Performance Analysis of Flexible Duplexing using Multi Slope Path loss Models

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Approval

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Abstract

The increasing demand for data traffic can be answered by effective utilization of spectrum through Full Duplexing(FD) Heterogeneous Networks(HetNets).We can achieve better results bys using both Full Duplex and Half Duplex(HD) as Half Duplex gives better results in regions where self interference for FD is higher.We in this paper are presenting distance based duplexing schemes exploiting multi slope path loss models with power control mechanism.Multi slope path loss models captures the effect of environment in better way as compared to single slope path loss models.In our proposed scheme,user will connect to Base Station(BS) based on maximum received power.After connection,the value of critical distance is analyzed after which user can best operate in FD.Open loop power control was implemented for maintaining the fairness of system.Simulated results shows the agreement with assumptions of FD performing better than HD in interference limited models.Results for sum rate & percentage improvement is given for both uplink & downlink.

Dedication

I dedicate this thesis to my parents.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

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Acknowledgment

I would like to thank my advisor & my friends.

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Chapter 1

Introduction

Mobile connection in the world are increasing at greater rate.According to industry experts, growth in traffic volume will increase by 1000X by the end of 2020.The surging demands for connectivity provides opportunities as well as network operators will also face unprecedented risk.Users require qulality and reliability from network operator.Network operators are trying hard to meet this requirements by increasing network coverage and capacity but with limited resources.Mobile operators in the world are investing heavily on faster 4G infrastructures.LTE 4G is delivering quantum gains.But this is not enough to meet demands.Traditional macro cells build outs are not able to scale profitably for meeting these demands.Networks operators have to find new and efficient ways of increasing capacity,coverage and quality by reducing cost requirements.

We can meet these demands by either adding more spectrum to the system or using current spectrum efficiently.The latter can be addressed using radio link & by through network evolution towards small cells.For the increasing demand for data rate & effective usage of available spectrum communication networks have to move towards radio link techniques such as Full Duplex Communication.Full Duplex Communication systems are emerging as attractive solutions for answering spectral efficiency problems.Full Duplex systems theoretically doubles the capacity of system by using same resource for signal transmission and reception.

One emerging strategy that can be for meeting such demand and for minimizing the cost/capacity gap is to provide Full Duplex Based Heterogeneous access networks.

This chapter presents a brief introduction of Heterogeneous Networks & Full Duplex Schemes in Heterogeneous Networks.After this contribution is presented and then thesis organization concludes this chapter.

1.1 Heterogeneous Networks

Heterogeneous Networks have already been proven to provide higher data rates User demands high data rates with low latency.The increasing demands of data rates can be addressed by deploying Heterogeneous Networks.In Heterogeneous Networks we deploy small cells.This improves capacity as well as coverage of a network.Heterogeneous Network brings network close to the user.Heterogeneous Networks offloads traffic from macrobase station by shifting load to small cells(femto cells,pico cells,micro cells).According to analysts around 11 million small cells will be in use by the end of 2018.

1.1.1 What is HetNet

The capacity of network can be increased by deploying small cells.Small cells can be used effectively for meeting user demands.They can be used for providing coverage to area left by macro network. Network performance and service quality can be improved by balancing the load of macro cells.Load sharing schemes are used for small cells. These features results in increased bit rates per unit area in a heterogeneous network in which large macro-cells are used in combination with small cells. Cells in Heterogeneous Networks differ from each other on the basis of size and are called macro-, micro-, pico- and femto-cells.Macro base station have highest base station power while femto cells have least base station powers. The actual size of cell dependson the following factors:

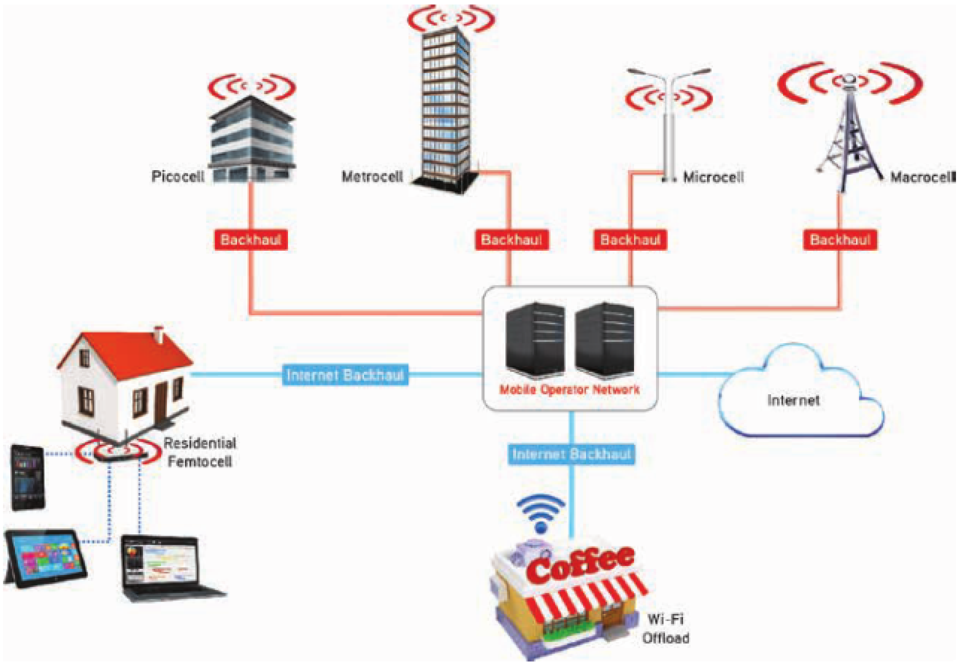


Figure 1.1: Heterogeneous Network

- eNB power
- antenna position
- location environment; e.g. rural or city, indoor or outdoor .

The HeNB (Home eNB) was introduced in LTE Release 9 (R9).

1.1.2 Why moving to Heterogeneous Networks

- Installation of Base station in a dense area is a challenging task.Base Station needs to be placed where maximum users can benefit.
- User at cell edge shows limited performance due to higher interference

level and low received power.

- Reduced in power consumption in Heterogeneous Networks.Both base station and user will be operating at low power levels.
- Reduced installation as well as maintenance cost.

1.1.3 Benefits of Heterogeneous Networks

Heterogeneous Networks provide following benefits:

- Spectrum reuse
- Better coverage and capacity
- Improved Performance

1.2 Full Duplex Communication Networks

Currently wirelss communication systems are performing bi directional communication using separate resource for uplink and downlink.Most commonly used duplexing schemes are Frequency Division Duplexing (FDD) & Time Division Duplexing(TDD).

In Frequency division duplexing, two different frequencies are used for uplink and downlink that are isolated with each other.With this technique both nodes share information at same time between each other by using different frequencies.This prevents interference between two nodes because both frequencies are spatially isolated.4G Long Term Evolution (LTE) uses FDD.The use of two frequencies s cost inefficient as network operators have to buy license for both uplink and downlink frequency.In Time Division Duplexing two nodes communicate with each other using same frequency but in different time slots.Interference is avoided by using separate time slots for uplink and downlink.Communication using TDD is not simultaneous and hence is known as half duplexing.Wireless Local Area Networks (WLAN 802.11) uses TDD.

Problems in TDD and FDD can be addressed using Full Duplex technology.Full Duplex technology is appearing as future of next generation networks due to its distinguished features.In Full Duplex(FD) ,both nodes can communicate with each other at a time using same frequency.Using same frequency resource for uplink and downlink causes self interference problems. Simultaneous and reception are deemed unfeasible until recently due to self interference problems.But now there are self interference cancellation schemes which are making FD radio's a reality.

1.2.1 Features of Full Duplex Communication

Features of FD technology include theoretically doubling the capacity of the network ref [4, 29], reducing feedback delay [31], decreasing end-to-end delay [27], improving secrecy of network [62], & increasing the efficiency of higher layers network protocols [5], in addition to the possibility of merging FD technology with other proposed solutions to accomplish significant improvements in the performance of wireless networks.

1.3 Distance Based Full Duplex Schemes

In Distance based full Duplex schemes,user connects with base station having greater received power.After initial connection,user operates in Full Duplex mode based on critical distance set by operator.If user lies within the radius of critical distance it will operate in full duplex mode.Other wise user will operate in half duplex mode.

1.4 Thesis Contribution

Hybrid Duplexing Scheme with multi slope path loss model is presented in this thesis.Both user and base station are half duplex & full duplex capable.Key contributions are:

- Values of Critical Distance is analyzed after which user can best operate in full duplex mode.
- Sum rate is optimized by minimizing interference.

1.5 Thesis Organization

The rest of the thesis is organized as follows: Chapter 2 presents the existing literature on Full Duplex communication & Heterogeneous Networks. In chapter 3, system is presented.Chapter 4 will have results and chapter 5 have conclusion & future directions.

Chapter 2

Literature Review

This chapter presents the literature review for Heterogeneous Networks,Full Duplex Communication and Hybrid Duplexing in Heterogeneous Networks.It will also discuss these with models having dual slope path loss models.

2.1 Heterogeneous Networks

Network operators are exploiting the concept of heterogeneity for meeting ever increasing traffic demands.In this small cells are deployed having different transmit powers.ref [13, 33, 47, 51, 56] Macro only systems were expensive & difficult to deploy due to large power requirements for transmission.There was also restriction on choosing location for installation as macro base stations needs to installed at place where maximum area can be covered.Flexible & economic deployment can be achieved using Heterogeneous-networks (HetNets) [12].Coverage dead zones are created with macro base stations.These dead zones are covered with the help of small cells.Small cells are also used for alleviating traffic hot zones [19].Small cells gives us wider coverage area.Authors in [59] proposed Reverse Frequency Allocation for better spectrum utilization & interference avoidance.The performance of device to device (D2D) cooperative heterogeneous was analyzed by [55].They proposed strategy for enhancing coverage to macro cells by utilizing idle femto cells.Authors in [58] showed that coverage probability of femto user can be enhanced by dividing coverage area into multiple regions.Femto user equipment on cell edge suffers greatly from interference which can degrade networks performance.Authors in [37] gave game theory based optimal resource allocation schemes for such femto cells that are at the edge of macro cell.Authors optimized the networks resources for improving sum rate & maximizing the energy efficiency in [38].The performance of system also showed improvement with power control mechanism.The performance of Heterogeneous Networks was enhanced when Macro stations used massive MIMO with small cells operating on mm Wave. [54].

The reduced distance between transmitter and receiver enhances the radio link quality, and.Efficient spectrum reuse can be achieved by using larger number of cells which reults in larger data rates. [36].The system capacity of a wireless link can be improved by bringing the transmitter and receiver closer to each other.We can also achieve higher link quality and better spectrum reuse by bringing the transmitter and receiver closer. [9].

Significant technical issues and substantial challenges arise along with the attraction of HetNets [36].The sum-rate of the network can be increased by delpoying small cells .But interference and centralized control in such a scenerio becomes a challenging issue. [9].Authors in [24] gave scheme for mitigating the effect of interference by efficient utilization of resources. The key technical challenges faced by HetNets are Self-organization, backhauling, handover, and interference . [36].

Mobile traffic has reached 1,000 petabytes per month according to research study carried by Mobile Experts, Cisco VNI and Ericsson. [7].Mobile Networks are being upgraded based on Long term Evolution(LTE) which promises higher spectrum efficiency.LTE was introduced in release 8 of 3GPP. Heterogeneous Networks are being employed in parallel with LTE due to better throughput and efficiency.By Deploying HetNets, LTE is delivering maximum peak down link rate of 300 Mbps.LTE is providing 15 bits/s/Hz. [7].

In LTE HetNets uplink and downlink uses different resource blocks.This causes inefficient utilization of spectrum.Full Duplex exploits this by providing single resource block for uplink and downlink.

2.2 Full Duplex Communication

In full duple (FD) communication nodes communicate with each other using same frequency band.This doubles the spectral efficiency of communication system measured by number of information bits per second per Hz. [45].Research achievements regarding implementation of Full Duplex in practical system have been proposed in ref [11, 16].In [28], some devices are proposed which are FD capable.Theoratically FD systems are supposed to provide twice the capacity gains than that of Half Duplex(HD) systems.In reality Full duplex systems are unable to provide double capacity gains due to the self interference problems.Self Interference(SI) is caused due the use of same resource block for both uplink and downlinkref [22, 43]. The performance of FD systems suffer from SI.Large SI causes capacity of FD to fall below HD [50]. Self interference cancellation will be key to the implementation of FD system ref [2, 3, 41].SI is main hurdle in implementing FD.To remove this hurdle,various SI cancellation schemes have been studied in ref [10, 11, 17, 41, 42].Techniques used for mitigating the effect of self interference are i.e,passive suppression [43] and digital or analog cancellation.ref [11, 17]

Full Duplex gives better results in terms of throughput and lower outage probability but at the cost of increased implemenatation complexityref [32, 44].Half Duplex is suitable for implementation in less complex scenarios [48].The study regarding achievable throughput and capacity of FD as compared to HD is given in ref [8, 11, 26, 46].FD always gives better performance if self interference can be made less than noise.But HD performs better in scenarios where SI is higher due to smaller value of SINR [44].

In some cases where SI has greater influence HD can perform better than FD.In such cases hybrid HD/FD scheme can be used [61].

2.3 Hybrid Duplexing Heterogeneous Networks

FD-enabled HCNs have been recently attracting growing interest [30].Mathematical expressions were derived for finding the throughput of heterogeneous networks capable of operating in both HD & FD.Heterogeneous Network is composed of K-tiers , with Base Stations operating in each tier with differen trasnmit powers.Base stations can operate in FD mode or in downlink HD mode.with the advancement in FD communication,idea of hybrid duplexing heterogeneous network was presented in [34].The rate coverage probability for a downlink user is derived in [52].Small cell network having same transmit power with massive MIMO wireless backhauls was used for derivation [52].Previously interference mitigation schemes were designed for macro cells.Authors in [21] presented Full duplex assisted cross-tier inter-cell interference (ICI) mitigation scheme called fICIC, which operates on small cells.The performance of FD degards in the cases where self interference is higher. The closed-form expression was derived for finding the critical value of the self-interference attenuation power.After this critical value FD users outperform HD users in hybrid scenarios where all Base Stations(BSs) operated in FD mode [6].The effect of FD cells on the performance of the mixed system was presented in [20] for a single tier network in which BSs in small cells can operate in either FD or HD with users operating in HD. Analysis was carried out without considering an interference coordination scheme .

2.3.1 Distance Based Hybrid Duplexing Scheme

A novel hybrid-duplexing scheme based on distance for heterogeneous networks (HetNets) was presented in [53].Each user is operating in hybrid mode.User can choose between half or full duplex mode based on the maximum received power.Rates & coverage probability were derived for this schmes in [53].

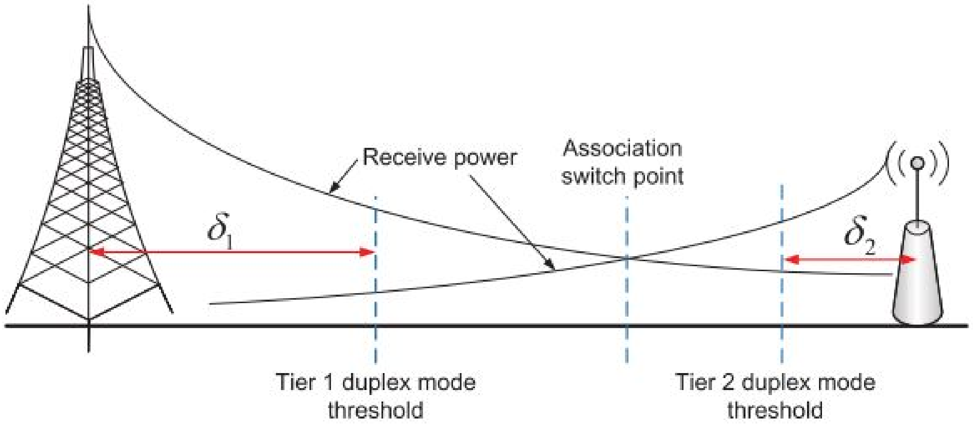


Figure 2.1: Distance Based Duplexing Scheme

2.4 Multi slope path loss models

Performance analysis of cellular networks, especially the ones using optimization theory uses single-slope path loss model for characterizing the propagation environment [15].Analysis with standard path loss models is easy but they cannot characterize all the links in a cell with a single path loss exponent (PLE) correctly.Single path loss models lacks precision in urban areas wher environment is dense [35].Single slope based models are unable to capture the dependence of the PLE on the link distance perfectly.This degrades with performance of network [25].Authors in [60] derived the Coverage probability and network throughput for downlink of cellular network by using multi-slope path loss model. Authors in [14] presented the comparison of their proposed path loss models with standard single path loss models.Authors incorporated both line-of-sight (LoS) and non line-of-sight (NLoS) transmission in their path loss model. They also calculated coverage probability with varying small cell densities using dual slope path loss model. They extended this work for finding the effect on association in HetNets using dual-slope path loss.The performance of resource allocation technique in a HetNet with dual slope path loss models was analyzed in [40].Network performance showed improvement when dual slope path loss was used. [39].

2.5 Power Control

Power control has very important role in HetNets for providing equal power to cell edge users.Long Term Evolution (LTE)improves systems performance by using power control mechanism.They improve performance by adjusting the transmission power [1].Power allocation can be device specific and it also can vary from cell to cell [57].Power control is the key system design features for proposing new wireless standards [18]. The LTE power control mechanism can be open ,closed or fractional. The open loop component uses the fractional power control algorithm to compensate For compensating the path loss and shadowing,open loop power control mechanism uses fractional power control algorithm.In fractional power control algorithm,value of alpha plays important role. The systems performance can be improved by compensating the fast variations of system using closed loop power control.The closed loop power control uses conventional closed loop algorithms for compensating these variations. ref [23, 49].

Chapter 3

Implementation

3.1 System Model

A single cell two tier HetNet with BS locations of tier $k(k = 1, 2)$ are distributed as an independent homogeneous PPP Φ_k having density λ_k. Small cell access points are overlaid on a macrocell. Let $\mathbf{B} = \{1, 2, \cdots, B\}$ be the set of BSs and $\mathbf{U} = \{1, 2, \cdots, U\}$ be the set of users. The location of users also follow an independent PPP Φ_u with density λ_u. The system bandwidth, B, is divided among BSs in such a way that each BS has $K = \{1, 2, \cdots, K_B\}$ subcarriers available, where K_B is the number of users connected with specific BS. So that users connected with particular BS do not interfere with each other as they are allocated orthogonal bands. The same bandwidth B is also allocated to rest of all BSs which introduces cross-tier interference between small and macro cell users. Taking imperfect SIC, the residual self-interference (RSI) of the BSs in two tiers and that of users are denoted by

$\{RSI_k\}_{k=\{1,2\}}$ and RSI_u, respectively.

Small scale fading is assumed to be Rayleigh distribution with dual slope path loss model. The channel between B^{th} BS and U^{th} user on C^{th} subcarrier is denoted by $h_{BU}[c]$, where as the distance between them is denoted by d_{BU}. Every BS of tier k has the same transmit power $\{P_k\}_{k=\{1,2\}}$, while the transmit power of user is P_u. The path loss is taken as $P_L(d) = d^{-\alpha_{t,r}}$, where d be the distance between transmitter and receiver pair, and $\alpha_{t,r} > 2$ is the path loss exponent between the transmitter t and receiver r.

Defining BS set as $\mathbf{B} = \{1, 2, \cdots, B\} = \bigcup\{M_{Bi}, S_{Bi}\}$ we can write $\mathbf{B} = \{M_B, S_{B1}, S_{B2}, \cdots, S_{Bs}\}$, where M_B, S_{Bi} are macro and small cells BSs respectively. A user is connected to a BS that provide maximum downlink received signal power, that is;

$$U_B = argmax \left\{ \bigcup_{\mathbf{B}} P_B d_B^{-\alpha_{i\{B,u\}}} h_{BU} \right\}, i = 1, 2 \tag{3.1}$$

After BS association, users are assigned duplexing based on distance from the BS. If the distance between a user and its serving BS is less than $\gamma_{d_{th}}$, the user and BS communicate using half-duplex mode, while if it is greater than $\gamma_{d_{th}}$ than full-duplex mode will be used.

$$U_x = \begin{cases} HD, & d_{BU} \leq \gamma_{d_{th}} \\ FD, & otherwise \end{cases} \tag{3.2}$$

The reason behind such a duplex mode selection policy is that, with imperfect SIC, the full-duplex SINR of a user may be worse than the half-duplex one. Hence, it may not be suitable for the cell edge users to use full-duplex. Besides, considering a distance measure to determine the duplex mode can also reflect the user SINR performance, since the small-scale fading could be averaged and the path loss is the main factor influencing the SINR in long term.

A pictorial view of system model is given in figure 3.1.

The SINR of a typical user can be expressed as;

$$SINR_{c,DL}^{HD} = \frac{P_k h_{BU}[c] \left(d_{BU}\right)^{-\alpha^{B}_{x\{B,U\}}}}{\sigma^2 + \sum_k I_c} \tag{3.3}$$

$$SINR_{c,UL}^{HD} = \frac{P_u h_{UB}[c] \left(d_{UB}\right)^{-\alpha^{U}_{x\{U,B\}}}}{\sigma^2 + \sum_k I_c} \tag{3.4}$$

$$SINR_{c,DL}^{FD} = \frac{P_k h_{BU}[c] \left(d_{BU}\right)^{-\alpha^{B}_{x\{B,U\}}}}{\sigma^2 + RSI_u + \sum_k I_c} \tag{3.5}$$

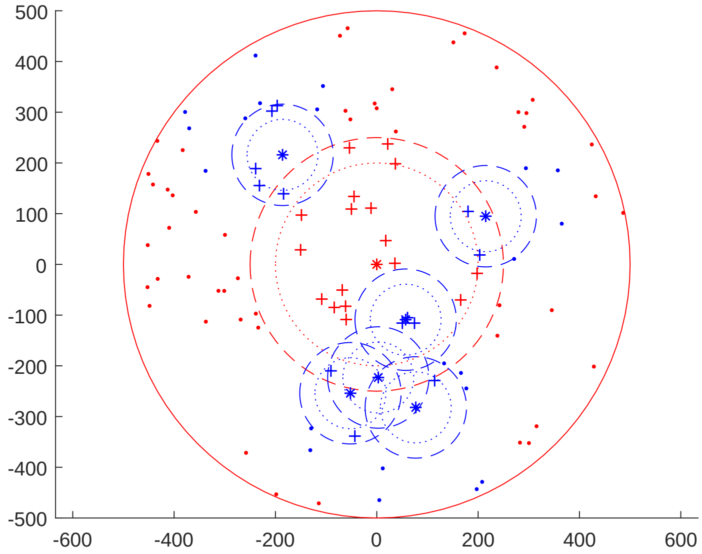


Figure 3.1: HetNet with asterisk represent BS, . represent HD users, + sign FD Users, Red for Macro, Blue for Small. Dotted circle represent dual path loss exponent value change and dashed circle represent duplex threshold distance.

$$SINR_{c,UL}^{FD} = \frac{P_u h_{UB}[c] \left(d_{UB}\right)^{-\alpha_{x\{U,B\}}^{U}}}{\sigma^2 + RSI_{+} \sum_k I_c} \tag{3.6}$$

where d_{BU} is same as d_{UB} and denotes distance between BS and user, $\alpha_{x\{B,U\}}^{B}$ represent dual slope path loss exponent between BS and user in downlink, $\alpha_{x\{U,B\}}^{U}$ represent dual slope path loss exponent between BS and user in uplink, I_c is the cumulative interference on C^{th} subcarrier, and σ^2 is the noise power. These cumulative interferences can be expressed as:

$$I_c = \sum_{u \in \mathbf{U}[\mathbf{c}] \setminus u_0} \left(P_u h_{uu} d_{uu}^{-\alpha_{x\{u,u\}}^{u}} \right) \tag{3.7}$$

where $\mathbf{U}[\mathbf{c}]$ are the users that are assigned same resource, u_o is the intended test user, $\alpha^{u}_{x\{u,u\}}$ is the user-to-user dual slope path loss exponent, and d_{uu} is the distance between users.

3.1.1 Radio Resource Allocation

Interference minimization is one of the key concerns in designing wireless networks. Scheme used in this piece of work is based on minimizing sum power of intra-subcarrier bands allocated to group of users. Which can be further explained as, a user is allocated subcarrier such that it contribute minimum interference within subcarrier. This interference level is determined based on received signal power from a typical user on a test user.

$$U_c = argmin \left\{ \bigcup_{i \in \mathbf{U} \setminus U_c} \sum_{j \in S_C} P_{U,j} \right\} \tag{3.8}$$

where U_c is allocated subcarrier to user, S_C is the set of subcarrier and $P_{U,j}$ is the received signal power from intended user to user with j^{th} subcarrier.

3.1.2 Path Loss Models

Single slope path loss model can be expressed as;

$$L(d)[dB] = 20log_{10}\left(\frac{4\pi}{\lambda_c}\right) + 10\alpha\log(d) + \zeta \tag{3.9}$$

where λ_c represents carrier wavelength, ζ is Gaussian random variable, α is pah loss exponent.

This model captures alot of path losses as experienced by signal while travelling through a distance d,but gets inaccurate for practical modelling of the system when it comes to accurately capture the wireless environment. So these limitation have given rise to analyse and use multi slope path loss models.

The general form of dual slope path loss model can be expressed as;

$$L(d)[dB] = \begin{cases} \beta + 10\alpha_1 \log_{10}(d) + \zeta & d \le r_c \\ \beta + 10\alpha_1 \log_{10}(r_c) + 10\alpha_2 \log(d/r_c) + \zeta & d > r_c \end{cases} \tag{3.10}$$

where r_c is the critical distance, α_1 and α_2 are path loss exponents and their value is greater than 2, d is the distance in meters and β denotes floating intercept.

3.2 Simulation Setup

In this section simulation setup and corresponding results are shown. One macrocell with radius of 500 meters is placed at the origin of coordinate system, and 6 small BS are distributed using PPP within this macro cell. 100 users are also distributed using PPP within this area. details of parameters are tabulated below:

Macro BS Parameters:

No. of Macro BS	01
Tx Power of Macro	46dBm
Macro cell Far Field Distance	01 meters
Radius of Macro cell	500 meters
Dual Path loss threshold	200 meters
Path loss exponent values	[2.5 3]

Small BS Parameters:

No. of Small BS	06
Tx Power of Small	30 dBm
Small cell Far Field Distance	0.4 meters
Radius of small cell	200 meters
Dual Path loss threshold	70 meters
Path loss exponent values	[2.7 3.2]

Users Parameters:

No. of Users	100
Tx Power	23 dBm
User Far Field Distance	0.2 meters
Dual Path loss threshold	50 meters
Path loss exponent values	[2.5 3]
No. of UL/DL Users	Uniformly distributed
No. of FD/HD Users	see equation 3.2

Network Parameters:

Operating Frequency	2.4 GHz
Noise Power	-174 dBm/Hz
Residual Self Interference	-75 dB

3.3 SINR Distribution

The SINR distribution of half/ full-duplex users are defined as

$$D^{HD}_{c,DL}(\eta) \triangleq \mathbb{P}(SINR^{HD}_{c,DL} > \eta) \tag{3.11}$$

$$D^{HD}_{c,UL}(\eta) \triangleq \mathbb{P}(SINR^{HD}_{c,UL} > \eta) \tag{3.12}$$

$$D^{FD}_{c,DL}(\eta) \triangleq \mathbb{P}(SINR^{HD}_{c,DL} > \eta) \tag{3.13}$$

$$D^{FD}_{c,UL}(\eta) \triangleq \mathbb{P}(SINR^{HD}_{c,UL} > \eta) \tag{3.14}$$

where $D^{HD}_{c,DL}(\eta)$ and $D^{HD}_{c,UL}(\eta)$ are the downlink and uplink SINR distribution of the half-duplex users in subcarrier c, respectively. Similarly the downlink and uplink SINR distribution of full-duplex users with subcarrier c are denoted by $D^{FD}_{c,DL}(\eta)$ and $D^{FD}_{c,UL}(\eta)$, respectively. $\mathbb{P}(X)$ denotes the probability that event X happens, and η is the SINR threshold.

3.4 Achievable Rates

Downlink and uplink rates for half and full-duplex systems are given as

$$R^{HD}_{c,DL} \triangleq \mathbb{E}\left[\frac{B}{N^k_c}\log(1 + D^{HD}_{c,DL}(\eta))\right] \tag{3.15}$$

$$R^{HD}_{c,UL} \triangleq \mathbb{E}\left[\frac{B}{N^k_c}\log(1 + D^{HD}_{c,UL}(\eta))\right] \tag{3.16}$$

$$R^{FD}_{c,DL} \triangleq \mathbb{E}\left[\frac{B}{N^k_c}\log(1 + D^{FD}_{c,DL}(\eta))\right] \tag{3.17}$$

$$R^{FD}_{c,UL} \triangleq \mathbb{E}\left[\frac{B}{N^k_c}\log(1 + D^{FD}_{c,UL}(\eta))\right] \tag{3.18}$$

where $R^{HD}_{c,DL}$ and $R^{HD}_{c,UL}$ are the downlink and uplink rates of the half-duplex users in subcarrier c, respectively. Similarly the downlink and uplink SINR distribution of full-duplex users with subcarrier c are denoted by $R^{FD}_{c,DL}$ and $R^{FD}_{c,UL}$, respectively. B is the system bandwidth while N^k_c denotes number of users connected that are using subcarrier c in all BS of tier k. $\mathbb{E}[\mathbb{X}]$ denotes the expected value of event X.

3.5 Power Control

According to 3GPP specification, UE transmit power can be given as:

$$P = \min\{P_{max}, 10\log_{10} M + P_0 + \alpha PL + \delta_{mcs} + f(\Delta_i)\}[dBm] \tag{3.19}$$

where:

- P_{max} is the maximum allowed transmit power.
- M is the number of physical resource blocks(PRB).
- P_0 is the cell/UE specific parameter. In this work, P_0 is assumed cell specific.
- α is the path loss compensation factor. Its range is [0 1].
- PL is the downlink path loss estimate. It is calculated in the UE based on pilot signal received power.
- δ_{mcs} is the cell/UE specific modulation and coding scheme defined in 3GPP.

- $f(\Delta_i)$ is UE specific closed loop iteration power adjustment value.

P_0 is calculated as:

$$P_0 = \alpha(SNR_0 + P_n) + (1 - \alpha)(P_{max} - 10\log_{10} M_0)[dBm] \tag{3.20}$$

where

- SNR_0 is the open loop SNR target.
- P_n is the noise power per PRB.
- M_0 defines the number of PRBs for which the SNR target is reached with full power.

3.5.1 Open Loop Power Control

In case of open loop power control methodology, Equation 3.19 becomes;

$$P = \min\{P_{max}, P_0 + \alpha PL\}[dBm] \tag{3.21}$$

and

$$P_0 = \alpha(SNR_0 + P_n) + (1 - \alpha)(P_{max})[dBm] \tag{3.22}$$

where $M = 1$ is assumed. Here α is accountable for compensation due to path loss. Taking $\alpha = 0$ will result in no power control, will full conventional full power control can be achieved by setting $\alpha = 1$. Values in between 0 and 1 gives fractional power control. 3GPP specifics follwoing values, α=[0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1].

Block diagram in Figure 3 gives steps involved in setting UL UE power using open loop control.

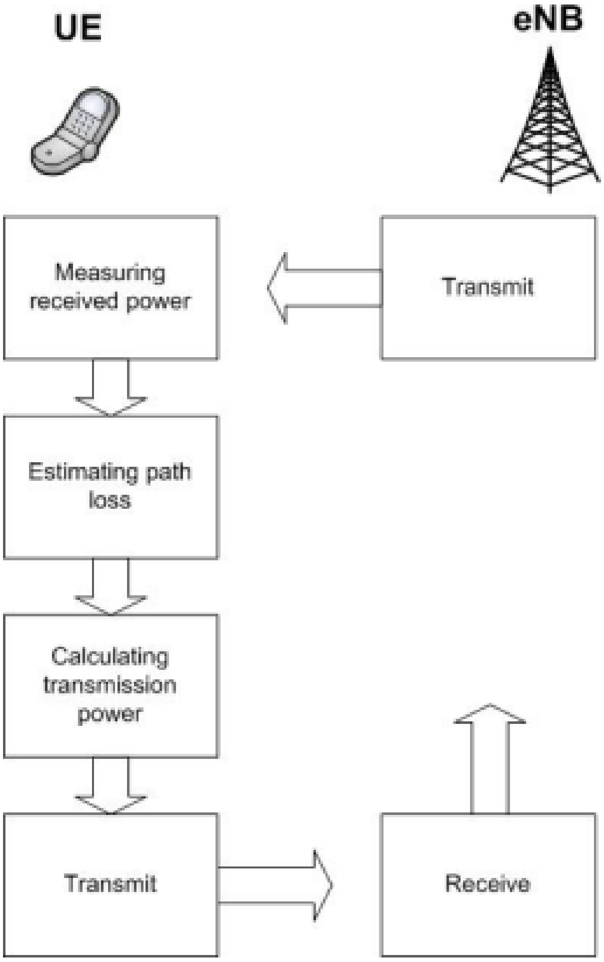


Figure 3.2: Block diagram for methodology for Open Loop Power Control in UL Channel.

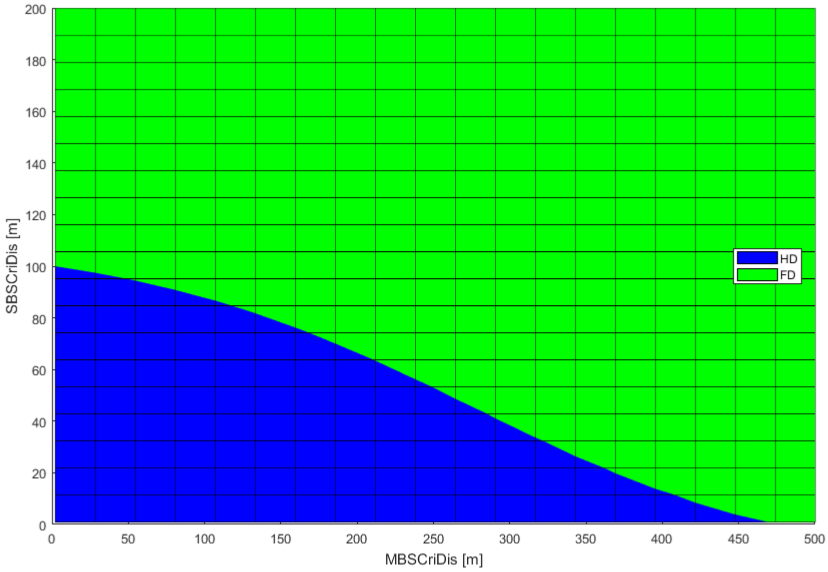
Chapter 4

Results and Analysis

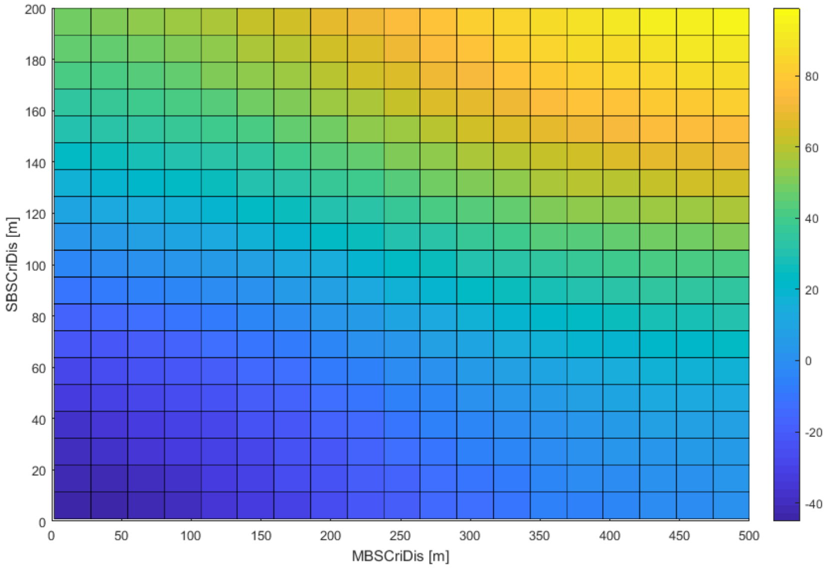
In this chapter Simulation results and analysis will be presented. First section will be on downlink and uplink rates without power control while second section is for power control implementation.

4.1 User Rates without Power Control

In this scheme no power control implementation at user uplink channel is implemented and hence users are transmitting at their fixed nominal value of 23dBm. Interference model is same as described in Chapter 3. A typical user experience interferences from all other users who are sharing the same subcarrier in both tier. SINR distributions are given in equations 3.11 - 3.14, while achievable rates are given by equation 3.15 - 3.18.



(a) Region of Rate Improvement, Green for FD and Blue for HD



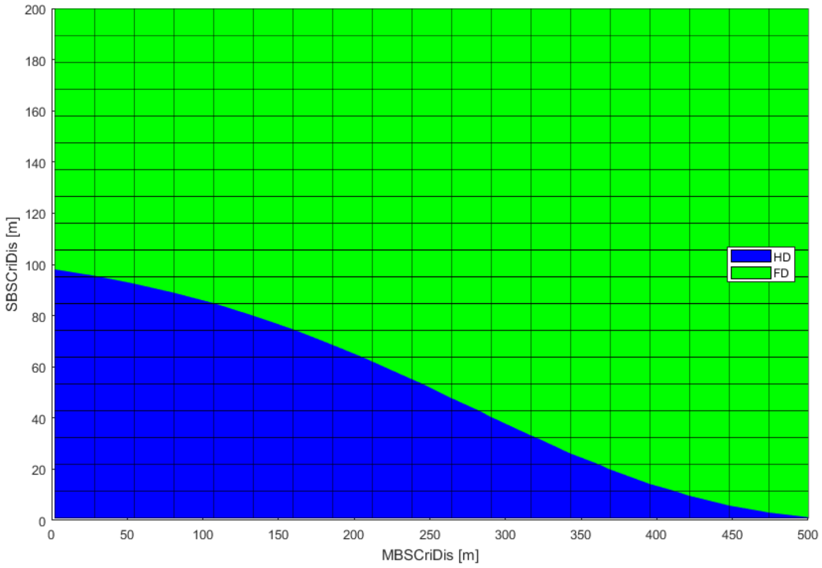
(b) Percentage Improvement in Rates

Figure 4.1: Downlink Rates

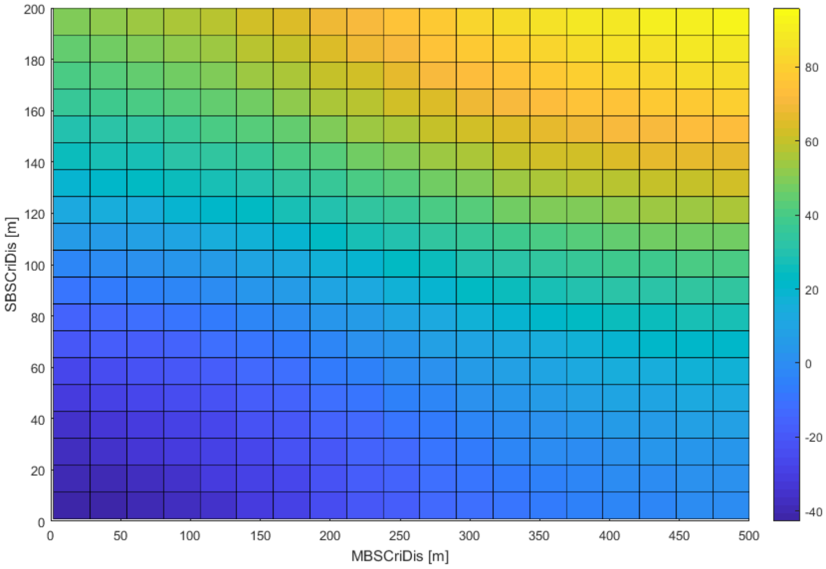
Figure 4.1(a) shows region where HD and FD are performing better in terms of downlink sum rates. It can be seen that when both macro and small

BS critical distances threshold are less, HD is performing well because most of the users are connected in HD. After this threshold switching distance most of the users are connected in FD and region is also quite wider than HD which shows that for most of the distance combinations, FD is performing well better than HD in terms of downlink sum rates.

Figure 4.1(b) shows percentage improvement of FD users over HD users in terms of downlink sum rates. It can be seen than least values are where most of the users are connected in HD and is roughly equal to -40% which is equivalent to saying that FD rates are 40% less than HD rates. 0% is the region where HD and FD rates are same and it is region where blue and green region in figure 4.1(a) are crossing each other. At extreme points where critical threshold distances of both macro and small small is maximum, almost all of the users are operating in FD, FD rates are approximately 90% more than HD downlink sum rates.



(a) Region of Rate Improvement, Green for FD and Blue for HD



(b) Percentage Improvement in Rates

Figure 4.2: Uplink Rates

Figure 4.2(a) shows region where HD and FD are performing better in terms of uplink sum rates. It can be seen that when both macro and small BS critical distances threshold are less, HD is performing well because most of the users are connected in HD. After this threshold switching distance most of the users are connected in FD and region is also quite wider than HD which shows that for most of the distance combinations, FD is performing well better than HD in terms of uplink sum rates.

Figure 4.2(b) shows percentage improvement of FD users over HD users in terms of uplink sum rates. It can be seen than least values are where most of the users are connected in HD and is roughly equal to -40% which is equivalent to saying that FD rates are 40% less than HD rates. 0% is the region where HD and FD rates are same and it is region where blue and green region in figure 4.2(a) are crossing each other. At extreme points where critical threshold distances of both macro and small small is maximum, almost all of the users are operating in FD, FD rates are approximately 90% more than HD uplink sum rates.

4.2 User Rates with Power Control

In this scheme user power is controlled through open loop power control and shown in figure 3.2. In this scheme, first a pilot is sent from BS to all users, then users estimate the path loss based on pilot received signal power. Finally the power is adjusted using equation 3.19.

4.2.1 No. of FD/HD Users:

Graphs below show the no. of FD and HD users in network for varying values of duplex threshold switching distance for macro and small base station. As explained in system model, users are connected as either FD or HD based on this threshold switching distance, so no. of connected users is not dependent on either target SNR, SNR_o or path loss compensation factor, α. Also note that users will be designated as FD if it is inside this threshold distance else it will be HD. So from figures below we can observe that when threshold distance values are small most of the users are in HD, and with increasing radius of switching distance most of the users operate in FD.

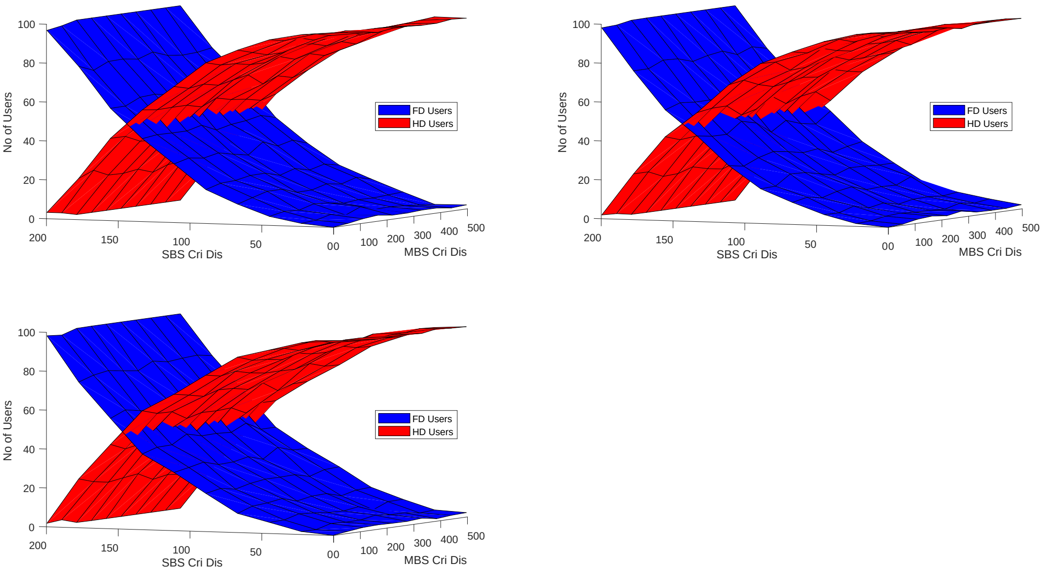


Figure 4.3: No. of FD and HD Users for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 0dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.3 shows the number of HD and FD users operating when open loop power control SNR threshold is set to 0 dB for no path loss compensation, fractional compensation of 0.7 and full compensation. From the figures it can be seen that when macro and small BS duplexing threshold distances are less, most of the users are operating in HD mode, while after this threshold distance number of FD users start to increase. Crossing of two plots is the distance where no of HD and FD users are same. It can be seen that number of connected HD and FD users are independent of path loss compensation factor which is quite intuitive because users are operating in HD and FD based on duplex threshold distance but not on power less or path loss.

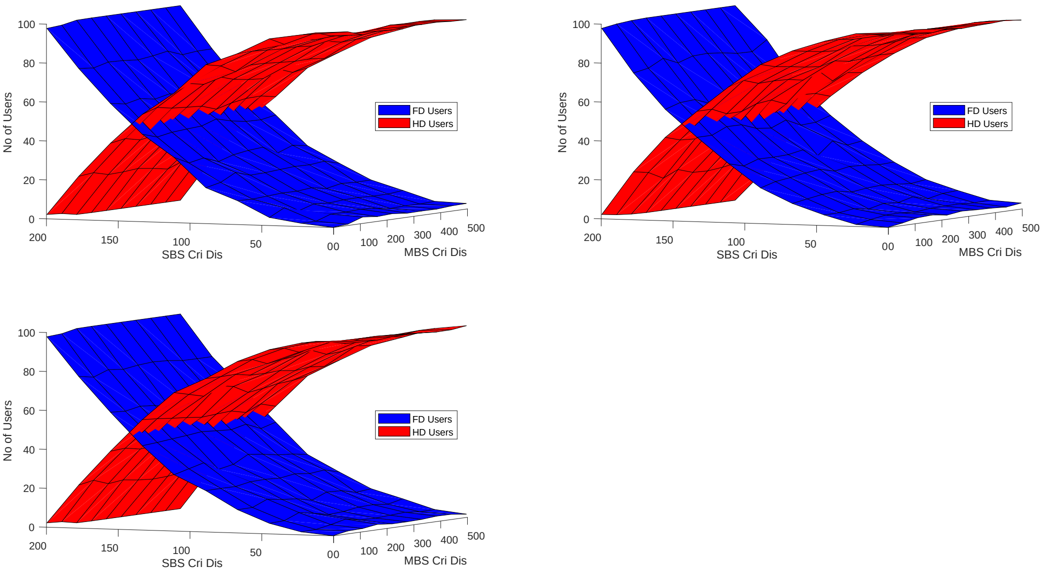


Figure 4.4: No. of FD and HD Users for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 10dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.4 shows the number of HD and FD users operating when open loop power control SNR threshold is set to 10dB for no path loss compensation, fractional compensation of 0.7 and full compensation. From the figures it can be seen that when macro and small BS duplexing threshold distances are less, most of the users are operating in HD mode, while after this threshold distance number of FD users start to increase. Crossing of two plots is the distance where no of HD and FD users are same. It can be seen that number of connected HD and FD users are independent of path loss compensation factor which is quite intuitive because users are operating in HD and FD based on duplex threshold distance but not on power less or path loss.

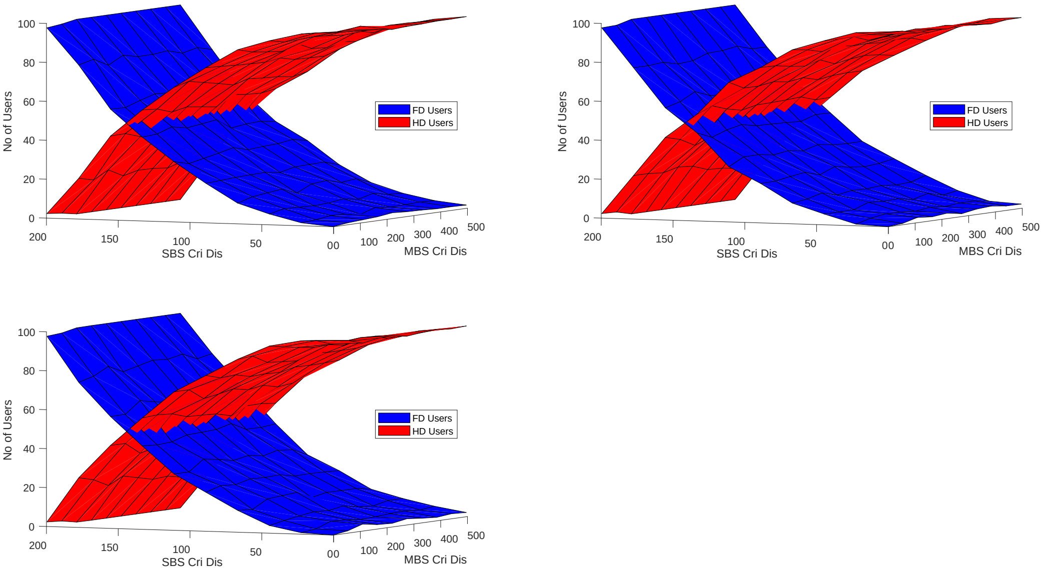


Figure 4.5: No. of FD and HD Users for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 20dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.5 shows the number of HD and FD users operating when open loop power control SNR threshold is set to 20dB for no path loss compensation, fractional compensation of 0.7 and full compensation. From the figures it can be seen that when macro and small BS duplexing threshold distances are less, most of the users are operating in HD mode, while after this threshold distance number of FD users start to increase. Crossing of two plots is the distance where no of HD and FD users are same. It can be seen that number of connected HD and FD users are independent of path loss compensation factor which is quite intuitive because users are operating in HD and FD based on duplex threshold distance but not on power less or path loss.

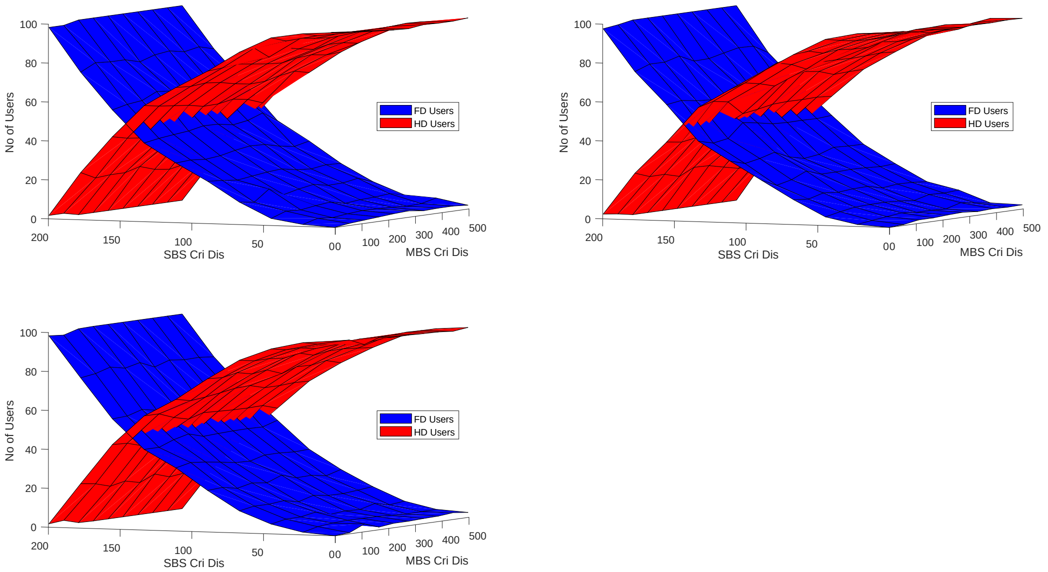


Figure 4.6: No. of FD and HD Users for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 30dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.6 shows the number of HD and FD users operating when open loop power control SNR threshold is set to 30 dB for no path loss compensation, fractional compensation of 0.7 and full compensation. From the figures it can be seen that when macro and small BS duplexing threshold distances are less, most of the users are operating in HD mode, while after this threshold distance number of FD users start to increase. Crossing of two plots is the distance where no of HD and FD users are same. It can be seen that number of connected HD and FD users are independent of path loss compensation factor which is quite intuitive because users are operating in HD and FD based on duplex threshold distance but not on power less or path loss.

From this section we can conclude that no of users operating in HD and FD is independent of open loop target SNR threshold and path loss compensation factor. This is because user duplexing mode is defined on distance from connected BS. If a user in within duplexing threshold distance, it will be operating as HD otherwise it will operate in FD.

4.2.2 FD/ HD UL Rates (Plotyy):

Graphs below show the UL rates for FD and HD users. xaxis specifies the duplexing threshold switching distance of macro cell while left yaxis shows the UL rates for HD and right yaxis show the UL rates for FD users. while each line on graph shows duplexing switching threshold distance of small BS. It can be observed that initially when no. of FD users are less rates are quite low, but when no. of FD users increase FD rates also start to increase with respect to HD rates.

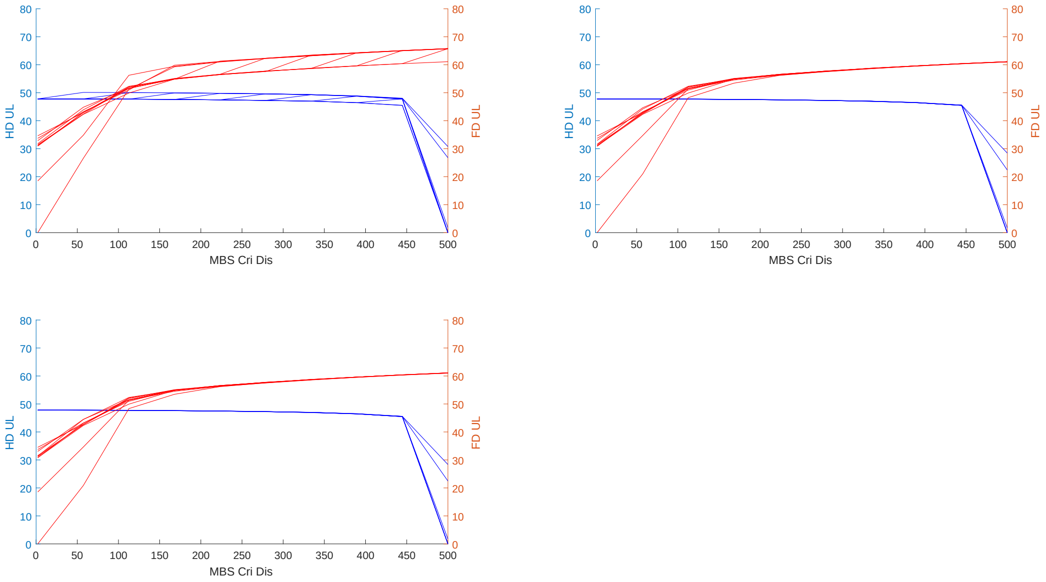


Figure 4.7: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 0dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.7 shows the UL rates for HD and FD for open loop SNR target threshold of 0dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that UL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

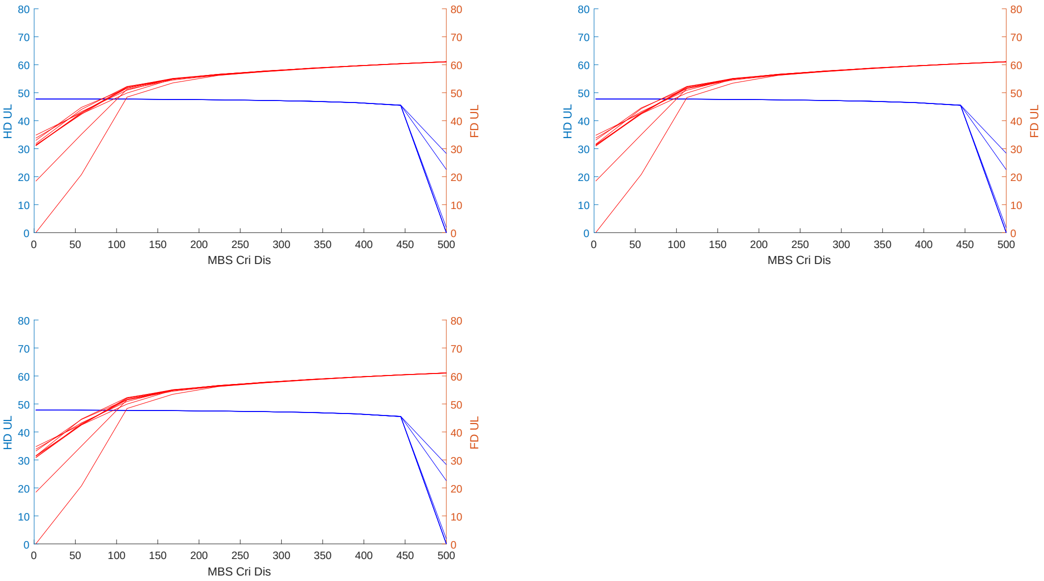


Figure 4.8: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 10dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.8 shows the UL rates for HD and FD for open loop SNR target threshold of 10dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that UL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

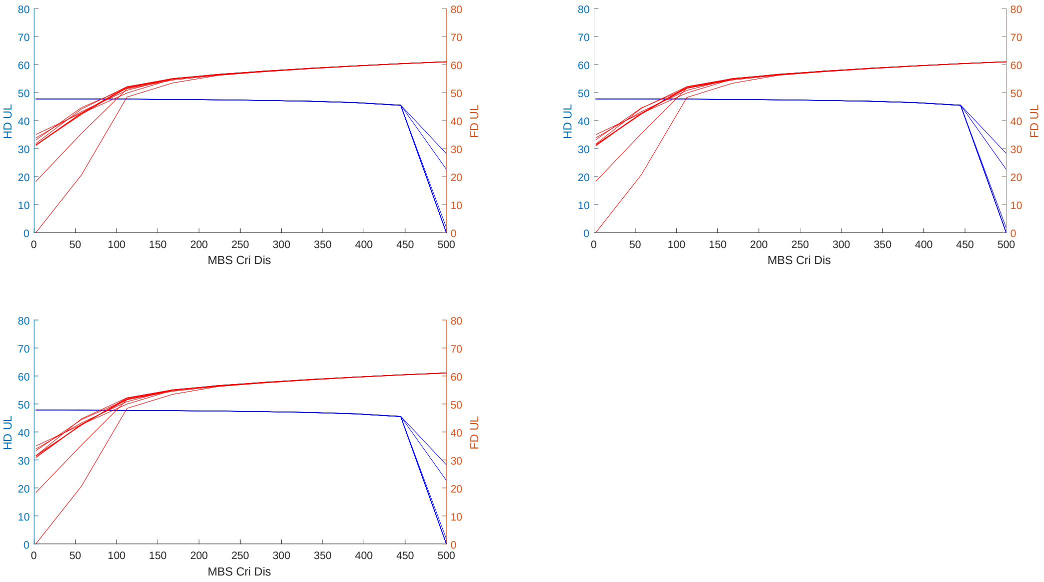


Figure 4.9: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 20dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.9 shows the UL rates for HD and FD for open loop SNR target threshold of 10dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that UL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

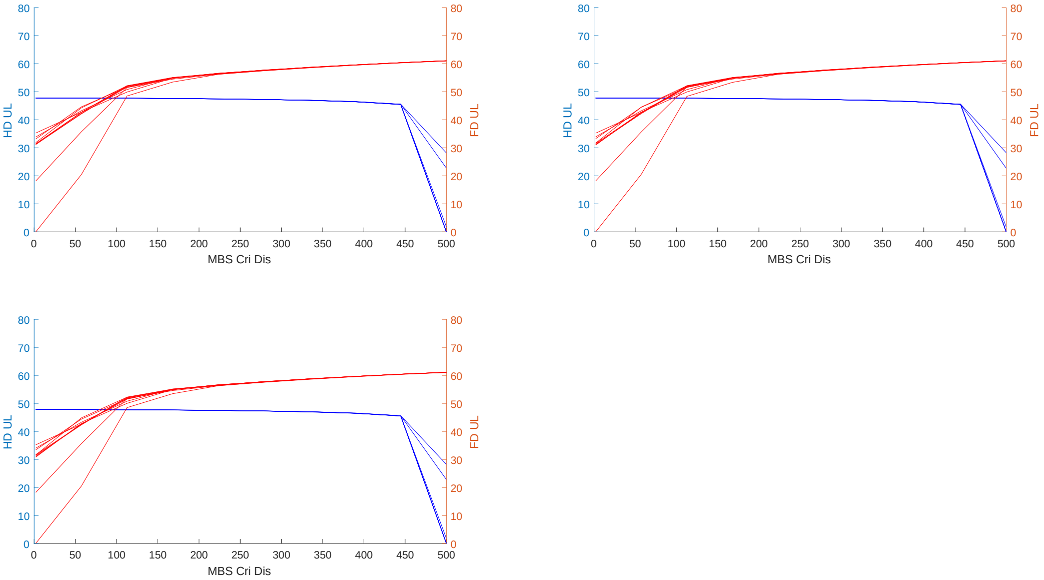


Figure 4.10: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 30dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.10 shows the UL rates for HD and FD for open loop SNR target threshold of 10dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that UL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

From this section we can conclude that FD rates are higher than HD rates after duplex switching threshold distance. Rates are pretty constant throughout the network area due to open loop power control.

4.2.3 FD/ HD DL Rates (Plotyy):

Graphs below show the DL rates for FD and HD users. xaxis specifies the duplexing threshold switching distance of macro cell while left yaxis shows the DL rates for HD and right yaxis show the DL rates for FD users. while each line on graph shows duplexing switching threshold distance of small BS. It can be observed that initially when no. of FD users are less rates are quite low, but when no. of FD users increase FD rates also start to increase with respect to HD rates.

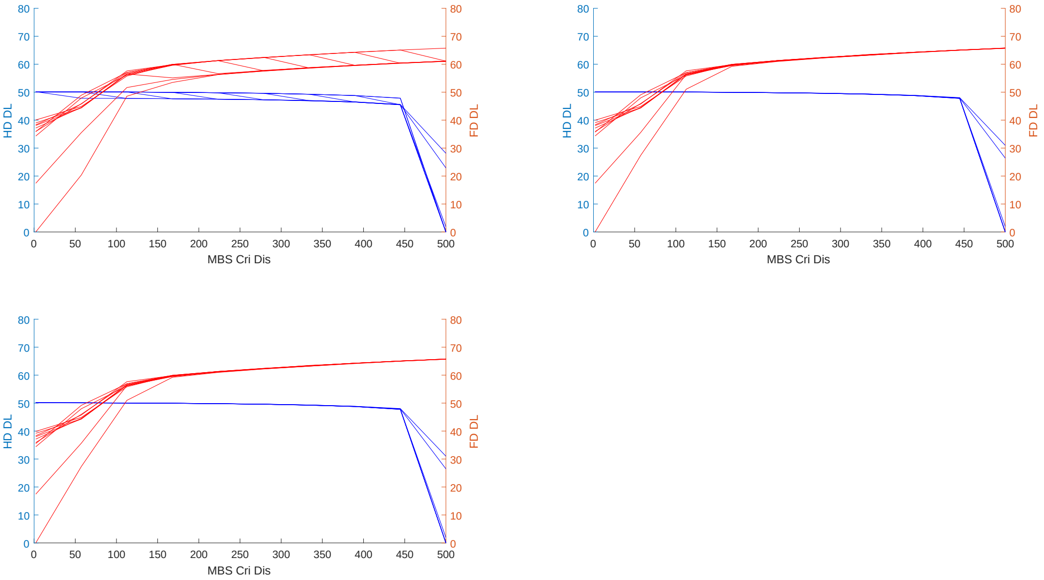


Figure 4.11: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 0dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.11 shows the DL rates for HD and FD for open loop SNR target threshold of 0dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that DL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

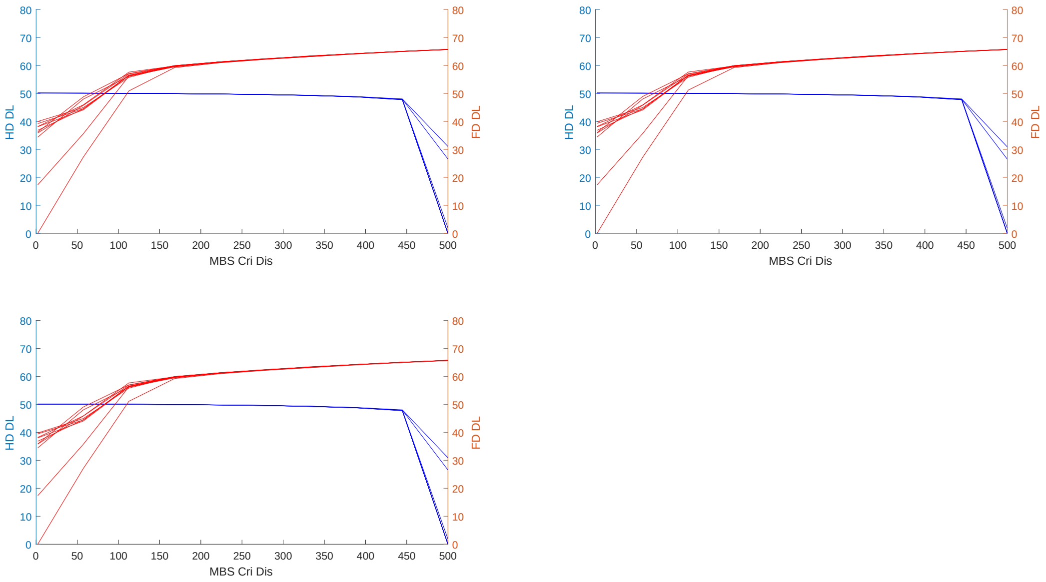


Figure 4.12: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 10dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.12 shows the DL rates for HD and FD for open loop SNR target threshold of 10dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that DL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

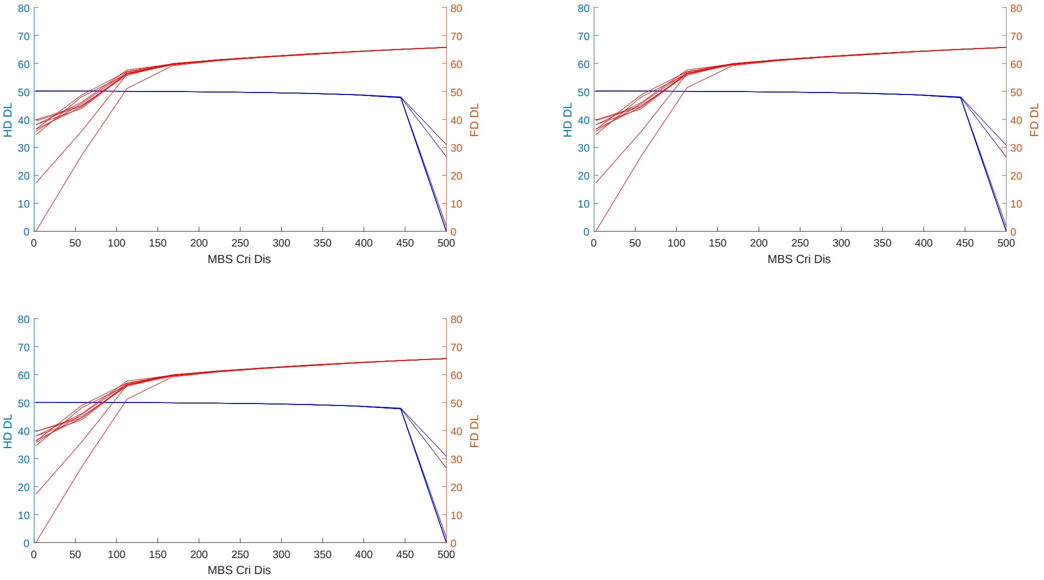


Figure 4.13: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 20dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.13 shows the DL rates for HD and FD for open loop SNR target threshold of 20dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that DL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

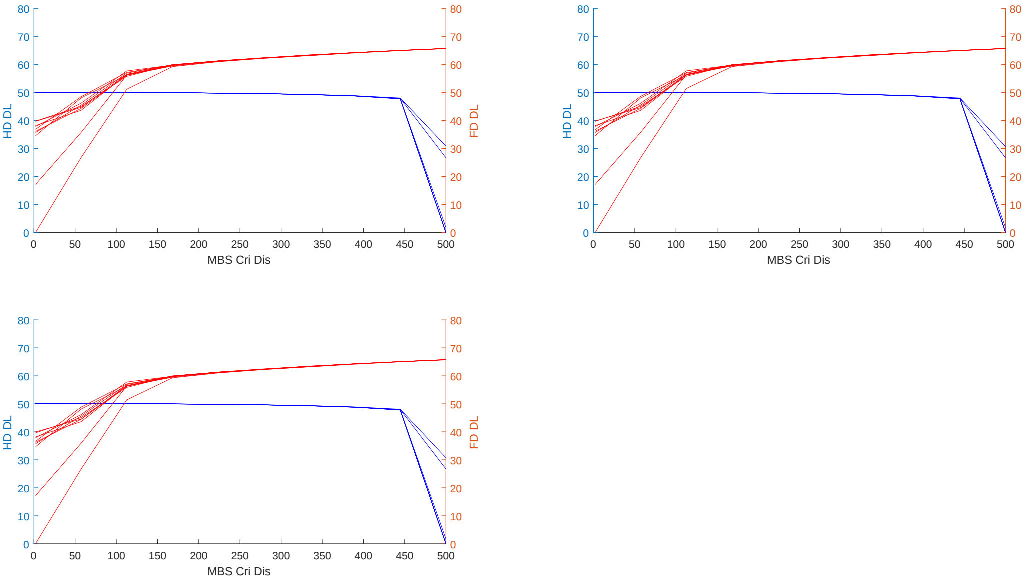


Figure 4.14: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 30dB$,$\alpha = [0, 0.7, 1]$.

Figure 4.14 shows the DL rates for HD and FD for open loop SNR target threshold of 30dB for path loss compensation values of 0, 0.7 and 1 corresponding to no, fractional and full compensation. From figures we can analyse that DL rates for FD are higher after duplexing switching distance threshold than HD rates. X-axis corresponds to macro duplex switching threshold values, left Y-axis corresponds to HD rates while right Y-axis corresponds to FD rates. Each line in graphs represent corresponding rates for different values of small BS duplex switching threshold distance.

From this section we can conclude that FD rates are higher than HD rates after duplex switching threshold distance. Rates are pretty constant throughout the network area due to open loop power control.

4.2.4 FD/ HD UL Rates (meshplot):

Graphs below show the UL rates for FD and HD users. One axis is for macro and other is for small BS duplex threshold switching distance. Graphs show that with increasing distance the rates of FD increases.

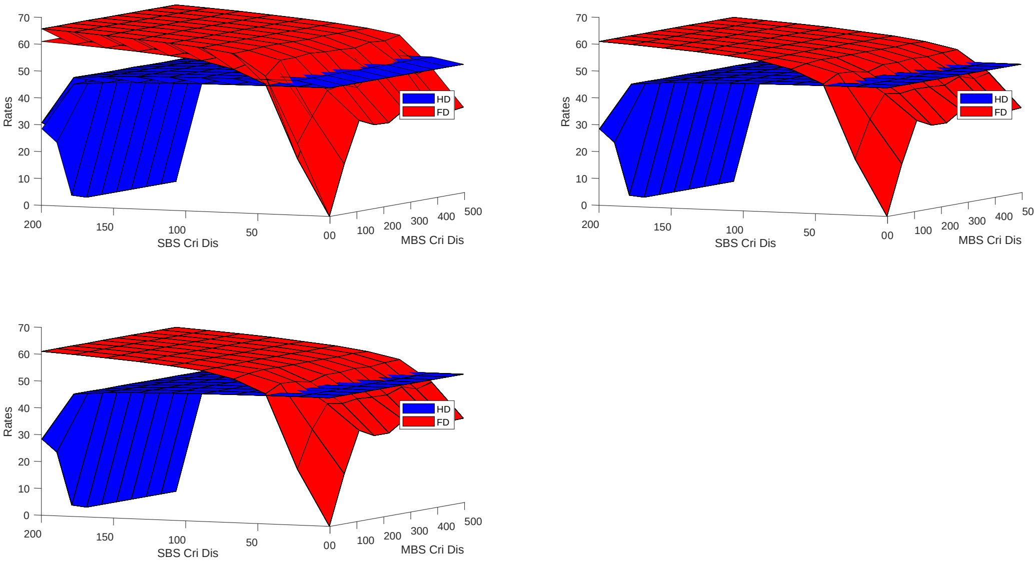


Figure 4.15: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 0dB$,$\alpha = [0, 0.7, 1]$.

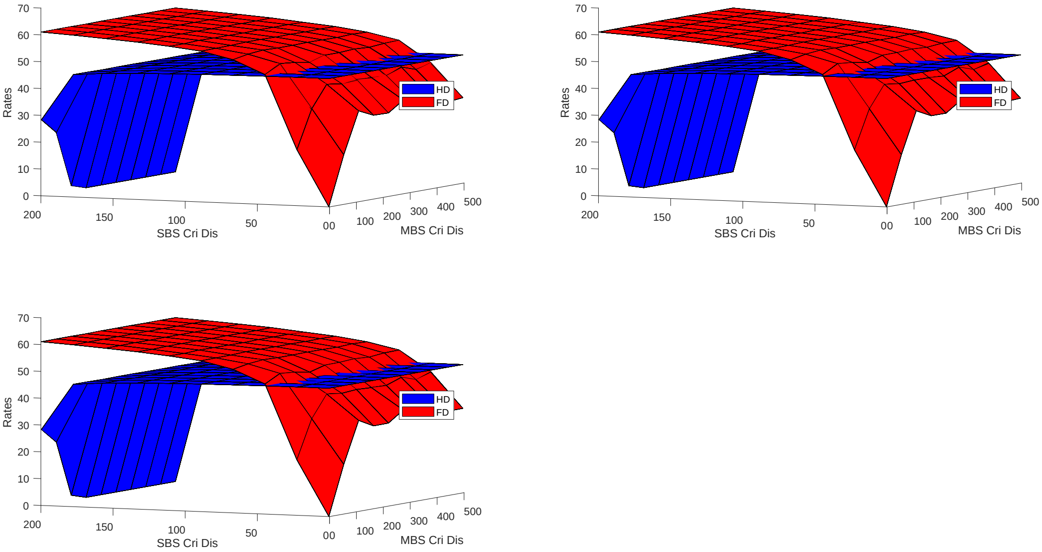


Figure 4.16: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 10dB$,$\alpha = [0, 0.7, 1]$.

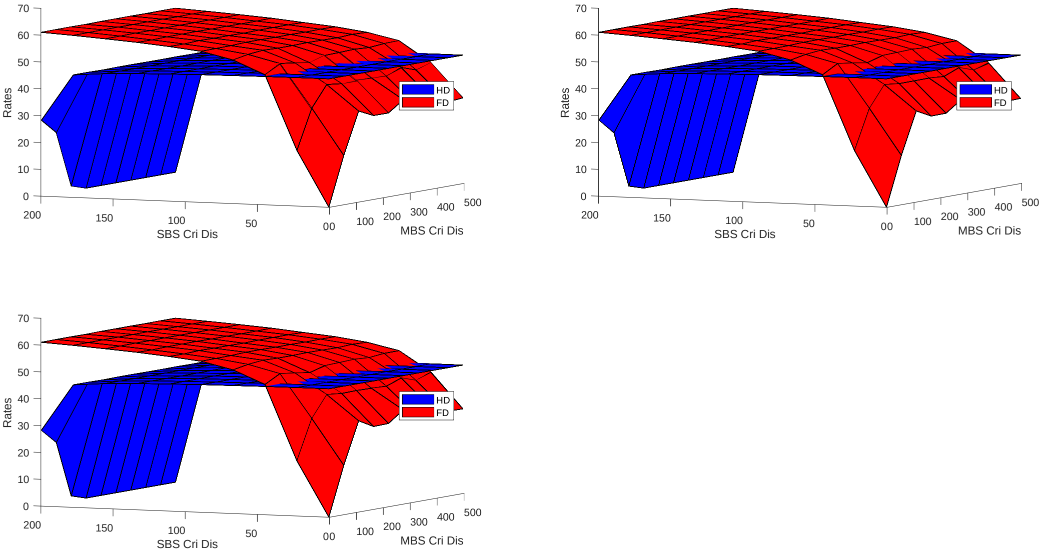


Figure 4.17: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 20dB$,$\alpha = [0, 0.7, 1]$.

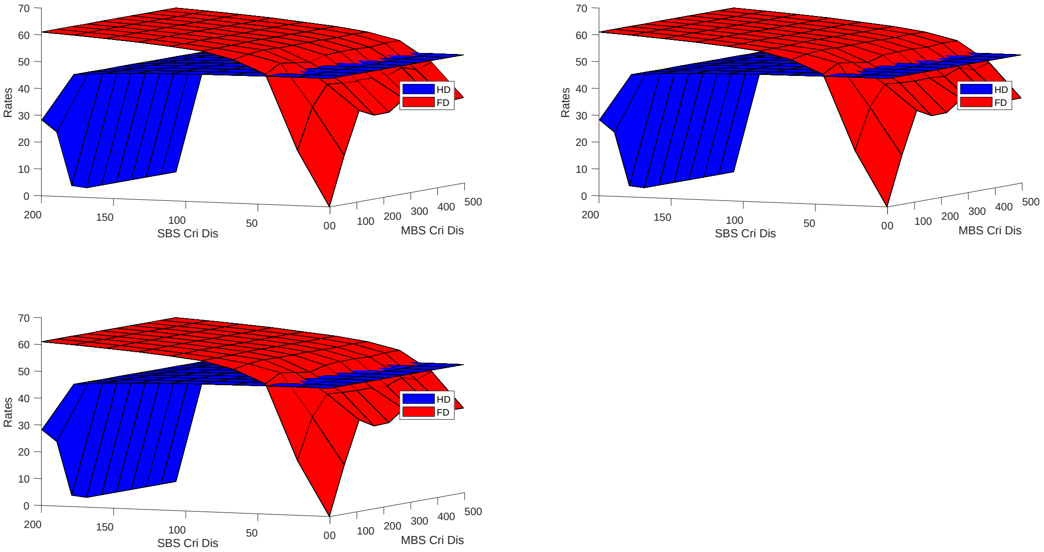


Figure 4.18: UL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 30dB$,$\alpha = [0, 0.7, 1]$.

4.2.5 FD/ HD DL Rates (meshplot):

Graphs below show the DL rates for FD and HD users. One axis is for macro and other is for small BS duplex threshold switching distance. Graphs show that with increasing distance the rates of FD increases.

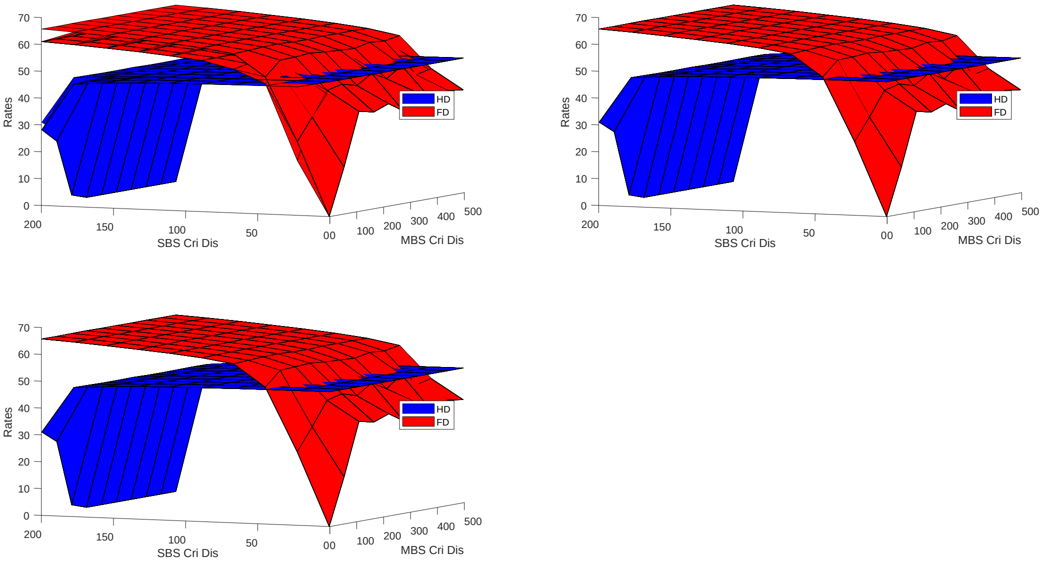


Figure 4.19: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 0dB$,$\alpha = [0, 0.7, 1]$.

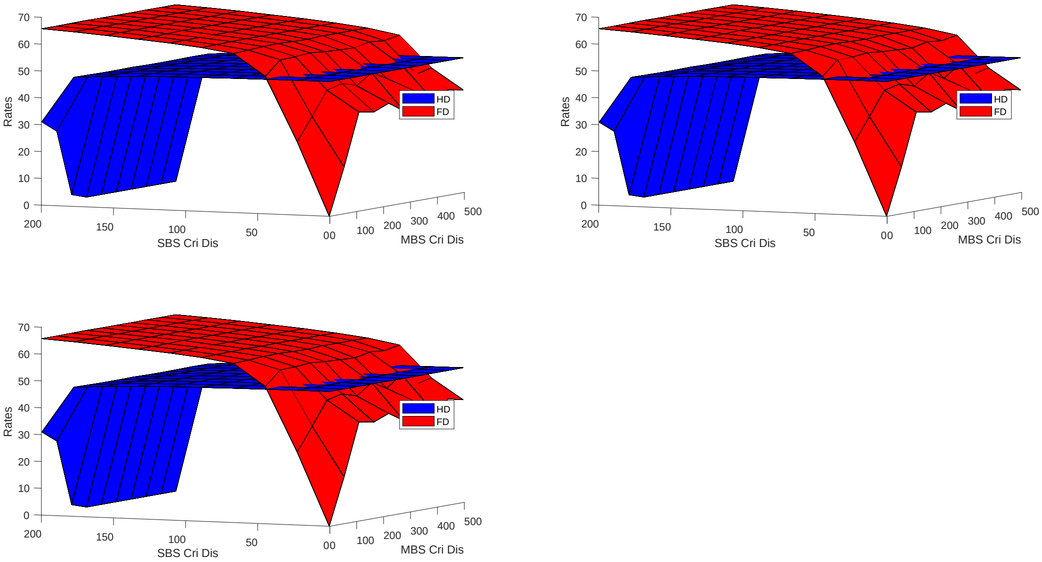


Figure 4.20: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 10dB$,$\alpha = [0, 0.7, 1]$.

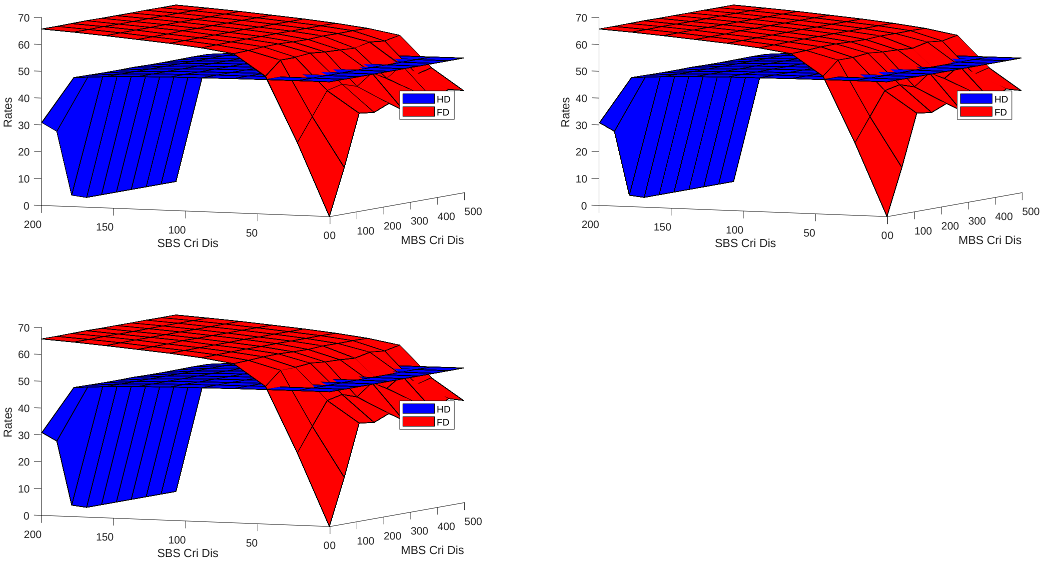


Figure 4.21: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 20dB$,$\alpha = [0, 0.7, 1]$.

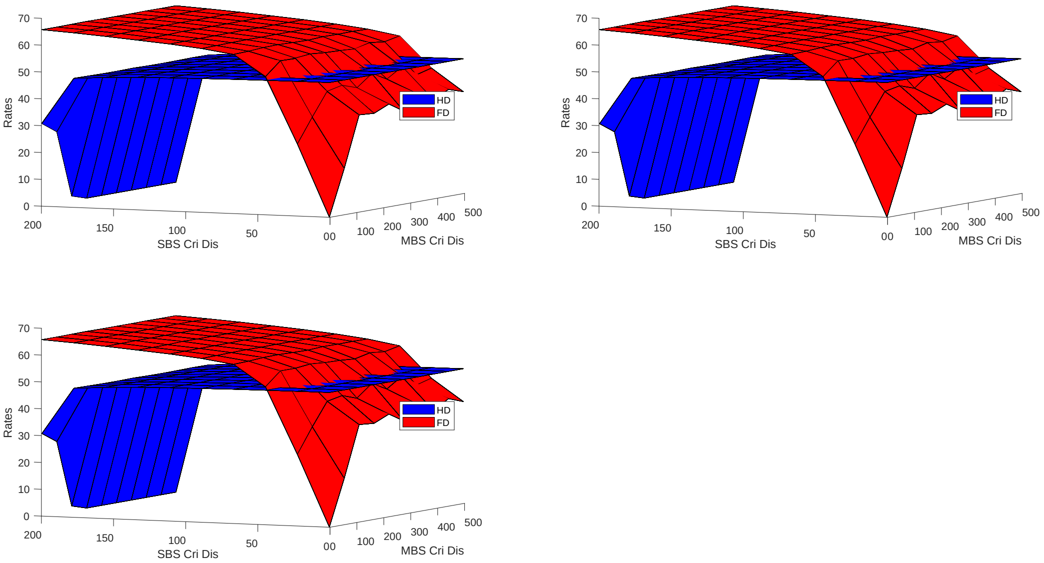


Figure 4.22: DL Rates for different values of Macro and Small Base station duplex threshold switching distance, $SNR_0 = 30dB$,$\alpha = [0, 0.7, 1]$.

Chapter 5

Conclusions and Future Directions

This chapter is based on conclusions and future directions.

5.1 Conclusions

In this work, we extended the application of full duplex radios with dual slope path loss model and distance based duplex mode selection,i.e., HD/FD.

- Chapter 1 deals with the basic problem formulation for modelling and analysis of full duplex HetNets based on dual slope path loss model. Road map is set up by first discussing the current technological trend and their corresponding achievements. Then need for moving to full duplexing is investigated and enlisted the benefits and challenges associated with it. This work extends and contribute by modelling the network with distance based threshold setting for mode selection.i.e.

HD/FD.

- Chapter 2 deals with literature review and current research work done in this field. This chapter first discusses different results contributed in full duplexing scheme and dual slope path loss model. Advantages of using this path loss model include more realistic approach to modelling of wireless channel. Secondly a review of using distance based association policies were investigated and finally the power control mechanisms required for simulation and modelling was presented.

- Chapter 3 deals with system modelling of proposed scheme, that is, hybrid duplexing scheme with dual slope path loss models and distance based duplexing association policies. Radio resource management scheme used is also presented to discuss the interference minimization and radio block assignment to user.This chapter also enlists the SINR distribution and Rate convergence in both HD and FD for downlink and uplink channels. Finally this chapter also describes the open loop power control mechanism implemented for analytical purpose.

- Chapter 4 presents and discusses the results obtained for uplink and downlink user rates in hybrid duplexing(HD/FD). This chapter is divided into two main section. First section deals with user rates without power control implementation and second section deals with results obtained by implementing open loop power control in uplink channel. Results include no. of users connected with macro and small cells resulting from changing the duplexing threshold distance, uplink and downlink rates, percentage improvement in FD rates over HD after duplexing threshold distance.

5.1.1 Executive Summary

Insightful results obtained in this piece of literature vigorously show the improvement and benefit of using full/ hybrid scheme. Although their are still some challenges in practical implementation of this scheme, like, residual self interference, successive channel interference and power control in hybrid circuitry. Still it is quite evident that significant improvement in radio resource allocation can be achieved by carefully deploying the scheme

5.2 Future Directions

This section will present future directions and pathway to further explore full/ hybrid duplexing scheme.

- Current 4G networks heavily rely on MIMO based HetNets. Examining full/ hybrid duplexing scheme in this context will be a great leap through advancement and improvement for efficient resource allocation.

This thesis investigated the scheme with single cell single antenna HetNet model. It can be extended to multicell with MIMO based diversity techniques to further explore the key results.

- Beamforming is also getting great attention for future wireless networks which direct the radio wave in particular geographical location. Integration of full/ hybrid scheme with beamforming will definitely improve the system performance as interference can be significantly reduced with directional beams, which is a key metric for performance evaluation of this scheme.

- Future wireless technology is also investigating new transmit and receive waveforms to further improve the spectrum utilization beyond LTE. Current research include Carrier Bank Multi Filter, windowed Filters, Index modulation. Full/ hybrid duplexing can also be a good candidate to investige the mixture of these waveforms.

- mmWave is also under investigation for both indoor and outdoor deployment. A great piece of work can be analysed with these modern schemes. mmWave along with massive MIMO has proven to be a great mix for high data rates. Full/ hybrid duplexing provides and helps to reduce the spectrum utilization, so entangled of two can be further explored.

- Ubiquitous networks, sensor networks and IoT based solution are also getting great popularity nowadays. This scheme can also be mixed and analysed for the feasibility and analysis with these technologies.

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