalized Proportional Fair (GPF) scheduling and RS uses Round Robin (RR) scheduling.

1) Initially, according to the distance between BS position and user position, K users are divided into BS region and different RS regions by K1 and K2. M RSs use RR scheduler and FCFS(First-Come-First-Serve) criterion to serve the users in a RS region in a relay scheduling queue;

2) For users in BS region, calculate and record their priorities $P_k(n)=\frac{[DRC_k(n)]}{[R_k(n)]}$, $DRC_k(n)\triangleq\overline{C}_{s,d}$ and classifying these users into the direct transmission set;

$$L_{direct}=K1$$

3) For each of the RS regions, calculate the first user k's channel priority $P_k(n)=\frac{[DRC_k(n)]}{[R_k(n)]}$ of its relay scheduling queue. The user's channel information includes the direct mode and the relay mode.

$$DRC_k(n) \triangleq \begin{cases} \overline{C}_{s,d}(n) & \text{direct mode} \\ \overline{C}_{s-r-d}(n) & \text{relay mode} \end{cases}$$

The length of relay transmission set in this stage is the number of RSs since each RS selects one MS as a candidate, L_{relay}=M;

4) Compare the first user's priority of direct mode with that of relay mode. If its direct mode priority is higher, add this user into the direct transmission set and remove it from the relay transmission set;

   If there are n users transferred from the relay transmission set to the direct transmission set, we have: L_{direct}=K1+n and L_{relay}=M-n.

   The direct transmission set and the relay transmission set constitute the candidates set. $L_{candidates}$= L_{direct}+L_{relay}=K1+M;

5) The BS scheduler picks user k with the highest priority in the candidates set.

$$k = \arg\max_{1 \le k \le K1+M} \{P_k(n)\} \tag{4.37}$$

   If user k uses a relay mode, the base station transmits data to the corresponding relay node r (k); otherwise, the base station transmits directly to user k;

6) The base station updates the average data-rate of all users and all relay stations $R_m(n) = \left(1 - \frac{1}{N_T}\right) R_m(n-1) + \frac{1}{N_T} DRC'_m(n-1) \qquad m \in \{1,2,...K\} \cup \{1,2,...M\}$ in equation (3.4) where $DRC'_m(n-1)$ denoting the actual received data-rate of user/relay m at time *n*-1. If user/relay m at time *n*-1 is not selected to receive data, $DRC'_m(n-1)$ = 0;

7) Record the user k's number and user k's instantaneous data rate and update the user's use time slots number;

8) Empty the candidates set, direct transmission set and relay transmission set. Retain the relay scheduling queues and goto 1).

We note that the relay station can transmit data to their destination users, when they are not scheduled to communicate with the base station.

Chapter 5

5. Performance Analysis

In this chapter, we compare the performance of two different relay-assisted scheduling cellular systems in terms of fairness, packet delay and throughput in the same channel with user position fixed. These two cellular systems have the same relay station scheduling scheme: Round Robin scheduler, but they have different base station scheduling schemes: one being the Maximum SNR scheduling scheme and the other one being the Generalized Proportional Fair Scheduling scheme. In both two systems, three different relay-assisted modes, which are no relay-assisted mode, amplify-and-forward relay-assisted mode and decode-and-forward relay-assisted mode, are simulated with other parameters remaining fixed.

We analyze the simulation results based on three important performance metrics: Fairness, Packet Delay and Throughput.

The numerical results of Fairness Factor will be obtained from the simulation. The users in this cell system are much more fairly served when the fairness factor value approaches to 1 and the service is unfairly provided to the users when the fairness factor approaches 1/K. In order to see the result more clearly, we investigate the relationship between the user distance and the number of user's allocated time slot which represent how many time slots a certain user is allocated from the BS in the whole simulation time. Having this relationship, we could further analyze how different relay-assisted modes affect the resource allocation to users.

Simulation results are expressed in terms of the CDF (cumulative distribution function) plots of different metrics The CDF plots are analyzed according to the following outage probability definition:

From the CDF plots for Packet Delays,

$$\text{Packet Delay Outage}=\Pr\{\text{Packet Delay}<=Y\} \tag{5.1}$$

From the CDF plot for Throughput,

$$\text{Throughput Outage} = \Pr\{\text{Throughput} <= X\} \tag{5.2}$$

5.1 Simulation Setup

The parameters used in the numerical simulations are listed below in Table 5.1.

Table 5.1: Simulation Parameters

Parameter	Value
Cell layout	Hexagonal
BS Carrier frequency	2.5GHZ
RS Carrier frequency	2.5GHZ
The number of mobile users	30
The number of relay stations	3
Cell radius	1 km
Threshold distance	0.5km
BS-RS distance	0.6km
BS transmit power	46dBm
Relay station transmit power	34dBm
Noise power	1pW(-90.0 dBm)
Rician value	1 and 4(mean=4.1272, variance=0.9663)
Simulation Time	10sec
Slot Length	33 ms
Threshold delay	1.667s
BS antenna height	30m
MS antenna height	1.5m
Shadowing Standard deviation	9.6876dB

Note: N=thermal noise (KTB) +receiver noise=-97dBm+7dBm=-90dBm

Where K is Boltzman's Constant = 1.38 *10-23 Joules/Kelvin, T is the noise temperature in Kelvin= 273+17=290 K (17°C is room temperature) and B is the bandwidth in hertz = 50 MHz=5 *10^7 Hz.

5.2 Simulation Configuration

In this thesis, we evaluate the performance among three relay assisted transmission modes with two different scheduling schemes in system. All M relays are assumed to be located at the same distance from the source.

Three different relay assisted transmission modes are:

- No Relay mode: No relay is deployed in the cellular system and all the users receive data packets from base station directly.
- DF mode: Fixed Decode-and-Forward (DF) Relays deployed in the fixed positions are used as the intermediate terminals to help the transmission between the BS and the users located in relay region.
- AF mode: Fixed Amplify-and-Forward (AF) Relays deployed in the fixed positions are used as the intermediate terminals to help the transmission between the BS and the users located in relay region.

Two different scheduling schemes are:

- MaxSNR+RR scheme: Base station applies maximum SNR scheduling and relay station applies round robin scheduling.
- GPF+RR scheme: Base station applies generalized proportional fair Scheduling and relay station applies round robin scheduling.

5.3 Relay Performance

5.3.1 DF Relay Performance

In order to investigate the effect of relays in DF mode, we observe one user's behavior in DF mode to check how DF relay works for it.

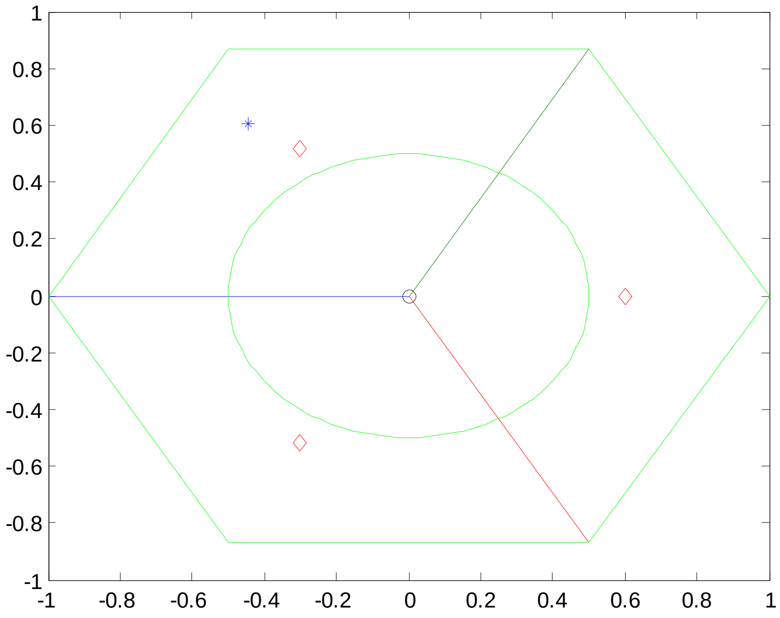


Figure 5.1: 1 User position and 3 Relay positions in simulated system

The user in Figure 5.1 is in the RS region. The calculation of this user's SNRs for both direct transmission link and relay transmission link as below:

```
 user distance=0.75166km, user_pathloss=120.68dB
BS-RS distance=0.6km,     relay_pathloss=116.3945dB
user_relay_distance= 0.17km,    relay_user_pathloss=92.3621dB

transmit_power_BS=46dBm, transmit_power_RS=34dB

user_shadowing=8.2876dB,

rician_fading=20*log10(ricernd(rician_v,rician_s))=11.8392dB   [5,16]

noise1 (noise without interference)
=10*log10((wgn(1,1,noise_power,'dBm'))^2)= -127.0785dB [-117 -130]

noise2 (noise with interference)=
10*log10(10^((h_a+p_s)/10)+(wgn(1,1,noise_power,'dBm')^2))= -85.7580
here,
p_s=transmit_power_BS=46dB;
h_a=-user_passloss(k)-user_shadowing-rician_fading=-131.7583dB;
```

The SNR of direct transmission link is

```
user_snr=transmit_power_BS-user_passloss-user_shadowing-
rician_fading-noise1=46-120.68-8.2876-11.8392-(-127.0785) =32.2717dB
```

The SNR of relay transmission link between BS and RS is

```
relay_snr=transmit_power_BS-relay_pathloss-noise1
=46-116.3945-(-127.0785) =56.6840dB
```

The SNR of relay transmission link between RS and MS is

```
user_relay_snr=transmit_power_RS-relay_user_pathloss-user_shadowing-
rician_fading-noise2=34-92.3621-8.2876-11.8392-(-85.7583) =7.2694dB
```

The SNR of relay transmission link is the minimum of 56.6840dB and 7.2694dB that is 7.2694dB, extremely smaller than the SNR of the direct transmission link (32.2717dB) since the interference in relay transmission link is too high. For the user in this distance from RS could not get benefits from the DF relay in transmission.

Based on above analysis, the difference between SNRs of direct transmission mode and relay transmission mode is around 25dB. When the RS-MS pathloss is less than 92-25=67dB , the SNR in relay transmission mode for the user would be higher than that in direct transmission mode and the DF relay will work for the user. Since the channel quality has certain dynamic range, when the MS-RS distance is within 200m, the user has chance to use near RS to transmission according to Figure 4.3(Path loss at 2.5G).

The factor affecting the work area of DF relay is the interference. Reducing interference in relay transmission link will make DF relay work area larger.

5.3.2 AF Relay Performance

For AF relay, fixed gain relays are assumed and its amplification factor is determined to be 56dB according to equation (4.13). The path loss increases sharply in the first 100m and the increased amount declines as the distance increases (see Figure 4.3). If BS intended to send packets to a user 0.8km away from it, the path loss is 122dB.The received signal power in AF relay is 46dB-122dB=-76dB. Putting an AF relay, with amplification factor of 56dB, 6km away from BS, the path loss is 116dB (0.6km) +95(0.2km)=211dB. The amplification factor and RS transmitter power (34dBm) are enough to compensate the path loss attenuation. The signal power MS got in the relay transmission is 46-116+34-95+56= -75dB. The noise in relay transmission link is usually worse than that in the direct transmission mode. Hence, AF relay work area could be a little less than 200 meters which is greater than that for DF mode in this simulation case.

5.4 Scheduling Performance

Results will be obtained from 10*30 independent simulation runs of 30 users in a single cell. There are 30 slots/frame devoted for DL.

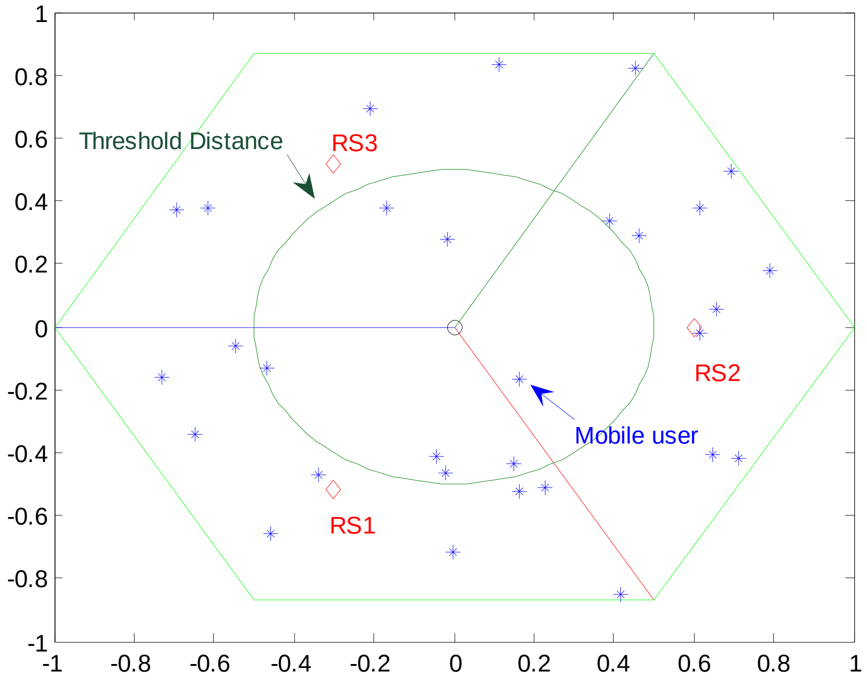


Figure 5.2: 30 User positions and 3 Relay positions in simulated system

Figure 5.2 illustrates the position distribution of 30 users (sampled from uniform distribution) and 3 relays in a single cell. The green circle denotes the threshold distance and it divides the whole cell into two different regions: RS region and BS region. In this simulation, there are three relay stations in a cell and the BS-RS distance is fixed to 0.6km for all the RSs inside one cell.

5.4.1 MaxSNR+RR Scheme Performance

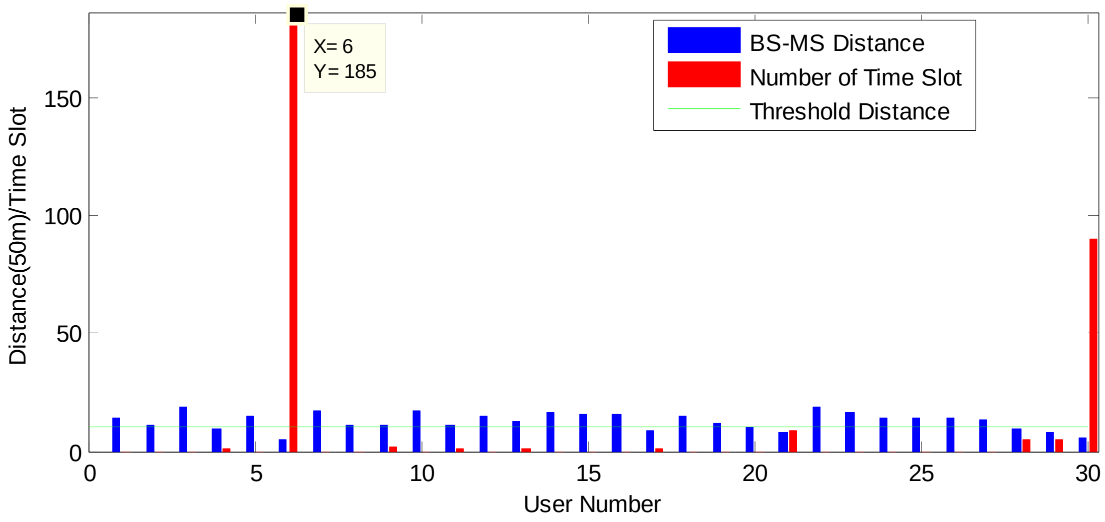


Figure 5.3: User distance vs. User's allocated time slot in MaxSNR+RR without RS

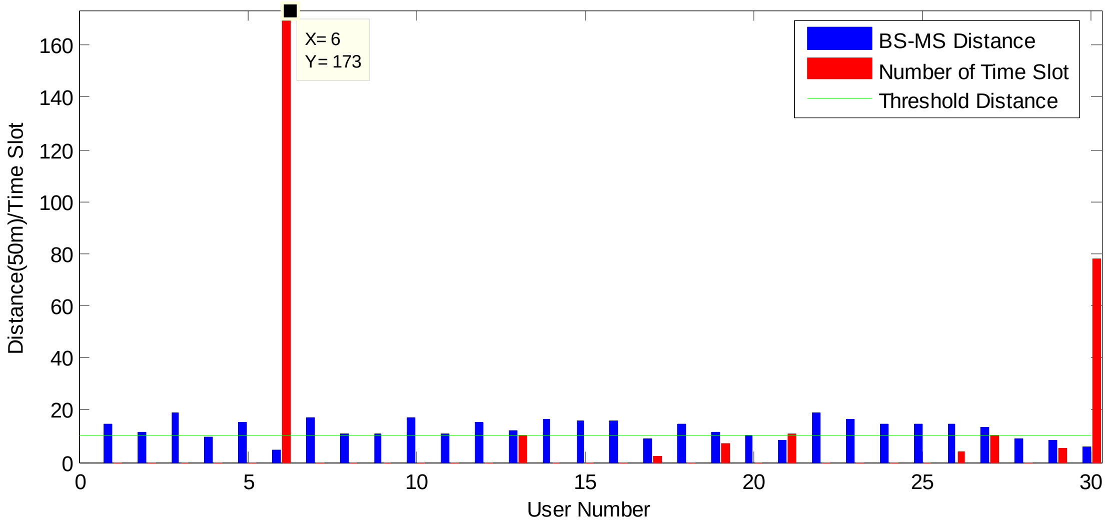


Figure 5.4: User distance vs. User's allocated time slot in MaxSNR+RR with DF

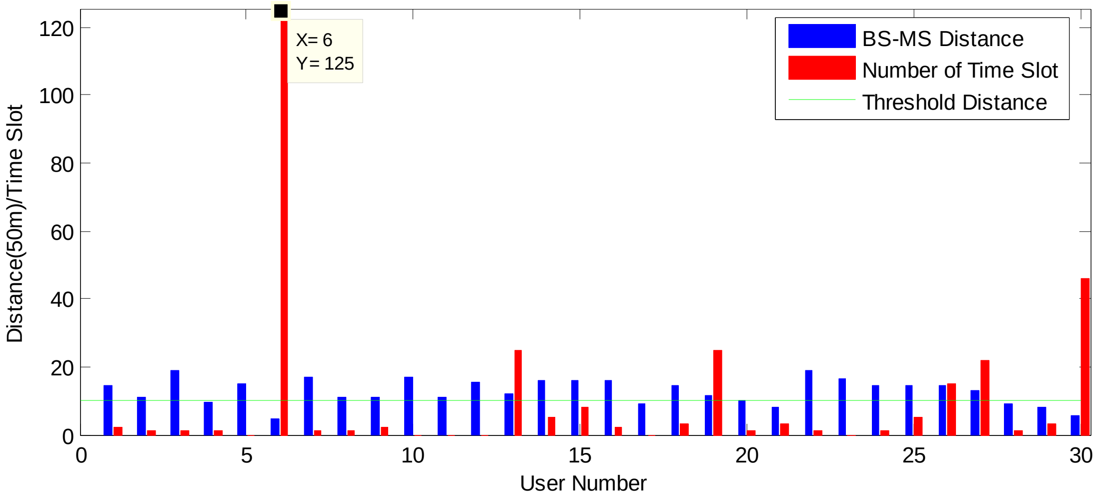


Figure 5.5: User distance vs. User's allocated time slot in MaxSNR+RR with AF

Figures 5.3-5.5 show the relationship between BS-MS distance and number of user's allocated time slot during the whole simulation time for 3 different relay assisted modes: no-relay mode, amplify-and-forward mode and decode-and-forward mode in MaxSNR+RR Scheme. As expected, there is a large penalty in fairness for all three relay modes in this scheduling scheme.

Table 5.2: Fairness Factor of 3 modes in MaxSNR+RR scheme

	MaxSNR + RR		
Relay mode	No Relay mode	DF mode	AF mode
Fairness Factor	0.07186	0.077529	0.15104

Table 5.3: DF and AF relay use times in MaxSNR+RR scheme

	Relay 1	Relay 2	Relay 3
DF mode	5	11	1
AF mode	42	55	24

From Figure 5.3, it can be seen that most of the time slots are allocated to the two users closer to BS, 185 time slots for user 6 and 90 time slots for user 30, while some long distance users are never allocated any resources. It tells that MaxSNR scheduler allocates much more time slots to the user who is much closer to BS. AF relays improve the performance of the other 28 users in the cell to squeeze out some time slots from the two closer users so that the fairness factor is increased from 0.07186 (no relay mode) to 0.15104 (AF relay mode) (see Table 5.2). As for DF mode, although DF relays also help some long distance users to be assigned more time slots than those in the non-relay mode, the DF mode does not perform as well as AF mode. It could be observed in Table 5.3 that the total relay use times (17) in DF mode is less than the total relay use times (121) in AF mode under the same simulation environment. The interference caused by two different packets aiming at two MSs at the same time slot in DF mode makes the SNR of relay-assisted transmission smaller than the SNR in direct transmission. Only the users within 100 meters close to DF relay may have chance to achieve better channel quality with DF relay than that without relay. In general, with the assistance of relay, the systems with AF mode and DF mode have a slight enhancement in the fairness factor and the MSs who are far away from the BS but close to their corresponding RSs in these two relay mode systems get more chance to be allocated the resources.

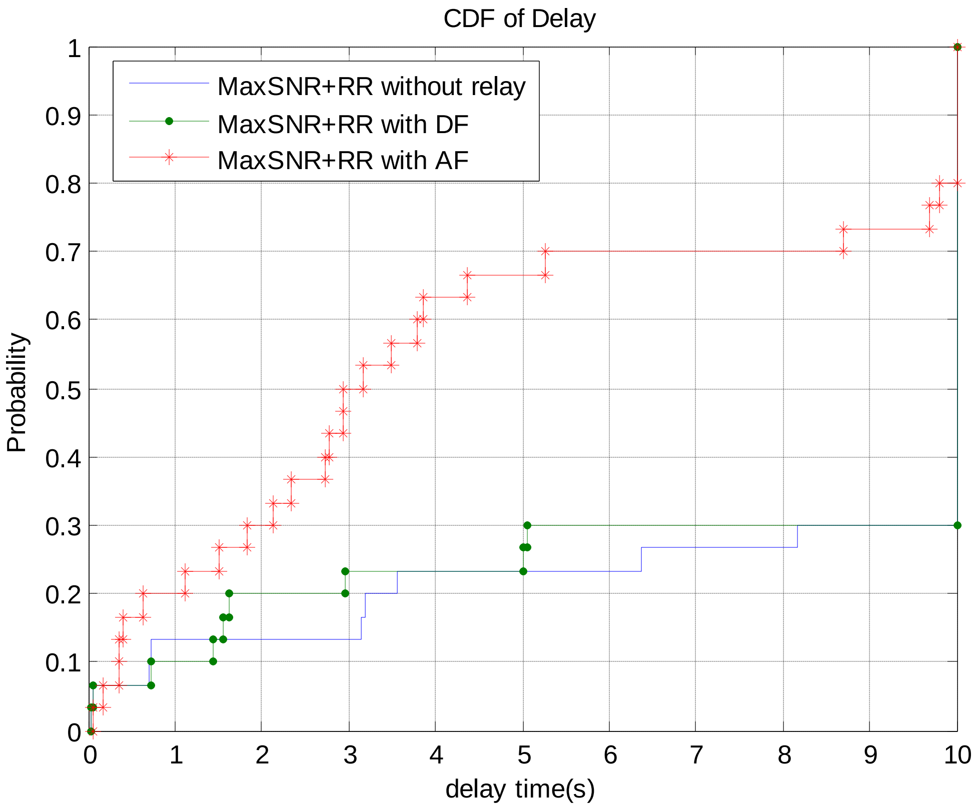


Figure 5.6: CDF of user delay of 3 modes in MaxSNR+RR scheme

Table 5.4: Average Packet Delay of 3 modes in MaxSNR+RR scheme

Scheme	MaxSNR + RR		
Relay mode	No Relay mode	DF mode	AF mode
Average Packet Delay (sec)	7.8651	7.6164	4.4825

Figure 5.6 and Table 5.4 give the performance of packet delay among our 3 different modes under MaxSNR+RR scheme. There are 70% of the packets in no relay mode having 10-second delay and the average packet delay is 7.8651 seconds. The probability of packets having 10-second delay in DF mode is the same as that in no relay mode while DF relays reduce the other 30% packets average transmission waiting time. Therefore, the average packet delay of DF mode is 3.16% smaller comparing with that

of the non-relay mode. In AF mode, 68% of the packets experience less than 5-second delay and only 20% of the packets delay exceeds 10 seconds. The average packet delay in AF mode is 4.4825 seconds, which is extremely less than those in other relay modes.

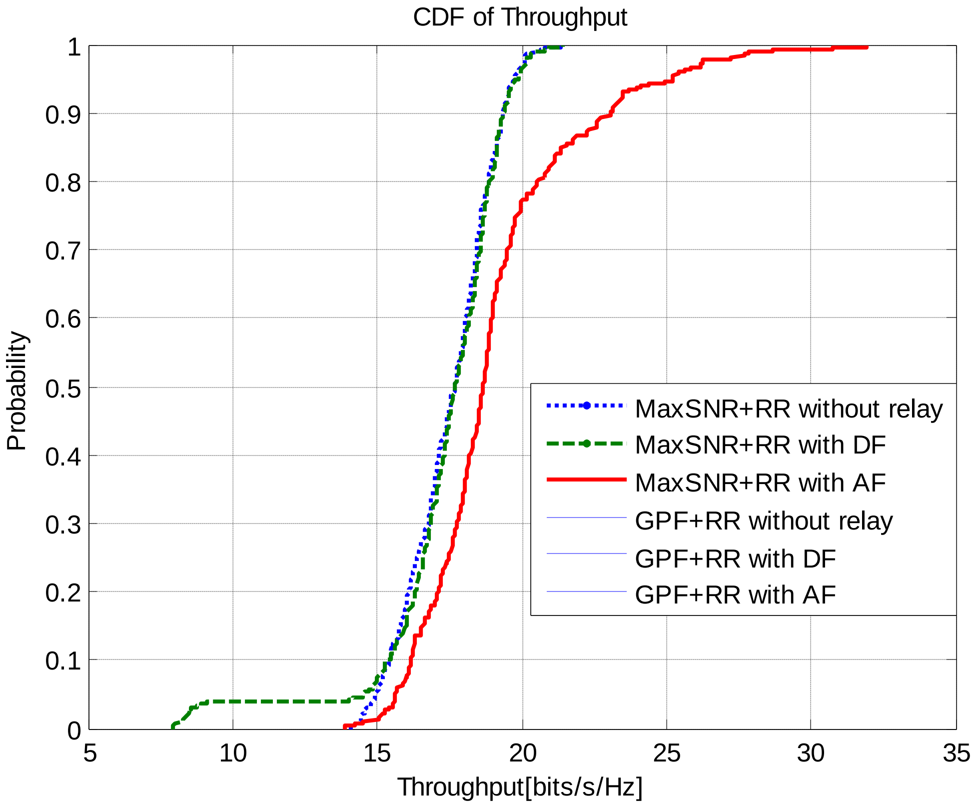


Figure 5.7: CDF of Throughput of 3 modes in MaxSNR+RR scheme

Table 5.5: Average throughput of 3 modes in MaxSNR+RR scheme

Scheme	MaxSNR + RR		
Relay mode	No Relay mode	DF mode	AF mode
Average Throughput(bits/s/Hz)	17.5235	17.3585	19.1187

The AF mode performs better than DF mode not only in terms of minimum packet delay but also in terms of maximum average throughput in MaxSNR+RR scheme in this simulation case. The average throughput in AF mode is increased by 9.1% and 10.14% comparing with the ones in no relay mode and in DF relay mode. DF mode performs worse than AF mode because of the interference added to the system when DF relay is used in the transmission. From Figure 5.7, we also notice that DF mode has an extra range of instantaneous throughput between 8 bits/s/Hz and 14 bits/s/Hz comparing to AF mode and no relay mode. This is because it takes two time slots to transmit one packet to the target user via a DF relay and the instantaneous data rate in any one of these two time slots is one half of the user asked transmission data rate.

5.4.2 GPF+RR Scheme Performance

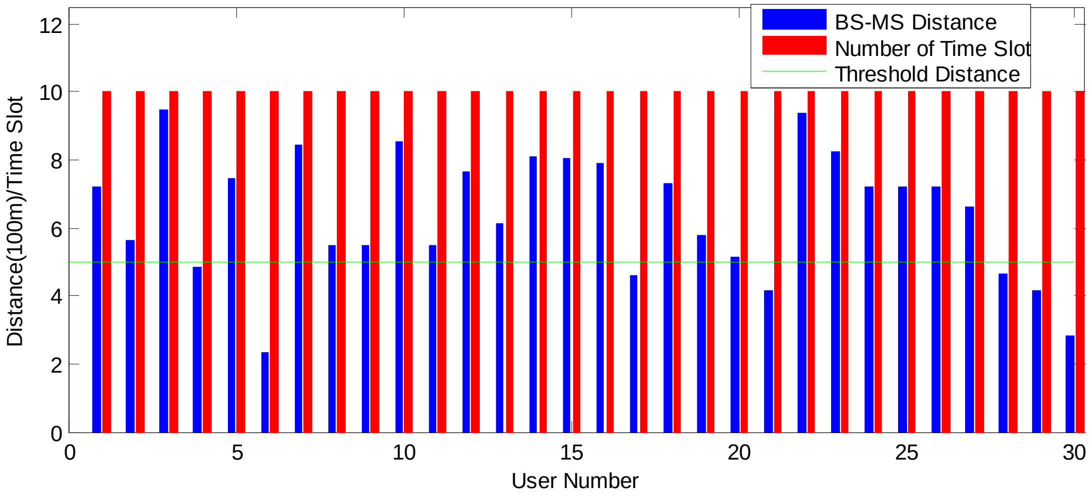


Figure 5.8: User distance vs. User's allocated time slot in GPF+RR without RS

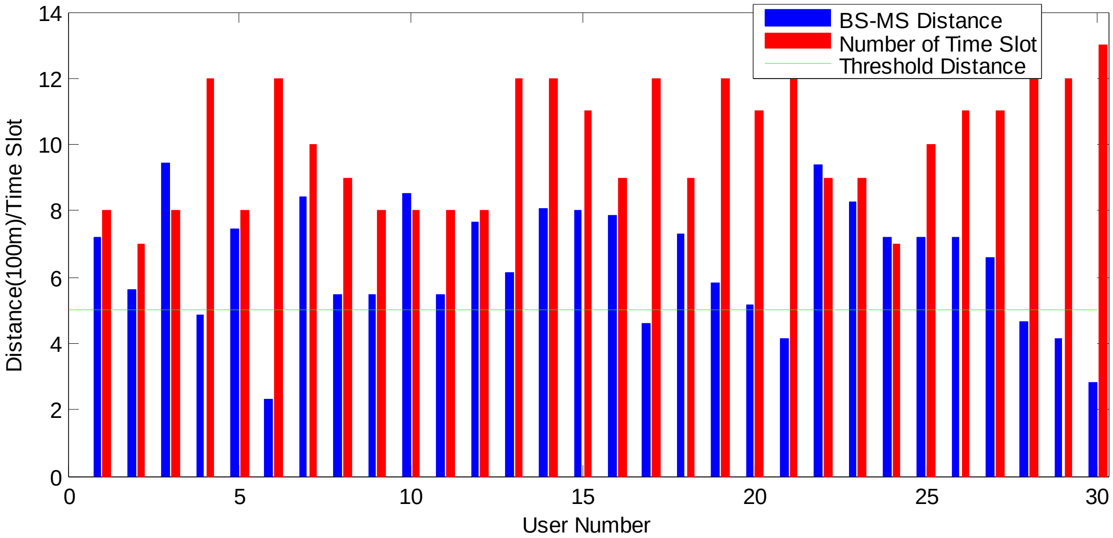


Figure 5.9: User distance vs. User's allocated time slot in GPF+RR+DF scheme

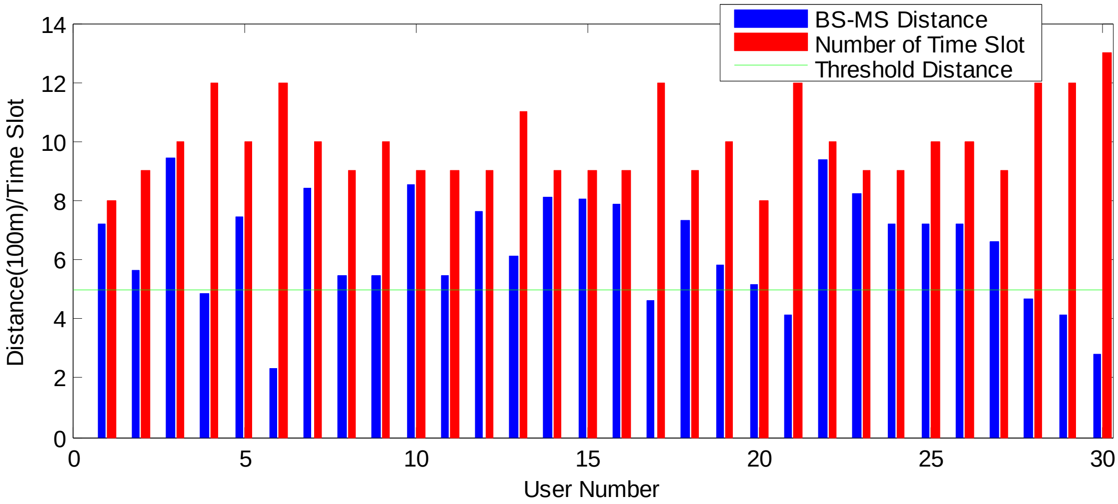


Figure 5.10: User distance vs. User's allocated time slot in GPF+RR+AF scheme

From Figures 5.8 to 5.10, one can find that Generalized Proportional Fair (GPF) scheduling maintains the long-term allocation fairness between users. The fairness in terms of time allocation of the system without relay is generally better than the system with relays since the users in relay region have to wait in relay queues before getting in the BS scheduler queue.

Table 5.6: Fairness Factor of 3 modes in GPF+RR scheme

	GPF + RR		
Relay mode	No Relay mode	DF mode	AF mode
Fairness factor	1	0.98296	0.98425

The fairness factor in no relay mode is 1, indicating a totally fair allocation (with all users equal). DF mode and AF mode give slightly smaller fairness factor, but these values are still high (above 0.98), showing the difference of time slots allocation is very small between the user very close to BS and the user around the cell edge.

Table 5.7: DF and AF relay use time in GPF+RR scheme

	Relay 1	Relay 2	Relay 3
DF mode	20	44	5
AF mode	6	14	1

Table 5.7 shows the DF and AF relay use times in GPF+RR scheme. We could find that in terms of relay use times, the DF and AF relays are actually in the opposite situation when they are under MaxSNR+RR scheme and GPF+RR scheme. For MaxSNR+RR scheme, the total relay use time in AF mode is much higher that that in DF mode while when it comes to GPF+RR scheme, the total relay use time(69) in DF mode exceeds the total relay use time(21) in AF mode. It is concluded that DF relay improves more users' channel qualities in its work area by the relay transmission mode but does not improve as much as AF relay does. Hence, AF relays have greater total relay use time in MaxSNR+RR scheme and DF relays are used more often in GPF+RR scheme.

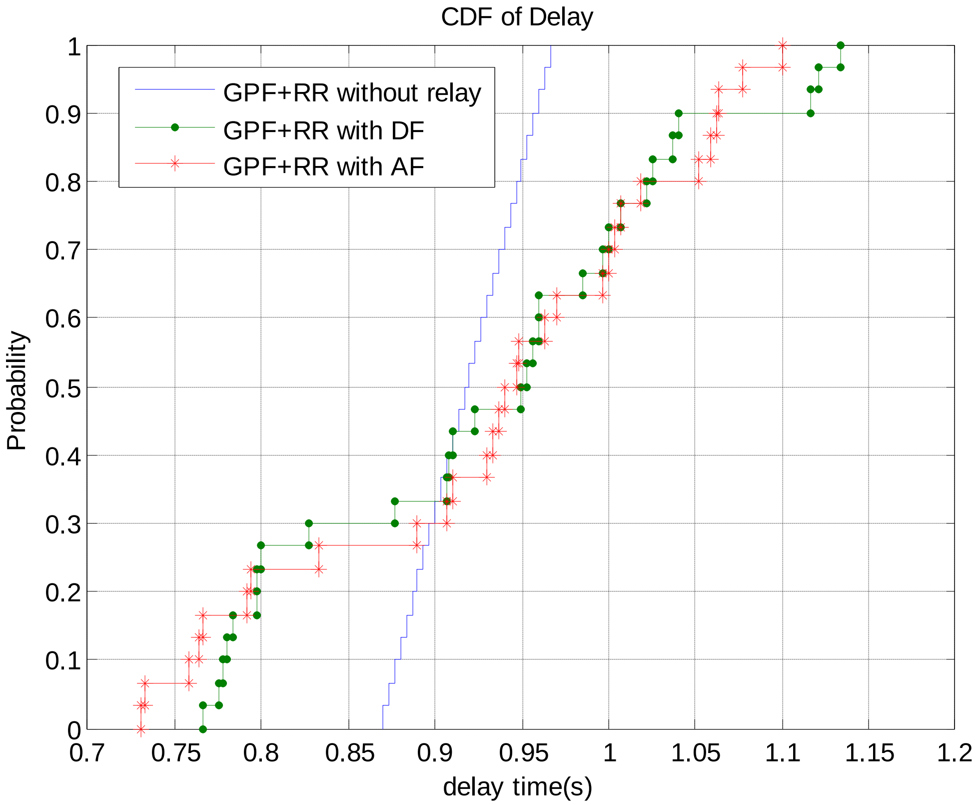


Figure 5.11: CDF of Packet Delay of 3 modes in GPF+RR scheme

Table 5.8: Average Packet Delay of 3 modes in GPF+RR scheme

Scheme	GPF + RR		
Relay mode	No Relay mode	DF mode	AF mode
Average Packet delay(sec)	0.91833	0.92979	0.92959

The packet delay performances for 3 different relay-assisted modes in the Generalized Proportional Fair scheduling scheme are given in Figure 5.11 and Table 5.8. In GPF scheme, the cellular systems with DF mode and AF mode make less than 40% packet delays smaller and over 60% packet delays greater while consistently increasing the average packet delay value compared to the cellular system without relays.

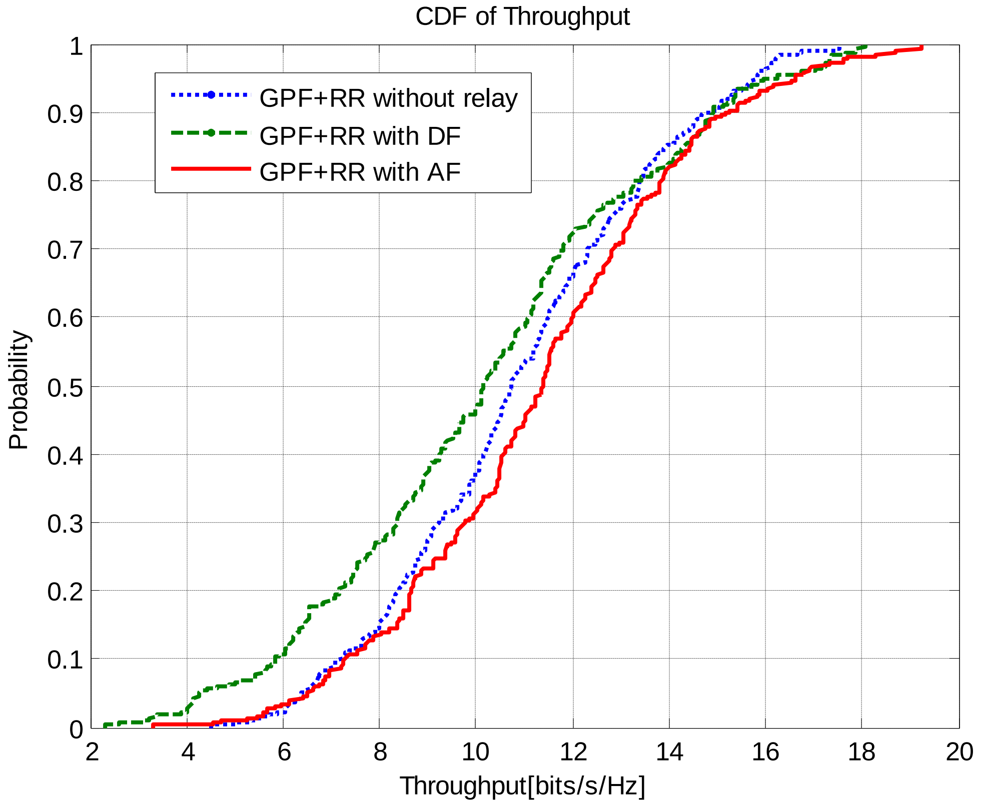


Figure 5.12: CDF of Throughput of 3 relay modes in GPF+RR scheme

Table 5.9: Average Throughput of 3 relay modes in GPF+RR scheme

Scheme	GPF + RR		
Relay mode	No Relay mode	DF mode	AF mode
Average Throughput(bits/s/Hz)	10.9222	10.2484	11.3659

The result in Figure 5.12 shows a considerable throughput reduction of DF mode since DF relays are used too often in GPF+RR scheme that they introduce a great deal of interference to the whole system. Beside, only one half of asked data rate for DF mode can be reached in the first of two time slots when BS chooses a DF relay to forward one packet to the target user, so we can notice from Figure 5.12 that DF mode experiences the low instantaneous data rate ranging from 2 to 4 bits/s/Hz while other modes' minimum instantaneous data rate is 4 bits/s/Hz. It is also seen from Table 5.9 that AF mode slightly outperforms no relay mode regarding to average throughput. The reason is that those AF relays improve the transmission data rate of users close to RS by relay transmission.

5.5 Effect of the Number of Relays

We are interested in observing the effect of number of relays in a single cell.

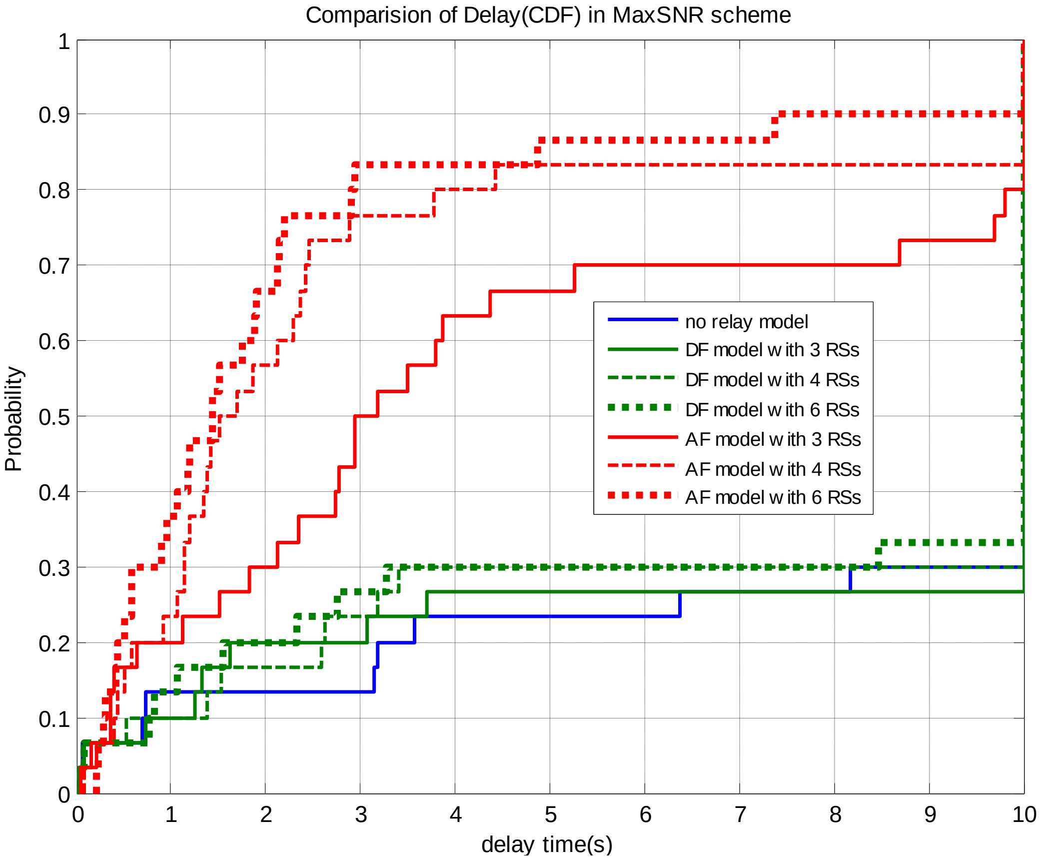


Figure 5.13: Comparisons of Packet Delay (CDF) for 3 relay modes in MaxSNR+RR scheme when the number of relays M=3, 4, 6

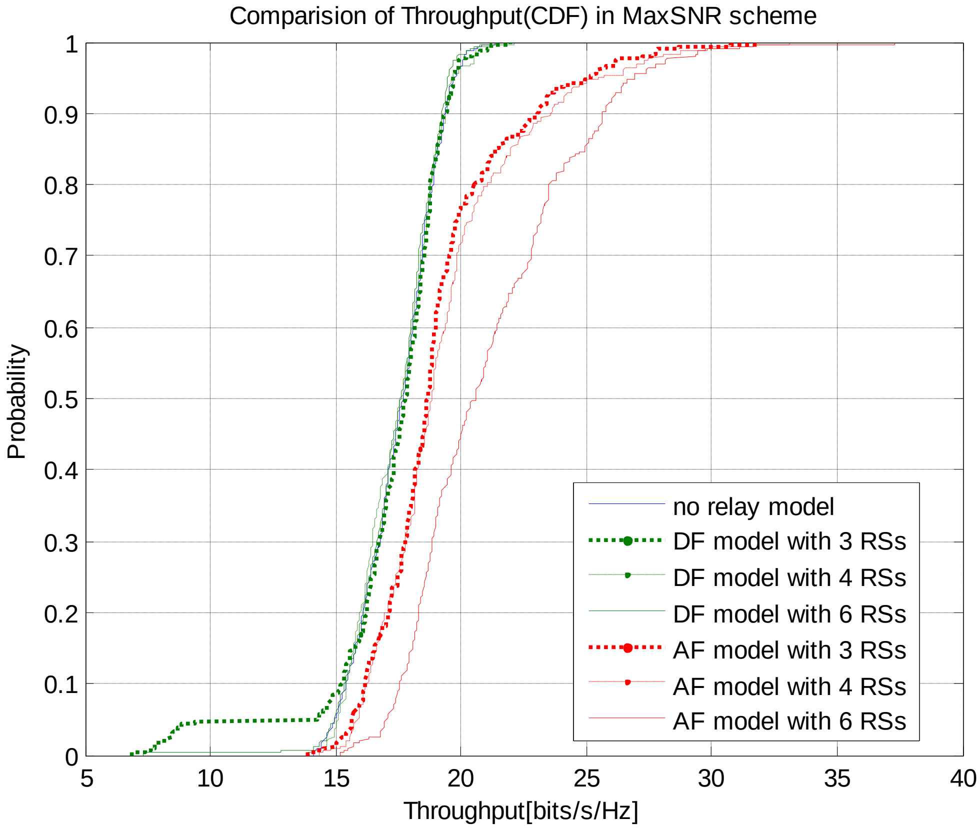


Figure 5.14: Comparison of Throughput (CDF) for 3 relay modes in MaxSNR+RR scheme when the number of relays M=3, 4, 6

Table5.10: Numerical results for M RSs, M=3, 4, 6

Scheduling Scheme	MaxSNR+RR					
Relay mode	DF Mode			AF mode		
Number of Relays	3	4	6	3	4	6
Fairness Factor	0.0797	0.0790	0.07520	0.1510	0.26302	0.4684
Average Packet Delay	7.7274	7.5110	7.3707	4.4825	2.9885	2.4465
Average Throughput	17.255	17.4837	17.422	19.119	19.3884	21.134
Scheduling Scheme	GPF+RR					
Relay mode	DF Mode			AF mode		
Number of Relays	3	4	6	3	4	6
Fairness Factor	0.9874	0.9881	0.9914	0.9862	0.9914	0.9927
Average Packet Delay	0.9287	0.9278	0.9219	0.9279	0.9242	0.9235
Average Throughput	10.214	10.4226	10.1735	11.049	11.130	11.221

As can be seen from Table 5.10 the number of relays has a significant impact on the performance of AF mode in both MaxSNR+RR scheme and GPF+RR scheme. That delay reduction and throughput enhancement is achieved by increasing the number of relays in a single cell, when we only apply one-relay transmission. The more AF relays in the cell, the higher probability of users in AF relay work area will be and the more packets will have chance to be transmitted in higher data rate.

The performances of DF mode in MaxSNR+RR scheme and GPF+RR scheme are not affected too much by the number of relays since DF relay work area is so small that the number of users in its work area is hardly increased obviously with more DF relays are deployed in the cell. But when more users use DF relay for transmission, the interference will lower the average throughput.

5.6 Effect of the Number of Users

We increase the number of users in the cell to 100 to compare the performance for our 3 different modes in 2 different scheduling schemes.

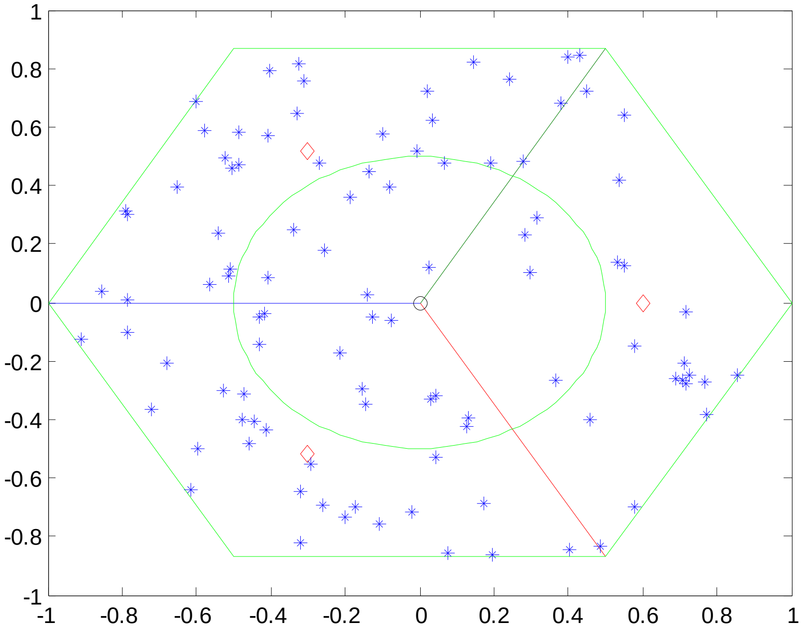


Figure 5.15: 100 User positions and 3 Relay positions in simulated system

Table 5.11 and Table 5.12 present the numerical results when the number of users is 30 and 100, respectively. We investigate the impact of the subscriber density to DF and AF relay performance in two scheduling algorithms.

Table 5.11: Numerical results when the number of users is 30

Scheduling Scheme	MaxSNR+RR			GPF+RR		
Relay mode	No Relay	DF	AF	No Relay	DF	AF
Fairness Factor	0.07186	0.077	0.151	1	0.983	0.984
Average Packet Delay(sec)	7.8651	7.616	4.483	0.91833	0.930	0.930
Average Throughput(bits/s/Hz)	17.5235	17.36	19.12	10.92	10.25	11.37

Table 5.12: Numerical results when the number of users is 100

Scheduling Scheme	MaxSNR+RR			GPF+RR		
Relay mode	No Relay	DF	AF	No Relay	DF	AF
Fairness Factor	0.02626	0.026	0.036	1	0.96	0.97
Average Packet Delay(sec)	9.3655	9.320	8.069	2.75	2.83	2.80
Average Throughput(bits/s/Hz)	22.0564	22.02	22.43	12.804	12.54	12.60

The results indicate that the number of users has some influence on DF mode and AF mode performance in both 2 schemes.

For the simulation of 100 users under MaxSNR+RR scheme, AF mode still performs the best in both average packet delay and average throughput among 3 modes. DF mode shows a little lower average packet delay as it does in the simulation of 30 users to no relay mode and it still performs the worst in average throughput. The performances of 3 relay modes do not change when the number of users is increased from 30 to 100.

As to GPF+RR scheme, when the number of users increased from30 to 100, AF mode and DF mode still provide greater packet delay than no relay mode. The difference is that AF mode does not enhance the average throughput as it does when the number of users is 30. On the contrary, the average throughput of AF mode becomes less than that in no relay mode. DF mode still has the lowest average throughput among three relay modes. The number of users only has some effects on throughput performance for AF mode in GPF+RR scheme.

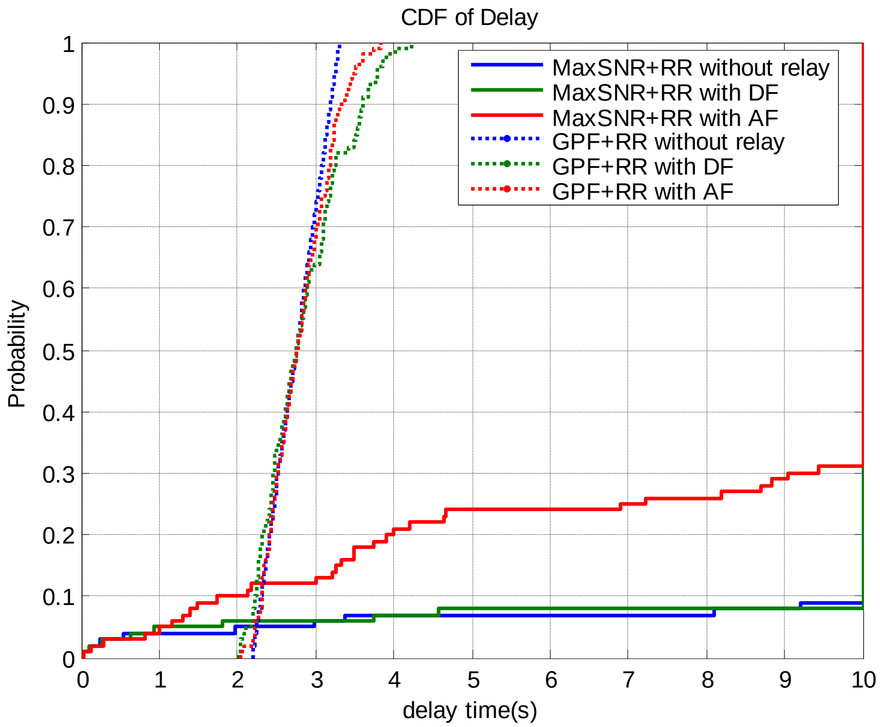


Figure 5.16: Comparisons of Packet Delay (CDF) for 3 relay modes in 2 schemes when the number of users is 100

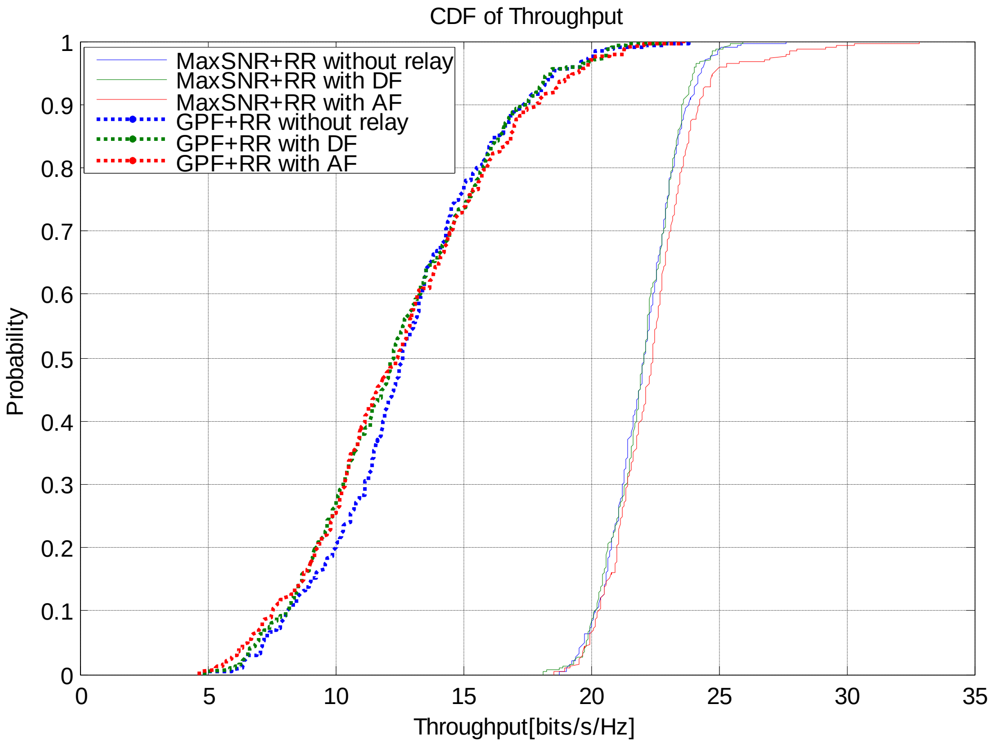


Figure 5.17: Comparisons of Throughput (CDF) for 3 relay modes in 2 schemes when the number of users is 100

5.7 Effect of Relay Position

5.7.1 DF mode in MaxSNR+RR Scheme

DF relay work area is affected by interference factor. High interference in relay transmission link leads to small work area for DF relay and makes few users utilize the DF relays in transmission. We further study the effect of relay position, which is also called BS-RS distance in this thesis, for the DF mode in MaxSNR+RR scheme.

Table 5.13: Numerical results for DF mode in MaxSNR+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km, Threshold Distance=0.5km

Relay Distance(km)	0.1	0.2	0.3	0.4	0.6	0.8
Fairness Factor	0.0784	0.0745	0.0765	0.0848	0.0722	0.0699
Average Packet Delay	8.0227	7.4864	7.7612	7.716	8.037	8.0541
Average Throughput	17.163	17.288	17.281	17.147	17.151	17.252

From Table 5.13, it can be seen that the relay position does not affect the performance of the system. When the threshold distance is fixed, the average packet delay and the average throughput is more or less the same and they do not change too much. We further explore the relationship between threshold distance and DF mode system performance.

Table 5.14: Numerical results for DF mode in MaxSNR+RR scheme when Threshold Distance is 0.3km, 0.4km, 0.5km, 0.6km, 0.7km, 0.8km, BS-RS distance =0.6km

Threshold Distance(km)	0.3	0.4	0.5	0.6	0.7	0.8
Fairness Factor	0.0623	0.0616	0.0707	0.0698	0.0806	0.07922
Average Packet Delay	8.4975	8.3722	8.028	7.9678	6.9141	7.1677
Average Throughput	17.021	17.0182	17.3108	17.4198	17.4491	17.5044

From Table 5.14 it can be seen that threshold distance has no effect on the performance of the system. It can be concluded that neither relay position nor threshold distance has influence on the performance of packet delay or throughput for DF mode in MaxSNR+RR scheme.

5.7.2 AF mode in MaxSNR+RR Scheme

Table 5.15: Simulation results for AF mode in MaxSNR+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

Relay Distance(km)	0.1	0.2	0.3	0.4	0.6	0.8
Fairness Factor	0.69832	0.73855	0.63586	0.48956	0.2488	0.15937
Average User Delay	2.7758	2.0203	1.7008	2.4577	3.0008	4.529
Average Throughput	31.9136	27.4456	24.7823	23.5686	22.3408	21.9617

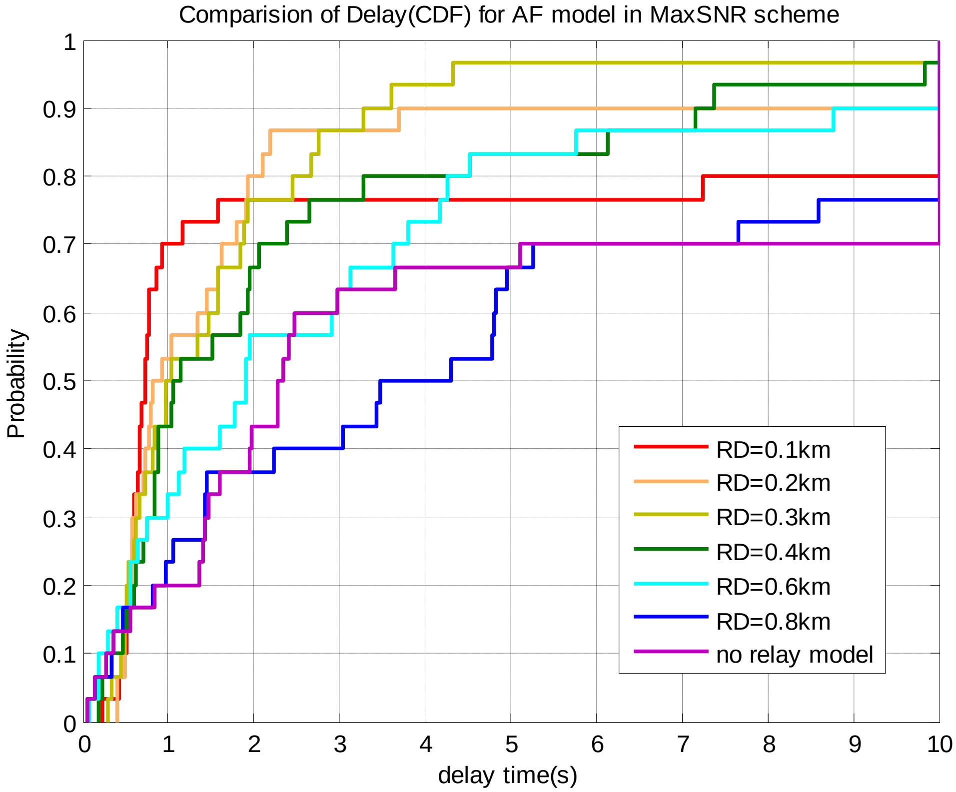


Figure 5.18: Comparison of Packet Delay (CDF) for AF mode in MaxSNR+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

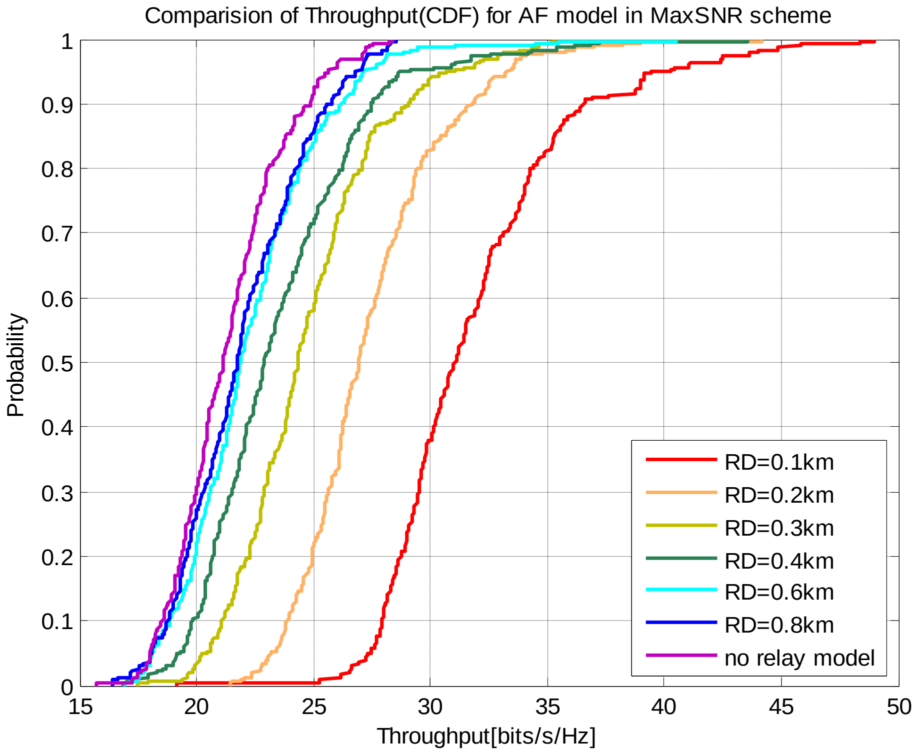


Figure 5.19: Comparison of Throughput (CDF) for AF mode in MaxSNR+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

From the CDF plots for Packet Delay in Figure 5.18, it suggests that the AF relay-assisted MaxSNR+RR scheme system with 0.3km BS-RS distance is clearly better than the other systems with respect to delay outage. Because AF relays with this distance to BS cover more users into its work area. When BS-RS distance is beyond 0.8km, the packet delay performance gets worse than non-relay mode. By looking at Figure 5.19, we see that in MaxSNR+RR scheme, as the distance of BS-RS decreases, the average throughput increases. However, the increase is more dramatic when the distance between the relay station and the base station is small. The shorter the distance between BS and RS, the better SNR we get after the signal amplification in RS. This leads to the increased data rate for transmission.

Table 5.16: AF Relay use time slots (total time slots is 30*10=300) in MaxSNR+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

Relay Distance(km)	0.1	0.2	0.3	0.4	0.6	0.8
RSs use time slots	85 114 99	72 99 98	53 79 87	30 60 65	18 26 21	5 9 7
Use total time slots	298	269	219	155	65	21
Use time slots (%)	99.33	89.67	73.00	51.67	21.67	7.00

As RS use time slots to total time slots ratio shown in Table 5.16, it can be seen that there is significant reduction for relay use time slots at BS-RS distance of 0.4km. Beyond 0.4km, AF relays occasionally are allocated some time slots to transmit packet to subscribers. Thus AF mode will take its advantage to improve system throughput when it is near the BS in MaxSNR+RR scheme.

5.7.3 DF mode in GPF+RR Scheme

Table 5.17: Numerical results for DF mode in GPF+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km, Threshold Distance =0.5km

Relay Distance(km)	0.1	0.2	0.3	0.4	0.6	0.8
Fairness Factor	0.97911	0.98555	0.98039	0.9772	0.98879	0.98749
Average User Delay	0.93814	0.92971	0.93429	0.93622	0.92726	0.92685
Average Throughput	10.3983	10.2182	10.3265	10.3967	10.5856	10.4245

From Table 5.17, it can be seen that the relay position does not affect the performance of the system. We further explore the relationship between threshold distance and DF mode system performance.

Table 5.18: Numerical results for DF mode in GPF+RR scheme when Threshold Distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km,Relay Distance=0.4km

Threshold Distance(km)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Fairness Factor	0.986	0.986	0.971	0.980	0.984	0.993	0.995	0.999	1
Average User Delay	0.926	0.930	0.937	0.933	0.933	0.923	0.922	0.919	0.918
Average Throughput	10.30	10.03	10.11	10.39	10.21	10.48	10.72	10.90	10.93

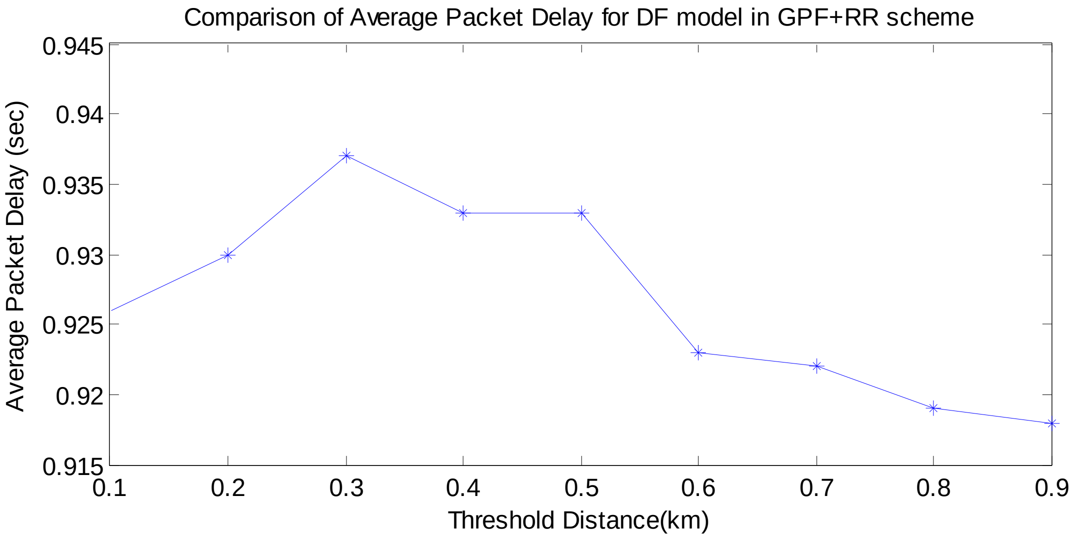


Figure 5.20: Average Packet Delay for DF mode in GPF+RR scheme when Threshold Distance is between 0.1km and 1.0 km, RS-BS distance is 0.3km

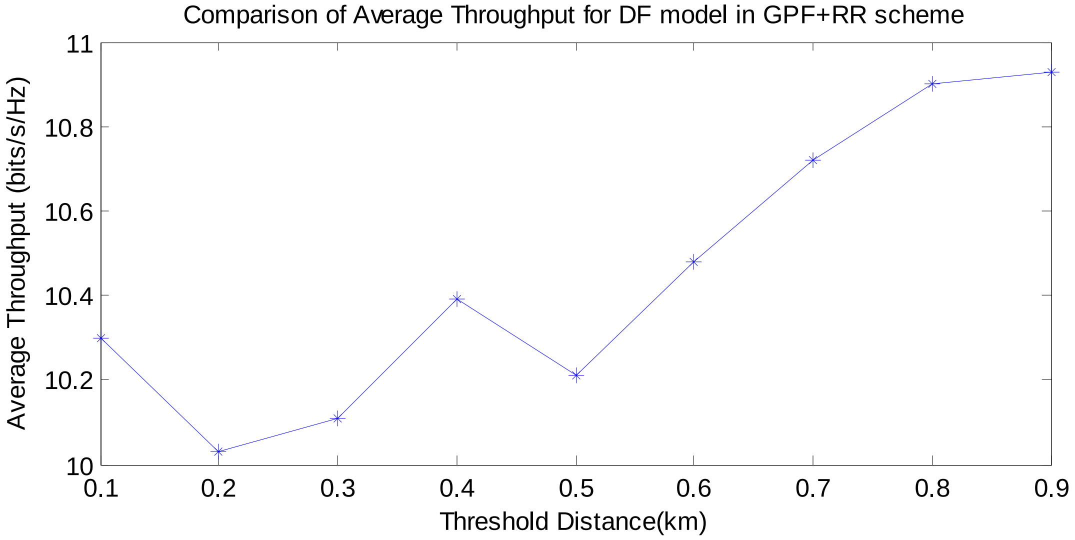


Figure 5.21: Average Throughput for DF mode in GPF+RR scheme when Threshold Distance is between 0.1km and 1.0 km, RS-BS distance is 0.3km

From the plot for average throughput in Figure 5.21 and the numerical results in Table 5.18, the average throughput rises with the increase of threshold distance for DF mode in GPF+RR scheme. When the threshold distance is greater than 0.3km, DF mode will shorten the average packet delay of the system, from 0.937s at 0.3km to 0.918s at 0.9km

(See Figure 5.20). As a conclusion, DF mode is much more suitable for working in the system with large threshold distance in GPF+RR scheme.

5.7.4 AF mode in GPF+RR Scheme

Table 5.19: Numerical results for AF mode in GPF+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

Relay Distance(km)	0.1	0.2	0.3	0.4	0.6	0.8
Fairness Factor	0.99206	0.98814	0.98778	0.98749	0.99075	0.98945
Average User Delay	0.92623	0.92818	0.92851	0.92645	0.92447	0.9233
Average Throughput	15.1848	13.3017	12.9629	12.8719	12.8217	12.5462

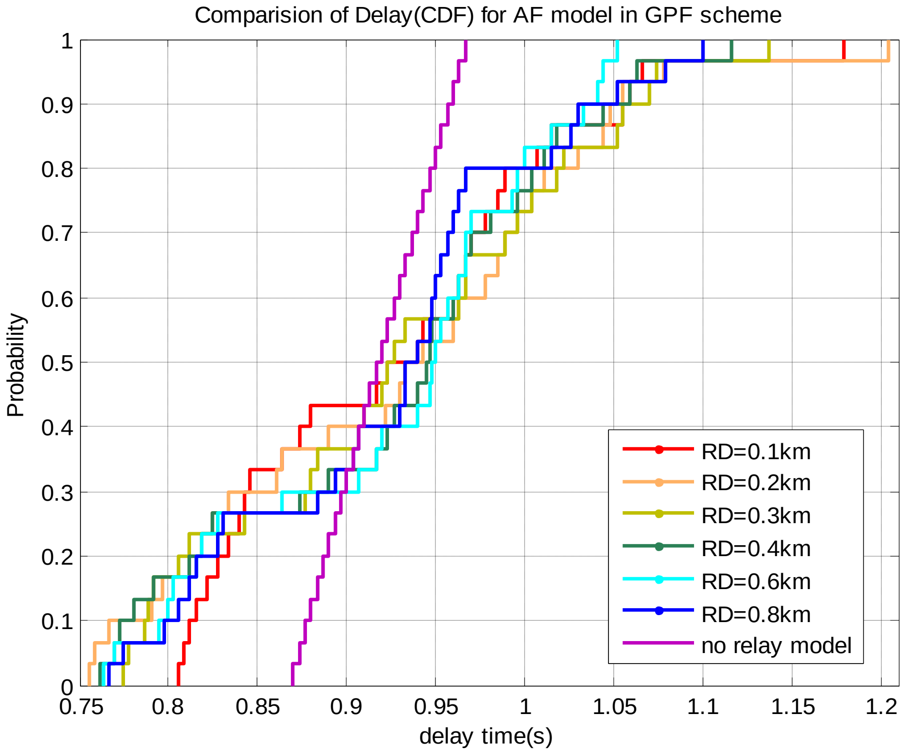


Figure 5.22: Comparison of Packet Delay (CDF) for AF mode in GPF+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

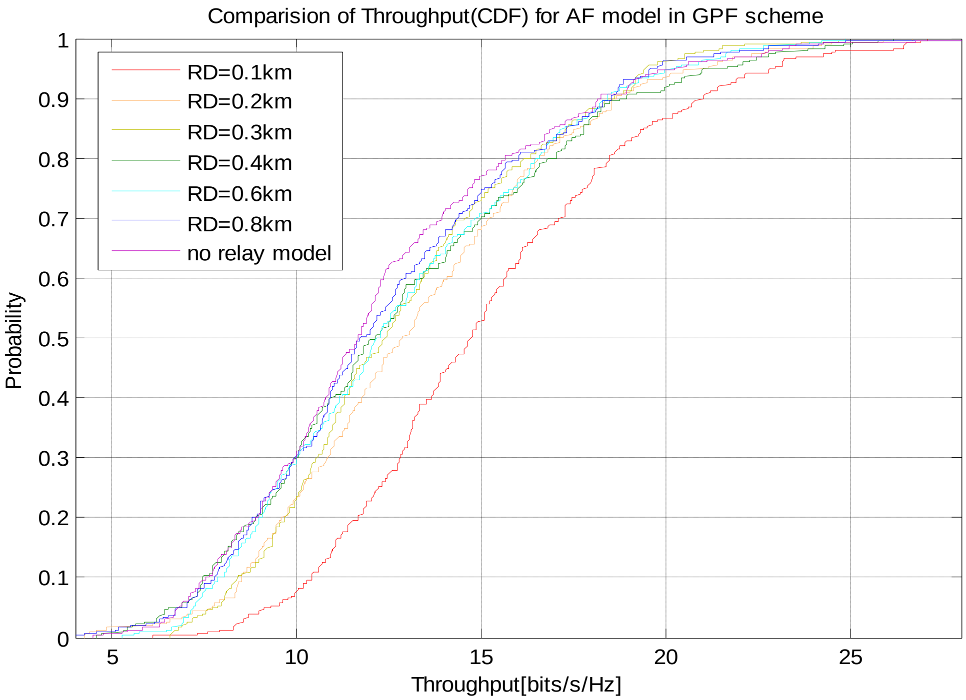


Figure 5.23: Comparison of Throughput (CDF) for AF mode in GPF+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

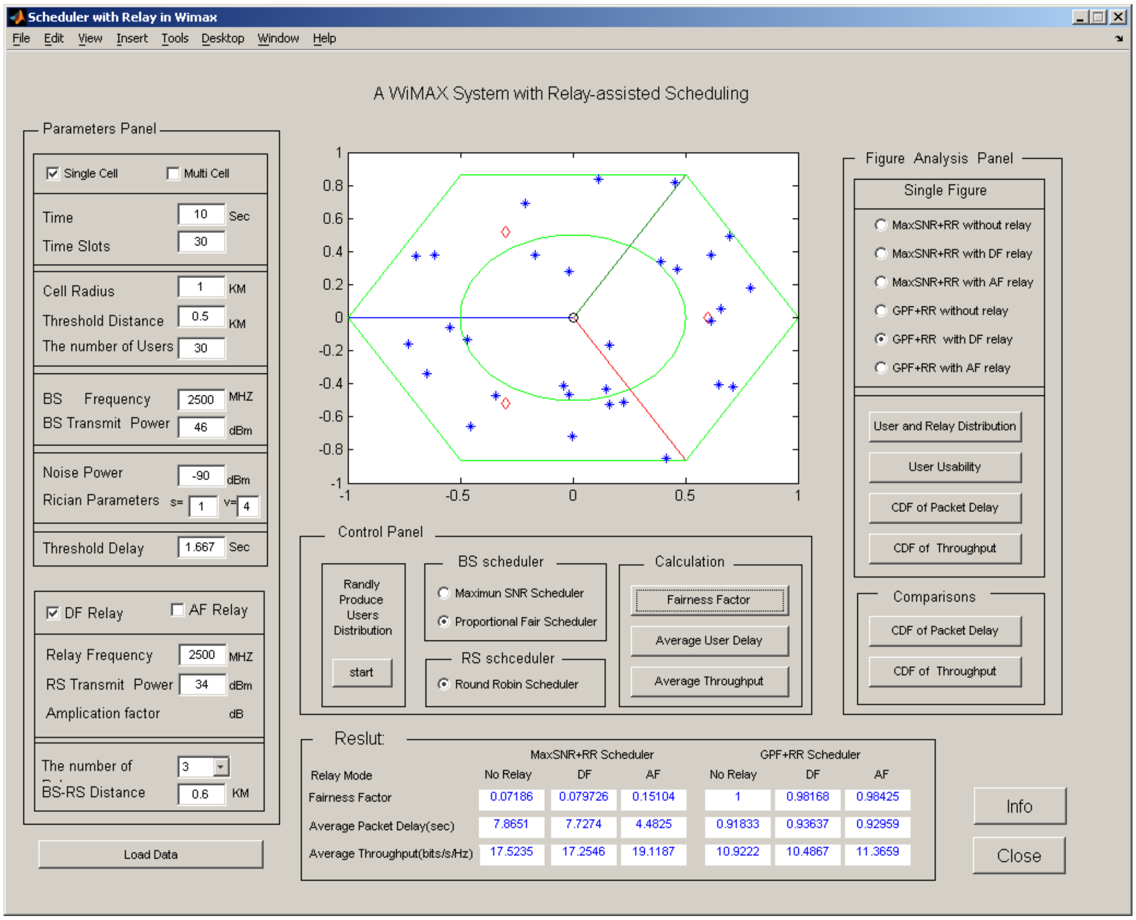
Table 5.20: AF Relay use time slots (total time slots is 30*10=300) in GPF+RR scheme when BS-RS distance is 0.1km, 0.2km, 0.3km, 0.4km, 0.6km, 0.8km

Relay Distance(km)	0.1	0.2	0.3	0.4	0.6	0.8
RSs use time slots	40 58 39	19 29 26	8 28 9	4 14 8	0 10 3	3 7 3
RS use total time slots	137	74	45	26	13	13
RS use time slots (%)	45.67	24.67	15.00	8.67	4.33	4.33

As can be seen from Figure 5.22, Figure 5.23 and Table 5.19, the BS-RS distance has a slight impact on the performance of fairness, packet delay, and throughput and relay use times. It can be clearly seen that the performance of system average packet delay and average throughput are the best when BS-RS distance is 0.1km. Table 5.20 shows that the total relay use times in AF mode decreases as putting RSs far away from the BS in GPF+RR scheme system and it drops very quickly in the first 0.3km.

5.8 Graphical User Interface

In this thesis, we consider a friendly multi-functional, Graphical User Interface (GUI) for exploring and analyzing the effect of different parameters.



Parameters Panel

☑ Single Cell ☐ Multi Cell

Time 10 Sec

Time Slots 30

Cell Radius 1 KM

Threshold Distance 0.5 KM

The number of Users 30

BS Frequency 2500 MHZ

BS Transmit Power 46 dBm

Noise Power -90 dBm

Rician Parameters s= 1 v= 4

Threshold Delay 1.667 Sec

☑ DF Relay ☐ AF Relay

Relay Frequency 2500 MHZ

RS Transmit Power 34 dBm

Amplication factor dB

The number of 3

BS-RS Distance 0.6 KM

BS scheduler: ○ Maximun SNR Scheduler ● Proportional Fair Scheduler

RS schceduler: ● Round Robin Scheduler

Single Figure:
○ MaxSNR+RR without relay
○ MaxSNR+RR with DF relay
○ MaxSNR+RR with AF relay
○ GPF+RR without relay
● GPF+RR with DF relay
○ GPF+RR with AF relay

Reslut:

	MaxSNR+RR Scheduler			GPF+RR Scheduler		
Relay Mode	No Relay	DF	AF	No Relay	DF	AF
Fairness Factor	0.07186	0.079726	0.15104	1	0.98168	0.98425
Average Packet Delay(sec)	7.8651	7.7274	4.4825	0.91833	0.93637	0.92959
Average Throughput(bits/s/Hz)	17.5235	17.2546	19.1187	10.9222	10.4867	11.3659

Figure5.24: Simulation User Interface

Figure 5.24 is the graphical user interface we designed. The graphical user interface consists of four panels and three buttons.

These four panels and three buttons are:

Parameters Panel: Allow users to select simulation models (single/multi-cell), the simulation parameters and relay-assisted modes.

Control Panel: Produce the position of mobile terminals and relay stations. Let the user to choose scheduling schemes for the system and calculate the performance.

Results Panel: Show the performance numerical result in the table.

Figure Analysis Panel: Plot performance figures for different cases in the figure frame.

Load Data Button: Load existing data to run the numerical simulation.

Info Button: Explain how to use this GUI.

Close Button: Close the simulator.

Simulation Steps:

1. Choose single cell or multi-cell environment in Parameters Panel and set parameter values.
2. Choose relay mode (decode-and-forward or amplify-and-forward) if wanted and set relay parameter values.
3. Press the 'start' button in the Control Panel to produce the users’ and relays’ positions.
4. Choose the schedulers for the BS and the RS.
5. Press the button in Calculation Panel to start the simulation.
6. The numerical results will be shown in the Result Panel
7. Observe the corresponding figures for different modes in Figure Analysis Panel.
8. Load Data button can let user load existing data to do comparison and figure analysis.

Chapter 6

6. Conclusion and further work

6.1 Conclusion

The simulation results have shown that DF and AF relays play different roles in a WiMAX system with different scheduling schemes. Without doubt there is a need for relaying in cellular networks due to the improved capacity and shorter delays which can be achieved by the aid of relaying.

For MaxSNR+RR scheme (Base station applies maximum SNR scheduling and relay station applies round robin scheduling), AF mode performs the best in both packet delay and overall throughput among 3 modes. DF mode shows a little lower average packet delay to no relay mode and it gives the worst performance in average throughput.

For GPF+RR scheme (Base station applies generalized proportional fair Scheduling and relay station applies round robin scheduling), AF mode and DF mode provide slightly greater packet delays than no relay mode. AF mode gives the highest average throughput while DF mode has the lowest average throughput among three relay modes.

In terms of relay use times, the DF and AF relays are actually in the opposite situation when they are under MaxSNR+RR scheme and GPF+RR scheme. AF relays have larger total relay use time in MaxSNR+RR scheme and DF relays are used more often in GPF+RR scheme.

It can be concluded that AF relays outperform than DF relays in MaxSNR+RR scheme while DF relays are used more frequently is in GPF+RR scheme.

The number of relays does not affect the performance of DF mode but has a significant impact on AF mode in both MaxSNR+RR scheme and GPF+RR scheme. According to our results, the general rule is: more AF relays for increased throughput and reduced delay. Graphical User Interface could enable network operator to calculate the trade-off between the cost of relay deployment and the efficiency of the relays.

The number of users has some effects only on throughput performance for AF mode in GPF+RR scheme. The average throughput of AF mode is no longer the highest and it becomes less than that in no relay mode when the number of users is increased.

Relay Position has a significant impact on the performance of AF relay-assisted mode in MaxSNR+RR and GPF+RR schemes. Short BS-RS distance makes AF mode perform shorter delay and higher throughput. However, relay position has no effect on the performance of DF mode in these 2 schemes. Only in GPF+RR scheme, the performance of DF mode is slightly affected by threshold distance. Increasing threshold distance reduces the average packet waiting time and enhances average system throughput in GPF+RR schemes.

6.2 Future Work

In the future, the performance of IEEE 802.16j would make an interesting topic for further studies. Relay-assisted scheduling in cellular network is a rather hot concept in wireless communications. This means that there is a lot of research going on and many issues that remain to be solved. We have only focused on some parameters and have seen the effects of those parameters. However there are some issues that could be subject to further studies. All these studies can be extended to a more realistic setup where users in different geographic locations have different path losses.

One promising study could be to assume maximum number of users in sector and size/coverage of the sector, and find a location for RS such that a certain performance level is guaranteed. In addition to GPF, MaxSNR and RR schedulers, it is possible to study, e.g. different proportional fair schedulers.

So far in this thesis we have seen the effects of some parameters, and there are still some other parameters which we neglected for simplifying the system model. A general traffic model is assumed in this thesis. However, the traffic model variation affects the performance of different schemes that we have discussed in different ways. The impact should be investigated. The numerical simulation depends on the perfect CSI. Unreliable channel measurement may result in wrong decisions being made. It is important to study the effects of imperfect CSI, e.g. estimation error and feedback delay.

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