REDUCING CONTROL DATA IN JOINT TRANSMISSION USING HIERARCHICAL CLUSTER-HEAD TABLE

BY

OZULUONYE, Basil

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ABSTRACT

Users on the edge of the cell experience a combination of low received signal strength and high co-channel interference that originates from adjacent base stations. This significantly affects the perceived quality of mobile communication service at the edge user. In order to improve the poor indices of edge users, the concept of joint transmission was developed so that potential interferers would become potential co-transmitters of useful information to the edge user. Being co-transmitters implies that multiple base stations will transmit user data along with the main base station to the edge user. A set of multiple transmission points, also called cluster is coordinated by a central processing unit or cluster-head in an approach known as Coordinated Multipoint (COMP). For this to occur, control messages required for Coordination must be generated. The number of control messages required to perform joint transmission is prohibitive, and competes with the user data for bandwidth. The remaining bandwidth available for user may be insufficient for large number of users, especially the edge user. The lack of sufficient bandwidth further introduces significant delay causing the latency to increase. Both the problem of limited bandwidth for user data and increase in latency are detrimental to the goals of 5G communications. This research work focuses on reducing the number of control data required to perform COMP Joint Transmission (JT). The developed scheme, Hierarchical JT COMP develops a COMP weight from throughput and satisfaction index of base stations, and introduces a hierarchical table for JT COMP from which cluster-heads are selected. The Hierarchical JT COMP approach simplifies the method of selection of the cluster head for JT COMP by listing all base stations in an ordered table as potential cluster-heads. An algorithm for Hierarchical JT COMP is implemented on MATLAB 2019, and the outcomes are measured against state-of-the-art Direct CSI-Feedback to Elected Coordination-Station (DCEC) COMP JT for the control data and the latency. However the SINR index is measured against non-JT COMP transmission to project the clear advantage of JT COMP over non-JT COMP approach for edge users. Results obtained showed that control data in Hierarchical JT COMP achieved up to 10.5% reduction, while network latency improved by about 17.39% compared to DCEC JT COMP after incorporating delays from data fetching from saved Hierarchical tables. For the SINR, non-JT-COMP users on the edge performed 377% worse than the JT COMP users on the edge of the cell. This research shows that control data can be further reduced in JT COMP using the Hierarchical JT COMP to take up less bandwidth, which implies more bandwidth available for user data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Meaning
3GPP	3rd Generation Partnership Project
5G	Fifth Generation
ABS	Almost Blank Sub-Frame
BBU	Base Band Unit
BER	Bit Error Rate
BS	Base Station
CCU	Central Coordinating Unit
COMP	Coordinated Multipoint
CQI	Channel Quality Indicator
CB	Coordinated Beam-Forming
C-RAN	Cloud Radio Access Network
CSI	Channel State Information
DLL	Data Link Layer
FDD	Frequency-Division Duplexing
HETNET	Heterogeneous Network
HAP	High Altitude Platform
ICIC	Inter-Channel Interference Coordination
ISI	Inter-Symbol Interference
JTC	Joint Transmission Colouring
JTK	Joint Transmission Knapsack
JT	Joint Transmission
LTE	Long Term Evolution
MAC	Media Access Control

MS	Mobile Station
NFL	Network Function Layer
NOMA	Non-Orthogonal Multiple Access
OFC	Optical Fibre Cable
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak-to-Average Power Ratio
PRB	Physical Resource Block
PMI	Precoding Matrix Indicator
PTI	Precoding Type Indicator
RSS	Received Signal Strength
SON	Self-Organizing Network
SBS	Small Base Stations
SINR	Signal To Interference And Noise Ratio
TP	Transmission Point
UE	User Equipment
X2	Interface Exchange

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The increase in the density of user equipment in cellular coverage areas means that more users are distributed near the edge of the cell (Ling *et al.*, 2019). Other user equipment in the centre of the cell enjoy higher data rates, than users farther off at the edge for instance. The poor performance of users at the edge of the cell is primarily due to the large distance of separation from the base station.

Due to this large distance of separation, edge users experience low received signal strength from their serving base station. At the same time, the edge user also receives interfering signal with similar received signal strength from their main base station.

So combined with low signal quality reception, the inter-cell interference significantly reduces perceived network quality at the edge user (Bassoy *et al.,* 2019). The severity of interference experienced by the user equipment at the edge of the cell could worsen if the user also exists on the edge of a sector within its own cell. This adds another dimension called the intra-site interference.

The presence of interfering signals and low received signal strengths means an increase in the number of errors in the received messages. This will require messages to be resent therefore introducing generally larger average delays incurred during communication, since unique messages have to be sent more than once in order to complete the request acknowledgement (Mao *et al.,* 2019).

All these point to an unfavourable channel condition as experienced by the edge user, and these channel conditions make it challenging to achieve the all-time connectivity and stringent low latency requirements of the 5G communication. It becomes imperative to improve the received signal quality of the user equipment on the cell edge, and to also mitigate the impact of interferences by controlling the sources of interference (Bassoy *et al.,* 2019).

Multiple transmitters communicating jointly and constructively with an edge user can serve to boost both received signal strength and signal to interference and noise ratio. For more than one base station to transmit intelligent signals to the edge user, there has to be a form of coordination for the multiple transmitting base stations. This is known as coordinated multipoint, otherwise called COMP. This coordination will minimise interference by co-channel cells, and also improve diversity gains (Bassoy *et al.,* 2019).

1.2 Statement of the Research Problem

Due to the need to coordinate several base stations for joint transmission in Coordinated Multipoint (COMP), there is a resultant large number of control messages which is processed through the backhaul of the network. This creates the well-known problem of a backhaul "bottleneck," where control data messages use up a large portion of bandwidth and therefore competes for limited channel capacity with user data (Zakhour & Gesbert, 2011).

More data forwarded over the backhaul means an increased likelihood for congestion which can cause large queue delay on the network layer during routing of packets to cooperating base stations. When this occurs, achievable throughput of the UEs is greatly reduced since packets can be lost during queuing or reach the UE at a time greater than the cyclic prefix thus causing inter-symbol interference (Kazi & Wainer, 2020).

It is imperative to reduce the number of control data that will be required in the joint transmission scheme of COMP. This position is universal to researchers in this field. Research work in this field significantly seeks a measure that reduces the dependence of the cooperation network on the backhaul infrastructure.

1.3 Aim and Objectives

The aim of this research is to reduce the number of control data required in Joint Transmission using hierarchical cluster-head table.

The objectives of this research are to:

1 Implement a weighting criteria and cluster-head hierarchy in joint transmission for cluster-head selection.

2 Reduce the total number of control data exchanged between cooperating base stations in JT COMP using a prepared list of potential cluster-heads obtained from the cluster-head hierarchy.

3 Assess the impact of the weighting criteria and cluster-head hierarchy on network delay using CSI delay measurement.

1.4 Justification for the Study

One recurrent setback to the Joint Transmission Coordinated Multipoint (COMP) scheme is that it incurs significant overhead or number of control messages (Kazi & Wainer, 2020). The control data is used to manage communication between the base stations in a cluster (Irmer *et al.,* 2011). In order to limit the amount of control messages required for JT COMP, the state-of-the-art JT COMP called DCEC (Direct-CSI to Election Coordination) elected a coordinating base station using the best throughput approach. However, the election is bound to reoccur in the event of change in any base station throughput or if a new user is introduced into the cell. The event of re-election of coordinating base station causes the total control messages to rise. This research work implements a hierarchical approach which does not require an election in the event of a change in the throughput of any base station or in the event of entry of new users. An approach that eliminates the need for re-election effectively reduces the total amount of control messages required for JT COMP.

Throughout the research works reviewed relevant to the field of Joint Transmission (JT) Coordinated Multipoint (COMP) communications, no work to the best of the authors' knowledge adopted a fairness approach to the selection of cluster-heads. In this research, the authors implement a fairness approach by considering the relationship of the number of mobile users being served by the cluster-head to the available radio resources available to implement JT COMP since radio resources are fixed and the number of mobile users is variable. Using a quotient called "Satisfaction Index" from the work of Bassoy *et al* (2019) along with base station throughput, this research implemented a weighting criterion which is a fairness approach.

1.5 Scope of the Work

The research work is based on a homogeneous system. The achievable gains in heterogeneous networks are subject to certain criteria such as non-coherence and synchronisation Ralph *et al.*, (2014), Shuyi *et al.*, (2019), and Jiaqi *et al.*, (2019). These factors are not stringent for macro cells. However, the aim of this work in focus is to reduce the number of control data required in Joint Transmission using Hierarchical Cluster-head Table.

1.6 Motivation for the Study

Although the communication with various base stations improves link reliability and network performance, COMP schemes come with significant cost to the network

(Zakhour & Gesbert, 2011), (Irmer *et al.*, 2011). This includes increase in number of control messages also referred to as signalling overheads, higher complexity due to scheduling of base stations cooperation, and tight synchronisation. The cost of control messaging is prohibitive and inherent in JT COMP, thus forming the motivation for the study and research in JT COMP.

1.7 Thesis Organisation

Chapter one of the research work introduces the concept of Joint Transmission (JT) Coordinated Multipoint (COMP), after which research works reviewed in the course of this research and relevant to JT COMP is detailed in Chapter two, The Literature Review. Chapter three addresses the methodology of this research, including formulas and parameters used in calculations and assumptions to reach the objective of the research. Chapter four contains the relevant Results and Discussions of the results obtained to show the extent to which each objective was met. Chapter five is the Conclusion and Recommendations. The work concludes with References and Appendices which include the MATLAB 2014 Program code used to simulate the Hierarchical JT COMP developed in the research work and a Conference publication by the authors.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Preamble

A diverse collection of papers in the field of coordinated multipoint and more specifically joint transmission were reviewed during this research. The papers in this field have contributed in the research indices that have been developed for implementation. The literature review will start from a general perspective of papers in COMP. It will converge into discussions on joint transmission and finally end with some analyses of works as well as a table that summarises the works reviewed.

2.1.1 Types of Coordination Architecture in Joint Transmission

Two principal types of coordination architecture in joint transmission are (Kazi & Wainer, 2020):

a. Centralised architecture, and
b. Distributed architecture

In the centralised architecture, a Control Unit (CU) is responsible for network management functions including processing the CSI transmitted from the base stations in the cluster and scheduling communication resources for joint transmission by those base stations. The base stations will initially receive CSI from the edge users and transmit this CSI to the control unit. The control unit in turn processes the information, and shares with the base stations in the cluster as shown in Figure 2.1 (adapted from Kazi & Wainer, 2020).

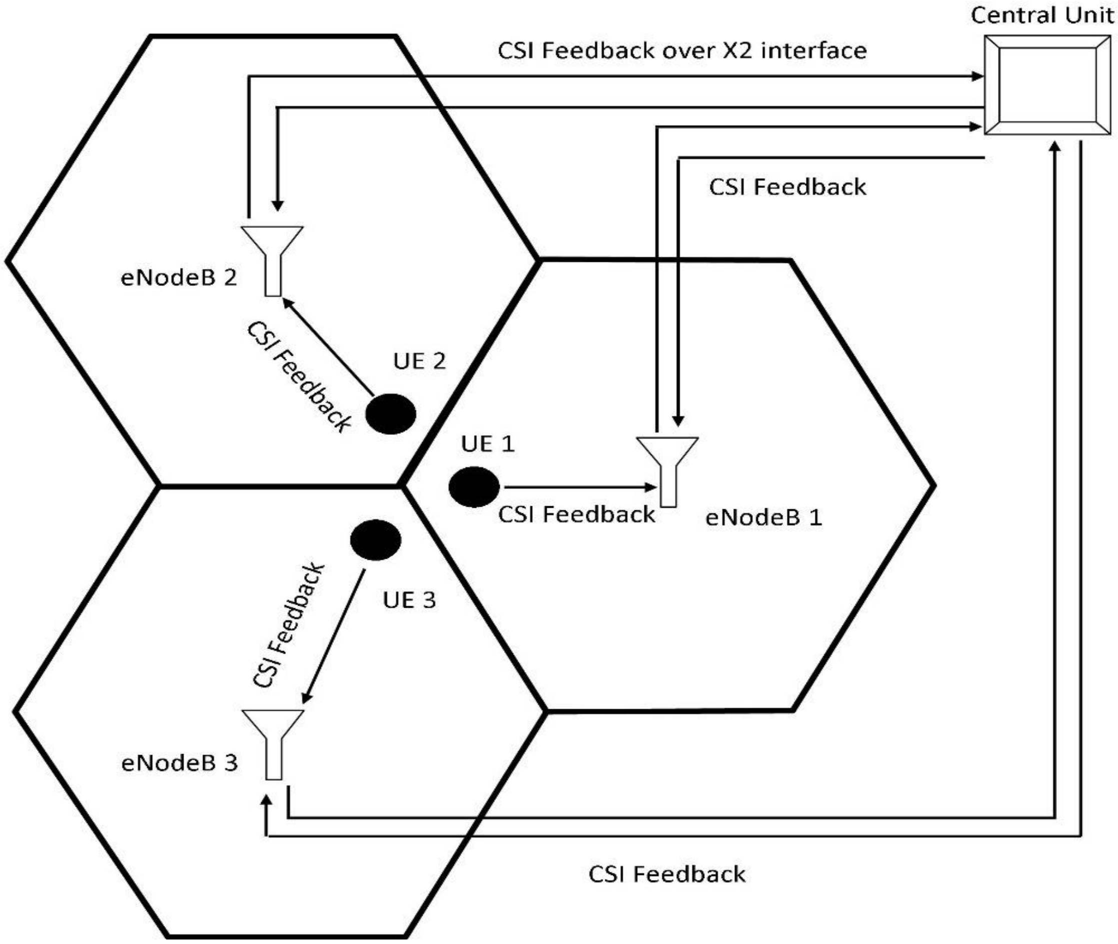

Figure 2.1: The Centralised Joint Transmission Architecture (adapted from Kazi and Wainer, 2020)

Kazi & Wainer (2020) notes that this architecture incurs significantly less control data signalling required to carry out joint transmission by base stations in a cluster than the second principal architecture – the distributed joint transmission architecture.

In the distributed architecture, there is not central unit that manages network functions such as processing of CSI and scheduling of communication resources. The various base stations in the cluster perform this role independently of each other. When an edge user send CSI to its main base station, the base station shares this CSI with other base stations in the cluster as shown in Figure 2.2.

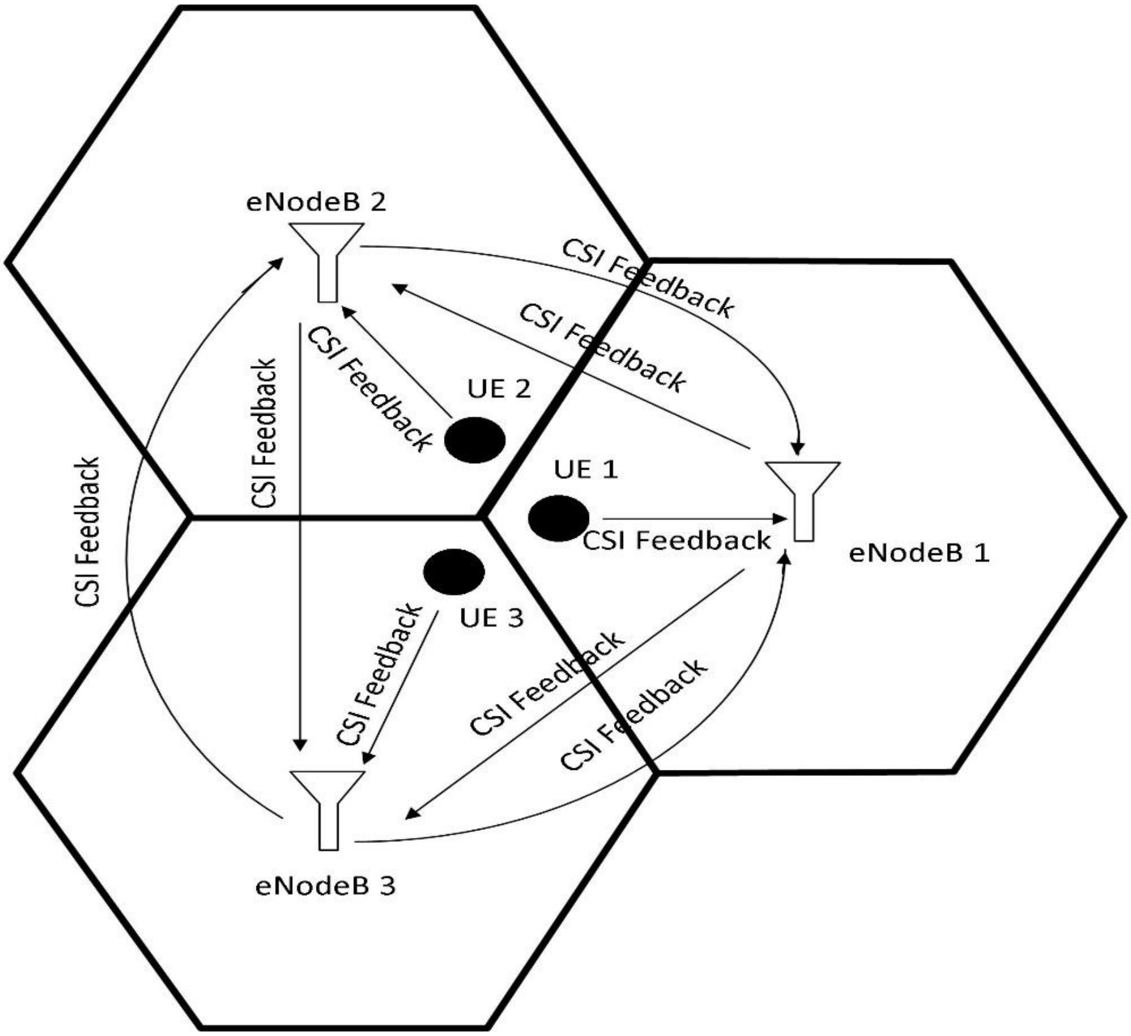

Figure 2.2: The Distributed Joint Transmission Architecture (Adapted from Kazi and Wainer, 2020)

From the analyses of Kazi & Wainer (2020), the distributed architecture was shown to require more control signalling than the centralised architecture in order to carry out joint transmission.

2.1.2 JT in Mobile Telecommunication

Joint transmission was first introduced to mobile telecommunications beginning from the 3GPP Release 11 for LTE. Here both the main base station and some of the adjacent base stations would be required to transmit user data to a user on the edge of the cell. This way, the potential interferers, mainly the adjacent base stations will join in transmitting useful data to the edge user. By doing so, the potential interferers also perform interference cancellation for the edge user. At the same time, additively, the user experiences higher received signal strength due to combination of signal powers from base stations that jointly transmit to it.

2.1.3 Clustering and the X2 Interface

In order to implement joint transmission in COMP, the set of base stations which will be involved in the cooperation must be identified. This selection of cooperating base stations follows different criteria, and different authors have designed different approaches that define how best to cluster base stations in a logical manner.

In figure 2.3 a cluster of three base stations has been depicted, and the X2 interface exchange in orange connecting lines can be seen to form a triangle. This cluster of three base stations which have been preselected based on receive signal strength threshold is responsible for jointly serving the edge user in the case of joint transmission.

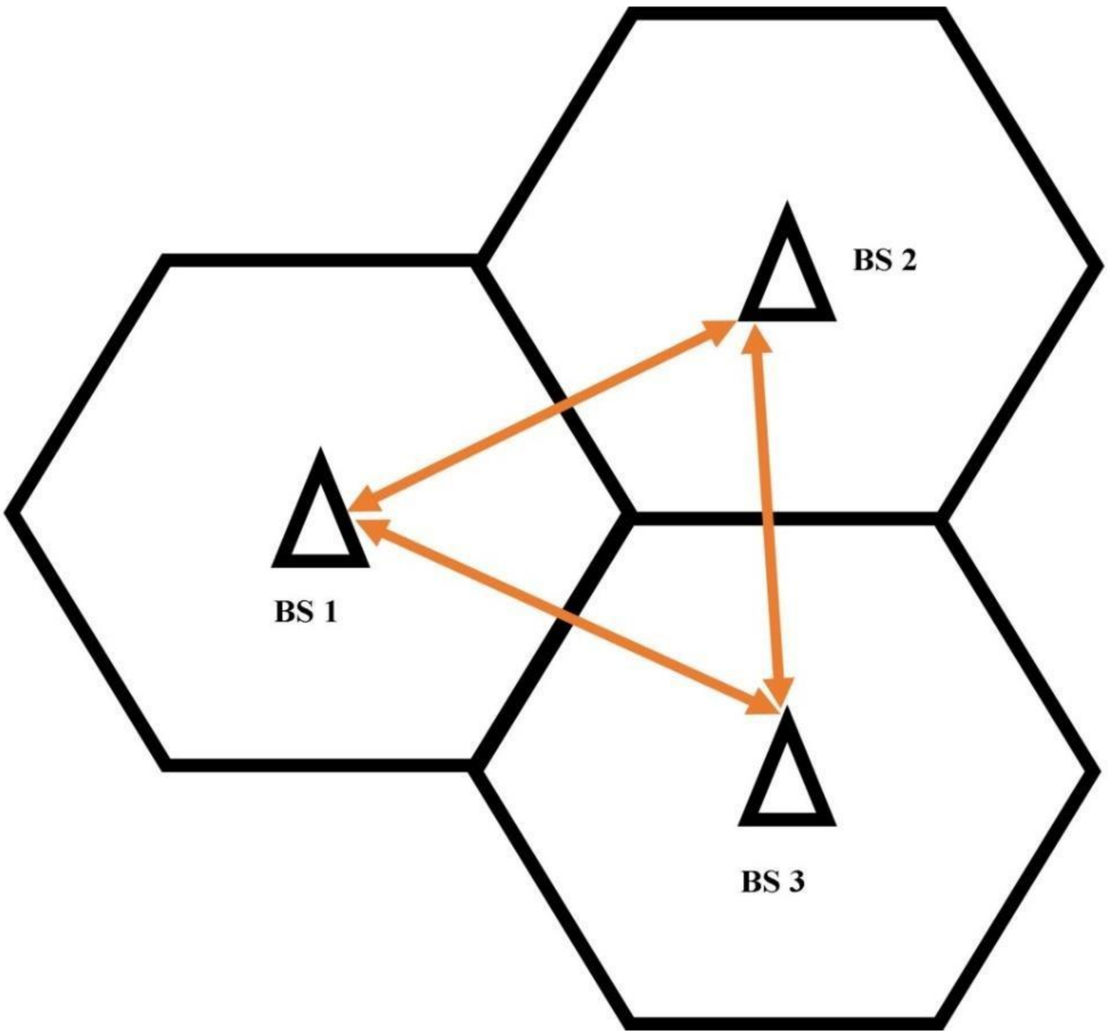

Figure 2.3: Cluster of Base Stations (adapted from Li *et al.*, 2013)

Most commonly, the nearest base stations to the edge user are made to be part of the cooperating set for the target UE. Clusters may be fixed in terms of the number of base stations that can form one, or may be dynamic.

There are two types of approach to clustering (Bassoy *et al.*, 2017), (Kazi &Wainer, 2020):

a. Network-centric cluster, and

b. User-centric cluster

In the network-centric cluster, the cluster of base stations is pre-selected by the network for the user who is located in any particular cell edge region. This cluster does not change, it is fixed and all UEs within the edge region of coverage will be served by that cluster of base stations. Figure 2.4 presents a pictorial summary of the types of clustering approach in COMP joint transmission.

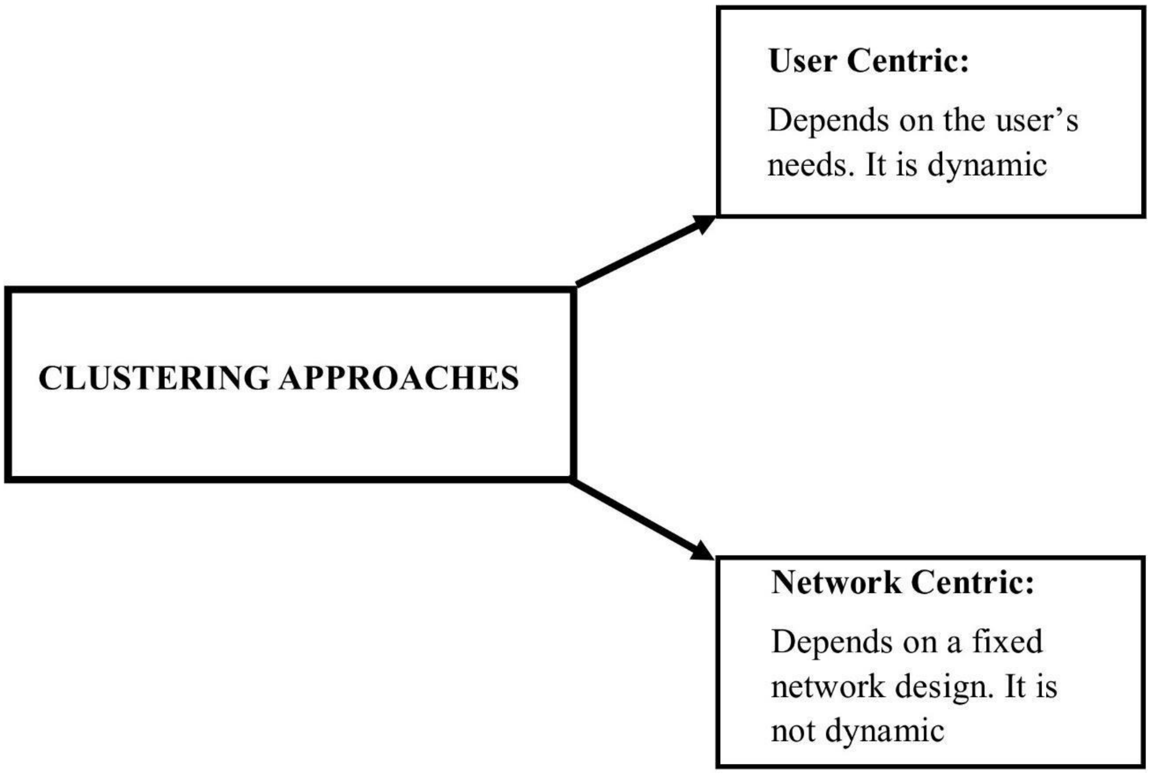

Figure 2.4: Summary of Types of Clustering Approach in JT COMP

In the user-centric cluster, the cluster of base stations is selected according to the specific needs of the edge user in that network. This need could be the power of transmission, or the proximity to the base station, or the threshold. Based upon these needs as reported in the CSI updates, a user's cluster can be determined usually by its serving base station.

The X2 Interface

The X2 interface is the logical link or interconnecting interface between two base stations (Mohamed *et al.,* 2013) and performs several functions including inter cell interference coordination, load management, handover preparation functions.

2.1.4 Challenges for the Technology and Researchers in JT COMP

The number of control data signalling increases unfavourably with the edge user density in joint transmission (Giovanni *et al.*, 2019). This increased control data signalling, gives rise to bottlenecks in backhauling and has an adverse impact on the required minimum delay of the system. Also, increased control data signalling due to JT COMP can reduce the actual bandwidth available for user data (Bassoy *et al.,* 2019).

The developed scheme in this research marginally but very significantly reduces the number of control data signalling required to perform joint transmission. The developed scheme also significantly improved on the feedback latency across the network, reducing the time delay experienced by feedback packets in the network.

2.2 Fundamental Concepts of JT COMP

The literature review is split into general and specific aspects both of which address the fundamental concepts of JT COMP. For the general literature review, a look at several works that investigated areas of JT Coordinated Multipoint is taken. They convey general aspects of the COMP research area as follows:

2.2.1 Coordinated Multipoint – Cache Approach

Downlink and uplink rate, as well as backhaul capacity of the transmission link were investigated for MIMO in Deghel *et al.*, (2015). The scheme implemented limited the number of overhead messaged required to satisfy the mobile user request by generating special messages which were transmitted across the network while other messages were sourced locally at the base station. However, both SINR and latency were not captured relative to achieving higher throughput.

In a scheme called the Rate-Splitting Multiple Access or RSMA, the authors in Mao *et al.,* (2019) were able to implement interference cancellation at the receivers in downlink JT COMP and consequently improve the Quality of Service (QoS). This was achieved by decoding interference in JT COMP and treating it as noise using a Weighted Sum Rate approach or WSR. The work considered rate-splitting approach, where more than one base station in the cooperation set will split the content of the message being transmitted. So while one base station has the private messages for the UE, the cooperating nodes transmit the shared message. In addition, this approach marginally improves the latency of communication and reduce reliance on network infrastructure such as the backhaul, since not all information need to be sourced from mobile network servers.

2.2.2 Coordinated Multipoint – Scheduler Approach

The problem of interference and throughput in downlink massive MIMO was the focus of research done in Hasnain *et al* (2017). The work improved on solutions to interference, link reliability and throughput are problems using multi-antenna systems that transmit simultaneously to users. It proposed a more suitable way to assign base stations to UEs, based on a beamformer decision that would limit the user data transfer rate with two algorithms which solve relaxation and norm minimisation problems for beam-forming and joint clustering. Regularised channel inversion receivers were used to mitigate potential interferences arising from use of multiple antennas. However, the implication of multiple antennas processing updated CSI from multiple antennas was not discussed, as well as the impact of various user traffic scenarios.

Interference problems for cooperative networks was the focus of the work done by Fumiyuki *et al.*, (2019) on distributed MIMO in cooperative transmission. When multiple base stations transmit information to a user in a coordinated approach, the user enjoys less interference and higher spectrum efficiency. Numerical and computational analysis of distributed and coordinated transmission of MIMO was evaluated in the work for the following performance metrics including Bit Error Rate (BER), link capacity, and Peak-to-Average Power Ratio (PAPR)-complexity trade-off. The work also studied distributed and centralized schemes for inter-cell interference coordination with TDD being used to estimate channel state via channel reciprocity. The work sought to improve on spectrum efficiency by determining an approach for UE clustering and adaptive inter-channel interference coordination. The user clustering method used in the work is network centric and as such not sensitive to network needs of UE such as perceived interference levels.

In both uplink and downlink COMP, the problem of joint scheduling for transmission from multiple transmitters is the focus of the work in Yan *et al.,* (2020). Joint Scheduling problem was solved by implementing a type of multiple access, the OFDMA. For the OFDMA Joint Scheduling (OJS) the authors derived a mathematical decomposition approach similar to Baccelli and Giovanidis (2014). The problem of OJS proved to be NP hard, to solve this, they chopped the problem into various smaller composite problems in order to make the solution tractable. The approach clustered base stations that were connected by a backhaul, while leaving out any node without a direct backhaul connection to the serving base station. The OJS problem was solved quite intuitively by using the dual approach of Colouring and Knapsack, referred to in the work as Joint Transmission Colouring (JTC) and Joint Transmission Knapsack (JTK) both of which solutions are combined to give the optimal solution to the OJS problem. Although the work analysed backhaul processing, it was not clear how efficiently the scheduling method used the backhaul, and generally the work did not analyse the performance of its scheme in various user traffic conditions.

2.2.3 Coordinated Multipoint Joint Transmission in Heterogeneous Networks

Amount of control data and load balancing in JT COMP is studied for Heterogeneous Cellular Networks (HCNs) in the work of Ralph *et al*, (2014). It is shown that when small cells cooperate with macro Base Stations (BSs), JT COMP can reduce the amount of control data, and also reduce the complexity associated with both joint processing and coordinated scheduling. The authors in an analysis of cooperation in heterogeneous network showed that JT can also be applied to user-centric heterogeneous networks, but the gains achievable with it are severely limited by the extent to which synchronisation is achieved among the cooperating small base stations. It is discussed as a particularly promising application for JT given that even with little cooperation, small cells deployed within a large or macro cell shows higher throughput gains. The limitation of tight synchronisation and accurate CSI feedback required for the JT in Heterogeneous Network (HETNET) can be addressed by adopting non-coherent JT which is generally less stringent on the requirements for JT. However, the interference levels perceived by users in the small cells are is not assessed, especially in non-JT conditions. The performance of this scheme in varying user traffic conditions is also necessary to simulate real life situations, but this was not captured in the research.

The work in Beneyam *et al.*, (2015) was motivated by the prospects of JT COMP in Heterogeneous Network (HETNET) as an emerging solution. However, the problem of control data passing through the backhaul is a limitation for the COMP HETNET scheme. Using a limited-feedback COMP technique, the paper develops a solution for the backhaul bottleneck. This backhaul bottleneck occurs due to limited bandwidth, inter-cell interference and shared radio resources. Using tools from stochastic geometry, the paper derives an integral expression for the network coverage probability for a typical k-th user located at an arbitrary location in the cell. The UE is able to receive data from a set of base stations which are selected according to their transmit powers. There is no cluster-head for the group of co-transmitting base stations, and the scheme does not analyse performance for large and small group of users.

The problem of high amount of control data passing through the backhaul is discussed in Ericsson (2015). The paper states that backhaul problems such as use of bandwidth and delays in total latency can be mitigated in the presence of large control data by connecting additional infrastructure such as extra links between BSs. However, this approach suggested by the paper will result in higher marginal network costs. Other suggested techniques that mitigate the high number control messages for JT COMP include data compression, channel prediction and adaptive intra- and inter-site cooperation. The work suggests that small cells within the macro cell already enjoy a measure of synchronisation, and do not need to add to the traffic on the backhaul generated by users of inter-site COMP. The JT COMP proposed in the work initially performs a user-cluster analysis, where different base stations identify the users they intend to transmit jointly to, then the central base station performs an achievable rate calculation for each of the base stations (or cells). The serving or central base station estimates the achievable data rates for the users with and without JT COMP. A user set is complete if there is consistency in achievable data rates, else the central base stations keeps adding users until this consistent capacity can be realised. The work does not define the method of selecting the central base station for a cluster, and in what sequence the network determines maximum capacity of the central base station. Also the scheme did not analyse latency and the number of control messages required for its JT COMP.

Using a heterogeneous network structure in JT COMP, the problems of amount of control messages and time synchronisation for multiple coordination links are discussed in Jiaqi *et al.,* (2019). The authors developed the anisotropic path loss model, an algorithm for clustering among Small Base Stations (SBS) whose clustering was controlled by a central coordinating unit or CCU, usually resident in the serving base station of that macro cell. The introduced scheme significantly reduced the backhaul traffic, constrained to the available radio resources, and also managed the differences in time of arrival of received messages. However, analysed work shows that latency is a significant setback of the scheme, and the work was not analysed for different user traffic patterns.

Signal-to-Interference Ratio (SIR) was analysed for coherent JT in Yu *et al,* (2018). The paper was able to determine an upper and lower bound for SIR, which is useful for determining an important performance metric for JT networks. An activation threshold was considered as a criteria for joint transmission cluster in where the cooperation set for Small Base Stations (SBSs) is determined by the cooperation activation thresholds (such as the channel fading and path loss) of each base station tier. The work made no clear reference to its usage of radio resources while focusing on improving SINR. Also the scheme improvement on mitigating number of control messages was not highlighted.

Most research on JT COMP has studied 3 or more base stations in cooperation often with Small Base Station (SBS) or Remote Radio Heads (RRHs), but the work in Gaurav *et al.,* (2014) focused on 2-base station cooperation. The research found that a worst case COMP user on limited cooperation between 2 base stations will achieve significantly greater coverage probability than a regular user who does not use cooperation. However the costs of coordination was not discussed, especially backhaul implications and latency.

Faizan *et al.*, (2017) points to the ever present problem of backhaul data which arises due to the need for coordinating base stations to share coordination messages, and the work attempts to ease the backhaul bottleneck through its analysis. In order to address the amount of control data generated, the paper proposed the self-backhauling scheme. A rather analytical effort, the work develops some network performance metrics for evaluation such as derived capacity outage expressions. The paper also proposes an approach for relaxation of the self-backhauled strategy in low powered nodes, thus providing backhaul link SINR gains at the cell edge through the use of JT COMP in a Frequency-Division Duplexing (FDD) downlink system. Although significant improvements are made for backhaul processing of control messages, it does not analyse the performance of the scheme in different traffic situations.

The problems of interference and coordination for coherent JT COMP involving high power macro network level and low power pico network level are discussed in Supratim *et al.*, (2013). The paper developed different strategies for Inter-Channel Interference Coordination (ICIC) and the rules of association for the COMP. Importantly the work looked at the ICIC strategy in the MAC layer called Almost Blank Sub-frame (ABS) which enables the small cell base station and the large macro cell base station to efficiently communicate with their users with minimal interference caused by the higher powered macro base station. The paper lacks in demonstration to minimise control messages required for transmission and also shows no indices in latency.

2.3 Specific Literature Reviews: Coordinated Multipoint Joint Transmission in Homogeneous Networks

The following section looks at literatures that are more nuclear to the subject of research. It looks at the coherent and non-coherent JT COMP approaches, also delineating the JT COMP concept provided in the pivot paper as well as other supporting information.

2.3.1 Non-Coherent Joint Transmission

Users in COMP who experience fast displacement often have low network coverage and spectrum efficiency. This problem is discussed in Shangbin and Yinan, 2018, and it showed that distributed non-coherent JT COMP can serve COMP users in high displacement. The work submits that latency and mobility interruption time should be improved to guarantee smooth transitions when a user *k* is traveling from a certain cell *A* and through another cell *B*. The work ignores the latency across the backhaul and offers that each TP will perform single layer transmission to a UE (indicating a homogeneous network) and these TPs are grouped into a number of disjoint COMP sets, meaning that a TP will not be a member of two different COMP sets.

In user centric non coherent JT COMP where the user experiences hand-off due to movement, the work in Bao and Liang (2018) investigates various clustering modes in order to analyse the hand-off rates and downlink data rates for the JT COMP, both of which are captured as a trade-off of the other. The paper optimised the coordinated cluster size and analysed the average downlink user data rate under a common non-coherent JT COMP scheme. In the research the non-coherent JT produces significantly more overhead and cost of latency for this method was not analysed.

2.3.2 Coherent Joint Transmission

The problem of the number of COMP control messages is the focus of the research in Etemad (2017). The paper presents a new algorithm which can reduce the number of control messages, and consequently increase uplink and downlink data rates. The result is simulated on a Discrete Events Systems (DEVS) package, and it is also shown that latency both in user and control planes directly affects the throughput of the network. The research further shows that the network throughput can improve by 20% if the latency is reduced by 5 ms. The number of control messages is not shown, and the impact of various number of users is not analysed.

In order to solve the problem of resource allocation in COMP, the work in Anatolij *et al*., (2020) develops a scalable COMP scheme which is also network-centric, that is a scheme which only takes the needs of the network into consideration instead of user needs. The work jointly tries to limit interference coming from base station groups, as well as reducing the complexity of COMP. However, unlike other works it does not show a reduction in number of overhead messages. Also, it is not clear how a particular group of users will be catered to by a cluster of base stations irrespective of the number of mobile stations grouped together for the COMP transmission.

In ultra-dense networks (UDN) employing the use of JT COMP, interference is significant. The research in Shuyi *et al.,* (2019) performed a deep analysis of the promising role of joint transmission in small base stations network, considering complexities such as difficulty in determining the proper cell corner. One aspect of JT COMP that needs attention in this work is the number of control messages required in this scheme for JT COMP in UDNs.

In order to mitigate the persistent problem of prohibitive number of control messages, Antti *et al.*, (2018) uses coordinated scheduling and beamforming instead of the joint processing approach used by majority of writers in the literature. However, beamforming requires fast CSI exchange between the UE and the base station, which still has significant control messages to share on the network. In order to mitigate this problem of the number of control messages required, base stations were not required in the scheme to exchange control information but can simply assess the channel reciprocity and pilot signalling to decide on beamforming commands. But the interference mitigation technique employed by using training signals showed a relatively poor signal quality compared to other schemes.

The number of control messages in distributed JT COMP is a problem for the Access Points (APs) which are controlled by the network. In Giovanni *et al.*, 2019 it is shown that although it is intractable to scale the MIMO network for APs in distributed JT COMP, it can be achieved if the boundaries of cell networks are removed. Therefore the work presents a border-less network system called the "ubiquitous cell-free" massive MIMO. A concept that combines massive MIMO technology and user-centric transmission in a distributed network architecture. All the Transmission Points (TPs) in the network cooperate to jointly to serve a smaller number of users in the same time-frequency resource block segment. However, this coordination needs significant amounts of control signalling which introduces additional overhead. The work also does not show the effect of large and smaller numbers of users spread out in the network area.

JT COMP is shown in Ali *et al.,* (2017) to have computational complexity due to the need to achieve coordination among the base stations. Also the problem of throughput in JT COMP is discussed in the work. The JT approach was discussed under major themes, partial JT COMP, complete JT COMP. Whereas the complete JT COMP required all users within the cell to be jointly transmitted to, irrespective of the relative position of the UE, partial JT allows only cell corner users to use JT COMP to improve signal power and data rates. The work also derives an optimal scheduling approach for the various themes of JT aforementioned. The work did not show any improvements in other key aspects of JT COMP such as signal quality and amount of control messages sent.

The amount of control messages used in JT COMP differs from architecture to architecture. In Etemad (2017) these architectures are analysed, and it is shown that JT COMP may operate a centralized or a distributed structure. The work analysed the amounts of control messages for different layouts using tools like Python, Network Simulator-2 (NS-2)/Network Simulator-3 (NS-3), OPNET, and OMNET++. Irrespective of the architectural layout of the JT COMP, the work established that control messages remain prohibitively large in JT COMP, but did not demonstrate that it could reduce it. Also latency and user traffic were not analysed.

The problem of radio resource usage in JT COMP was discussed in the work of Sahrish and Munam, (2018) who suggested that a dynamic rather than an ossified or fixed network structure leads to efficient resource management. The work argues that it is more resource efficient for the UE to decide whether to use JT COMP. The decision for a UE to choose service with or without cooperation was directed by a family of geometric policies, depending on its relative position to its two closest TPs. However, the work did not sufficiently discuss interference, especially for the macro cell level and did not address the persistent JT COMP problem of control messages over the backhaul.

The number of control messages causing a bottleneck in the backhaul processing remains a problem for JT COMP. The research done in Bassoy *et al.,* (2017) suggests that control messages transmitted across the network depends on the size of the cooperating cluster. It discusses the Self-Organizing Networks (SON) approach to clustering as a way of limiting the required number of control messages across the network. In order to limit the inter-cell interference in the network, some base stations which will not transmit useful information in the joint transmissions would turn off. This scheme though intuitive did not address the result outcomes with various user traffic scenarios.

The quality of the channel indicated by SINR is used to assess the channel capacity for JT COMP and Denny *et al.,* (2019) suggests that capacity can be increased when the Non-Orthogonal Multiple Access (NOMA) is used with JT COMP. NOMA primarily shares the same physical resources to all users, but inherently determines different power allocations for each user. The work which is network centric did not discuss users' perceived quality of service, and the implication of the proposed systems on the backhaul.

Coverage and capacity in JT COMP were the focus of the research in Yan *et al.,* (2020). It makes quick analyses of statistical and deterministic models for COMP. An interesting part of the work is the determination of the geometric cell design, with polygons fitted in what is known as a tessellation. The polygons represented the actual cell, which is a deviation from fixed hexagonal concepts common in the research area. The reason suggested by the work for use of polygons is that cell boundaries are very irregular and should not be represented by regular repeating shapes. But the tessellation implies that there is no area without a cell coverage, and this may present a further challenge in the physical modelling of wireless cellular networks since there are areas without cellular coverage around many of our communities in Nigeria. Perhaps it presents a continued research focus, for the design of more realistic cell types that represent our reality better. Nothing was discussed about backhaul capacity which will have to process the control messages required for the JT COMP.

The JT COMP problem of optimal resource allocation is discussed in Baccelli and Giovanidis (2014). JT COMP is implemented with Orthogonal Frequency Division Multiplexing (OFDM) and to address the problem of resource allocation by unbundling the problem into four sub-problems and solving them individually in the algorithm in order to reduce the computational complexity. The scheme proposed by the work is network centric and does not cater to user needs in the spatial arena. The scheme proposed does not discuss the number of control messages in relation to the proposed scheme, nor does it analyse this with respect to number of users in the network.

In order to achieve lower complexity and low amounts of control messages required for the JT COMP approach, the work in Kazi and Wainer (2020) proposed the Direct-CSI to Election Coordination (DCEC) scheme for the COMP JT. It required the main base station to sample the calculated throughputs of each base station in the cluster and elect the base station with the highest throughput as cluster head. The cluster head will be responsible for coordinating the base stations to jointly transmit to the edge user. However, this system suffers a unique setback: whenever it elects its cluster head, a large amount of overhead is transacted. This implies that when there is a change in the throughput, or new members are introduced to the cluster, and a re-election occurs, the process of frequent election of cluster heads practically undoes the gains made in lowering the overhead.

2.3.3 COMP Joint Transmission Aerial

Beyond terrestrial based transmission points, Muhammad *et al*., (2019) shows that user-centric JT COMP can enhance the network capacity of terrestrial cellular systems when implemented on high altitude platforms (HAPs) which is the hosting plane of this proposed method. The work conducted Coordinated Multipoint (COMP) through an aerial vehicle is able to project beams to the surface of the ground for the users within its range to achieve very high coverage for a particular period of time. Joint transmission is also important here because beams may overlap, and also terrestrial based UEs can jointly process signals from the land base stations and the high-altitude platform. The work suggests that in order to achieve tight synchronisation with terrestrial e-NodeB's, a C-RAN is best suited to a distributed system which is more prone to acquiring large administrative overhead. The scheme does achieve larger coverage but incurs large control overhead. Latency was not analysed in the work, as well as impact of varying number of users.

2.4 Clustering and Clustering Approaches

In this work, the clustering approach requires the UE to transmit a report of the received signal strengths of interfering base stations, in order to determine the cluster that best suites the UE based on a predetermined threshold. Determining a cluster based on indices perceived by the end user is known as User-Centric Clustering.

Other clustering approach is called network centric clustering. Here the size of a cluster is fixed, and the edge user is automatically assigned to a cluster according to the network design. The edge user does not have an input to what determines the cluster for joint transmission. This approach incurs less control overhead data but does not maximise the spectral efficiency and COMP gains of the network. There is also hybrid clustering which involves a combination of both user-centric and network-centric clustering.

Table 2.1 shows that authors in the literature have designed various approaches to base station clustering, with various clustering criteria as tabulated.

Table 2.1: Some Common Clustering Concepts

S/N	Author	Criteria used in clustering
1	Shuyi *et al.,* (2019) Mao *et al.,* (2019) Anatolij *et al.,* (2020)	Proximity to base station, and pre-determined received power threshold
2	Kazi and Wainer (2020)	Best throughput based on predetermined threshold
3	Beneyam *et al.,* (2015)	Availability of radio resource for allocation

2.4.1 Reasons for Choosing the Threshold

The differential value in average received power from the main base station ensures that only base stations with similar received power levels are in the cluster to maximize interference cancellation from COMP and prevent the unnecessary addition of base stations to the cluster that increase coordination costs in the homogeneous network (Bassoy *et al.*, 2019). It also eliminates base stations which do not provide the required level of coverage for the cell edge users. It is expected that other base stations in the area are serving base stations to other sets of UEs in their cells. In order to capture the base stations in proximity of one hop length for homogeneous macro networks, 6dB threshold is recommended based on deterministic measurements (Bassoy *et al.*, 2019).

2.5 The Direct CSI-Feedback to Elected Coordination Station (DCEC) Joint Transmission Approach

Feedback latency and control data signalling are very significant factors in network degradation for cooperative networks, such as the COMP joint transmission. In the literature, one approach that significantly improved in these parameters of latency and amount of control data signalling is the DCEC. In the work by Kazi & Wainer (2020), the DCEC as analysed was demonstrated to be a type of centralised joint transmission coordination architecture. The work demonstrated that DCEC could reduce control data signalling by as much as 48%.

The DCEC approach used the received signal strengths of the base stations as reported in the CSI of the edge user as the criteria for selection of the cluster set. This implies that a threshold is pre-selected, such that only base stations that scale this threshold will be admitted into a cluster set. This suggests that the DCEC uses a user-centric cluster approach.

Unlike the centralised and distributed approach which have no cluster-heads, the DCEC introduced the “election of a cluster head” to oversee the coordination of the cooperative network. This election meant that one of the base stations, the elected head of cluster, will perform processing functions for the joint transmission. The criteria for becoming the cluster head is a network performance index known as “throughput.”

However, when there is a “random change,” that is, a change in the estimated throughput of any of the base stations in the cluster, the process of election of a cluster head is re-initiated. Also, during the entry or re-entry of an edge user into the edge region, the DCEC initiates an election for its cluster-head.

The process of election of the cluster head is shown from the work’s simulations to be control-data-intensive. This means that frequent entry into the edge region or relatively frequent changes in the throughput of the members of that cluster will drive up the amounts of control data used. This apparent setback degrades the performance of the DCEC approach. This approach of re-election of cluster head in the event of change in throughput of base station or entry of a new user is captured in Figure 2.5.

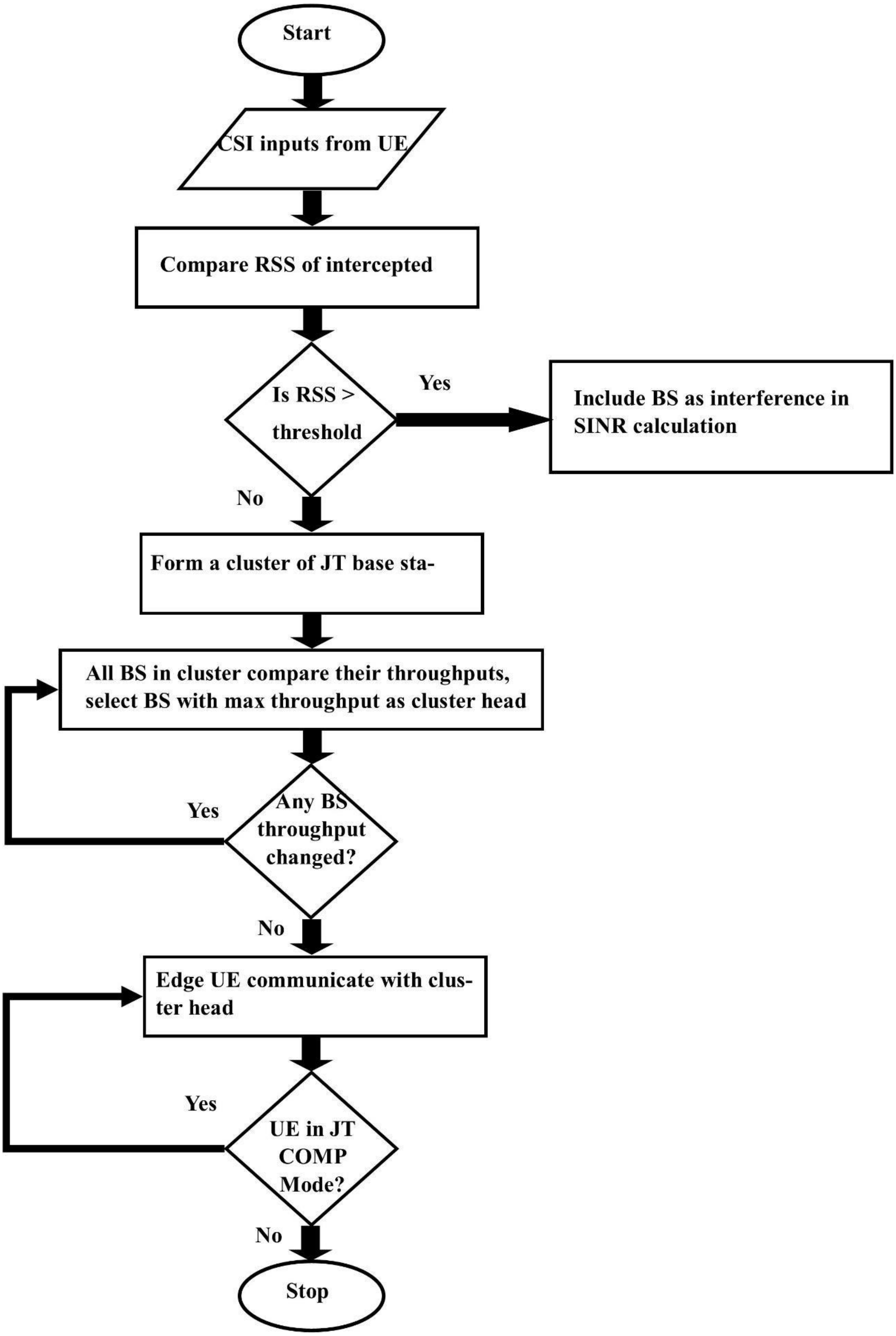

Figure 2.5: The DCEC Operation Flow Chart

2.6 Overview of the Coordination Schemes

In all coordination schemes simulated in this work, the main base station uses the CSI generated from the edge user equipment to determine the cluster for the user equipment. However, for the DCEC and the introduced Hierarchical JT Coordination Scheme, a cluster-head is elected to manage network functions for the cooperative network. Figure 2.6 shows a pictorial comparison between the centralised scheme which does not have a cluster head, the DCEC and the Hierarchical scheme which uses a cluster-head table.

The stages in which control data is transmitted along the X2 interface are highlighted in blue circles. For the centralised scheme, it can be seen in Figure 2.6a that the CSI is always passed on to the main base station, which in turn transmits same to the central unit for processing. The control data from the CSI input is passed along the X2 interface to the CU, and then in turn to the base stations which are members of the cluster.

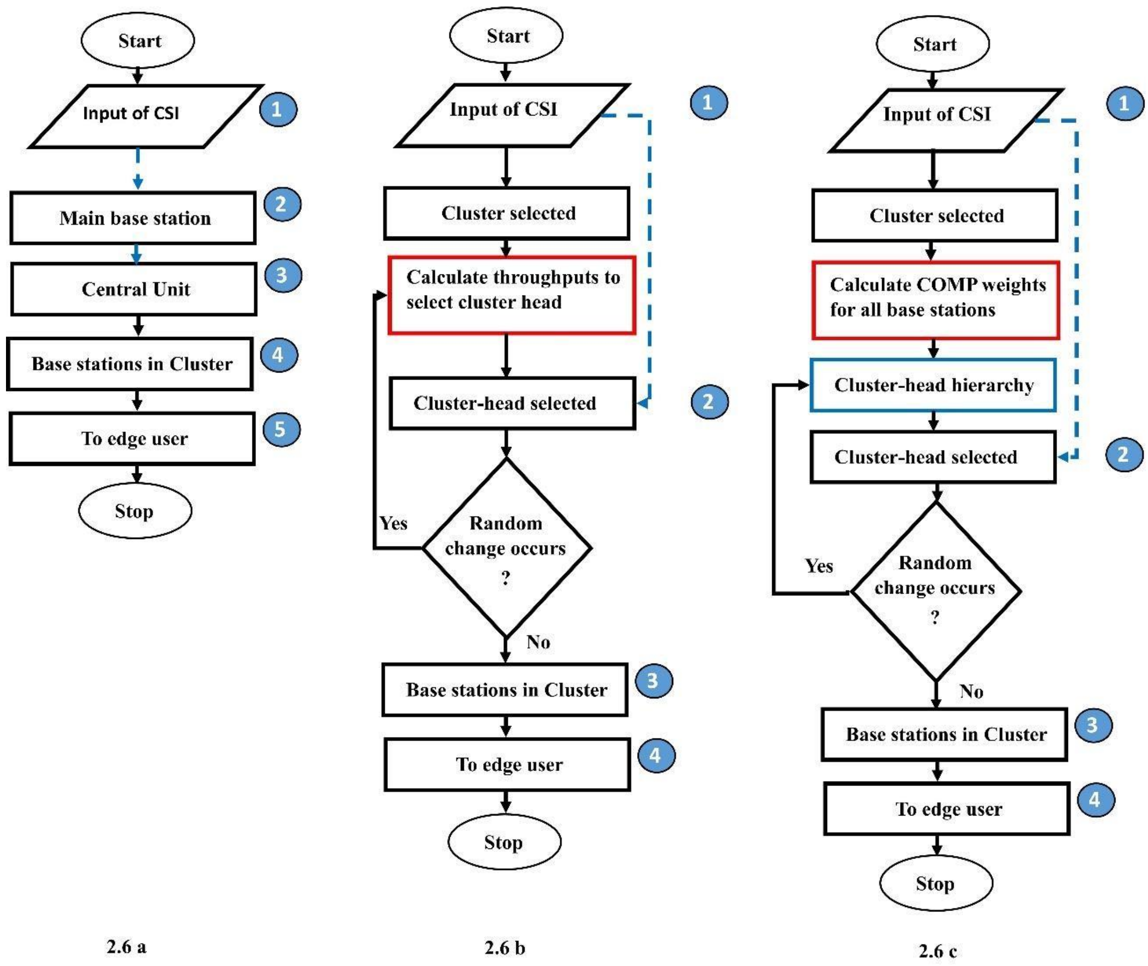

Figure 2.6 a – c: Overview of the Coordinating Schemes (2.6a – The Centralised Architecture, 2.6b – The DCEC Architecture, 2.6c – The Developed Hierarchical Cluster-Head Table Architecture)

The DCEC coordination approach, which is the project's benchmark, is shown in Figure 2.6b. After the control-data-intensive process of electing a cluster head, the CSI of the edge user is passed directly to the cluster head. Therefore, in the DCEC, control data along the X2 interface only passes from the cluster head to the base stations which are members of the cluster. Unlike the centralised architecture which has three points, there are just two points across which control data is passed along the X2 interface. The red box denotes the actual control-data-intensive segment of the DCEC coordination approach.

In Figure 2.6c, the developed scheme can be seen with two active stages in which control data signalling of the joint transmission is transmitted along the X2 interface. However, the hierarchical cluster-head table enables the developed scheme to bypass the requirement to re-iterate for the cluster-head. This is because the iteration for cluster head is a control-data-intensive process, and one of the objectives of this research is to reduce the amount of control data signalling required to perform joint transmission.

2.7 Summary of the Literature Reviewed

The literature reviewed showed various notable attempts to improve JT COMP by reducing the number of control messages or improving on the SINR index or in some cases reducing latency of communication. However, a majority of works did not use any fairness method to allocate cluster coordination to a base station, which means limited radio resources of their base stations could be stretched too thin so long as the base station implements JT COMP. also most of the work reviewed did not analyse JT COMP for different user traffic scenarios as in real life, which means there is a vague expectation of how their schemes will perform for large and small numbers of users alike.

Table 2.2 tabulates the summary in detail per work reviewed in JT COMP as follows:

Table 2.2 Summary of the Literature Reviewed

S/N	Reference	Research Method	Strength	Weakness
1	Hasnain A. A., Habib A. M., Bilal K., and Saad Z. (2017). Pairing and Scheduling for Large Array MIMO Using Regularized Channel Inversion Receivers over Nakagami-m Fading.	The work proposed an approach to assigning of base stations that would limit the user data transfer rate.	Relative computational simplicity by use of normalisation algorithms	Suffers from significant interference and not very suitable for heterogeneous environments
2	Deghel M., Stug E. B., Assaad M., and Debbah M. (2015). On the Benefits of Edge Caching for MIMO Interference Alignment	The scheme presented shares the requests from users into special and general data, which are sourced over the network and locally respectively to achieve higher rates	Higher throughput Better data rates	No SINR improvement captured Work did not assess latency in the network

S/N	Reference	Research Method	Strength	Weakness
3	Fumiyuki A., *et al* (2019). Distributed MIMO Cooperative Transmission Technique and Its Performance. IEEE/CIC International Conference on Communications in China (ICCC)	The authors studied various coordinated MIMO approaches, and proposed a method to improve on spectrum efficiency by determining base station clustering.	Improved throughput capacity	Large amount of control data; Significant backhaul requirement to implement coordinated MIMO
4	Yan L., Minghua X., and Sonia A. (2020). Coordinated Multi-Point Transmission: A Poisson-Delaunay Triangulation Based Approach.	The work acknowledges that cellular areas may not be regular. A decomposition approach was proposed to the problem of joint scheduling	Low interference index	High bandwidth required due to the large amount of base stations in the cluster
5	Ralph T, Sarabjot S., *et al* (2014). Analysis of Non-Coherent Joint-Transmission Cooperation in	The authors show that the gains that can be achieved in COMP deployed for small cells is very limited.	Marginally better data rates	Out-dated CSI problems for the UEs

S/N	Reference	Research Method	Strength	Weakness
	Heterogeneous Cellular Networks. IEEE International Conference on Communications.	Although improvements can be seen when implemented		
6	Beneyam B. H., Edward M. and Jyri H. (2015). Coordinated Multi-point Transmission for Relaxation of Self-backhauling Bottlenecks in Heterogeneous Networks. EURASIP Journal on Wireless Communications and Networking 2015	The cluster is formed according to perceived received signal powers. However the authors do not agree that gains can be made in non-coherent JT	Low complexity, Improved SINR	No mention about the bandwidth used up in coordination
7	Jiaqi C., *et al* (2019) A Novel JT COMP Scheme in 5G Fractal Small Cell Networks. IEEE Wireless Communications and Networking Conference (WCNC).	The authors developed an algorithm for clustering among Small Base Stations (SBS) whose clustering was determined by a cooperation activation threshold	High data rates were achieved in this work for the users in joint transmission	Synchronisation problems with SBS transmission points

S/N	Reference	Research Method	Strength	Weakness
8	Faizan Q., Kaharudin et al (2017). A Comprehensive Review on Coordinated Multi-point Operation for LTE-A.	The work analyses the cost of self-backhauling in micro sites, and goes on to develop some network performance metrics for evaluation	SINR gains in joint transmission. Power conservative system	Latency did not improve in this work, and backhaul capacity was not shown to reduce
9	Shangbin W. and Yinan Q. (2018). Centralized and Distributed Schedulers for non-Coherent Joint Transmission. IEEE Globecom Workshops.	Unlike most literature that limits the speed of the user, this work developed a joint transmission approach for users in high displacement and sensitive to latency	Less stringent network requirements such as application to users on faster speeds than 3kmph	Higher latency than expected; Synchronisation was not discussed
10	Etemad S. M. (2017). Simulation of Coordinated Multipoint Using Discrete Event Systems Specification	This work breaks from the norm for most, and proposes that users become co-processors in the joint transmission	Timely CSI exchange	Power drain at the user jointly performing calculations

S/N	Reference	Research Method	Strength	Weakness
11	Anatolij Z., Ahmad R., Suzan B. (2020). On Practical Cooperative Multi Point Transmission for 5G Networks. Computer Networks.	The work based their findings on site measurements, suggesting that COMP JT did not provide much gains compared to beam-forming for instance.	Lower overhead with beamforming	Synchronisation problems with the transmitters
12	Shuyi C., *et al* (2019). Performance Analysis of Downlink Coordinated Multipoint Joint Transmission in Ultra-Dense Networks – A Unified Approach. IEEE/ACM Transactions on Networking, Volume (28) Issue 1.	Analysis of JT COMP in small cells was performed here, and the problem of being able to determine proper cell corners was noticed.	Comparatively better spectral efficiency than non JT COMP for the small cell	Bandwidth usage in the backhaul was high
13	Antti T., *et al* (2018). Distributed Coordinated Transmission with Forward-Backward Training for 5G Radio Access.	Using time division duplexing (TDD) the authors proved that backhaul could be significantly minimised.	Lower need for backhaul use.	No discussion on synchronisation

S/N	Reference	Research Method	Strength	Weakness
				Lower delay measured
14	Giovanni I., Frenger P. and Erik G. L. (2019). Scalability Aspects of Cell-Free Massive MIMO. IEEE International Conference on Communications (ICC).	The work introduces the concept of cell-free MIMO over which JT COMP can be implemented.	Lower SINR index	Large amount of control signalling required
15	Ali M. S., Nadira P. and Md. F. U. (2017). Optimal scheduling of coordinated multipoint transmissions in cellular networks. International Journal on Communication Systems.	COMP scheduling was found to be less computationally exhaustive than JT COMP schemes	Optimised scheduling of transmission	Backhaul dependence is high
16	Sahrish K. T. and Munam A. S. (2018) Resource allocation in SDN based 5G	The work developed a JT COMP scheme in which the users will determine by various geometric	Improved latency across the network	Relatively poor SINR based on

S/N	Reference	Research Method	Strength	Weakness
	cellular networks. Peer-to-Peer Networking and Applications.	policies whether to use JT COMP or not.		existing significant interferers. Large control data
17	Kazi B. U. and Wainer G. (2020). Coordinated multi-cell Cooperation with User Centric Dynamic Coordination Station.	The work proposed an advancement in JT COMP in which the cluster control resides in one base station. It uses an election algorithm to select the cluster head.	Low amount of control data during the steady phase of JT COMP	High frequency of election of cluster heads election can undo the gains made in lowering control data
18	Muhammad *et al* (2019). Exploiting User-centric Joint Transmission Coordinated Multipoint with a High Altitude Platform System Architecture.	JT COMP can be implemented using aerial vehicles in what is known as high altitude platforms. It suggests that terrestrial base stations can cooperate	High SINR and quality signal reception even in situations of large	High amounts of overhead.

S/N	Reference	Research Method	Strength	Weakness
		with aerial vehicles to provide JT COMP gains for users.	crowding for events such as sports	Synchronisation problems between transmission points

CHAPTER THREE

3.0 METHODOLOGY

3.1 System Model

The joint transmission Coordinated Multipoint (JT COMP) system developed is modelled after the hexagonal cell, a well-known stochastic geometric format. As shown in Figure 3.1 the base stations are located in the middle of the cells, while the region of interest in this project is the cell edge region which extends from 300 metres outside the centre of the cell to 500 metres, for the cell whose radius is 500 metres.

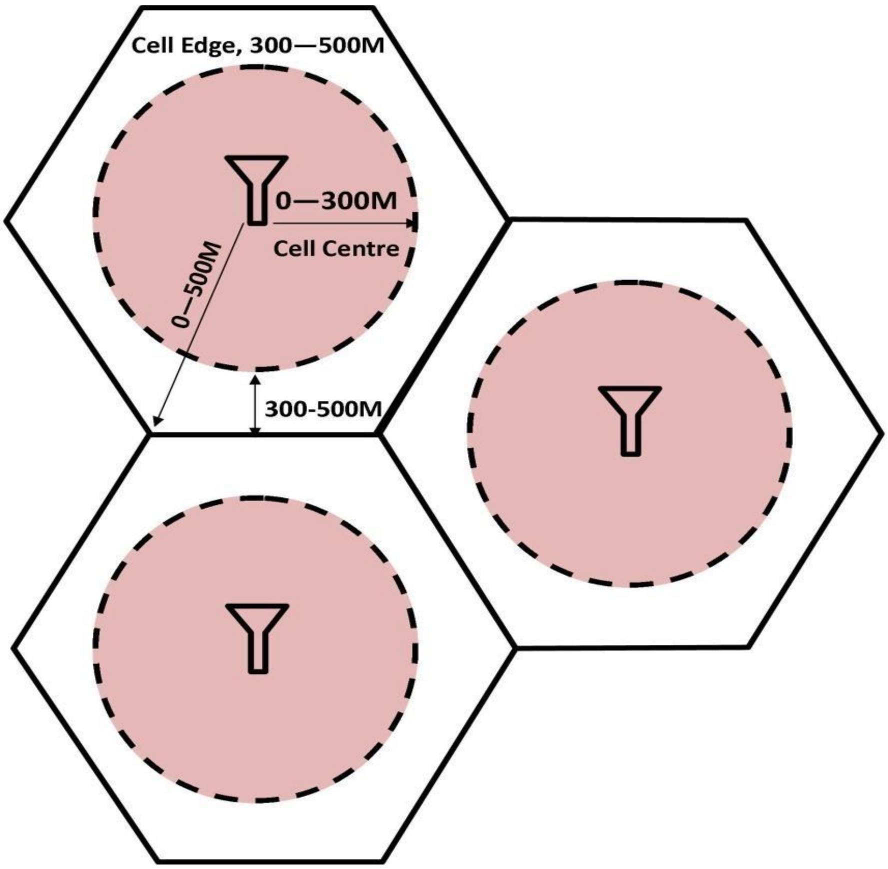

Figure 3.1: System Model Diagram (Adapted from Kazi and Wainer, 2020)

For the JT COMP to determine its cluster, *Ci*, first the *k-th* edge user in the cell intercepts and reports the received signal strengths of various adjacent base stations *Bi* for all *i = (1,* *2, . . . , n)* whose downlink pilots it has received. Thereafter receiving the CSI feedback, MeNB uses the report of the received signal strengths of adjacent interferers, to determine the set of base stations that can jointly transmit to the target edge user.

3.1.1 The Transmitted and Received Signals

MeNB which serves the k-th edge user initiates the election algorithm by forwarding an initialisation message to other base stations which meet the minimum required interfering signal strength based on the predetermined threshold that pre-qualifies the adjacent base stations to participate in JT COMP. In this work, it is assumed that resource blocks (RBs) for cell edge users will always be present for joint transmission with other base stations in the cluster.

From Giovanni *et al.*, (2019) we can model the transmitted signal as follows:

$$x = \sqrt{\rho_d} \sum_{k=1}^{K} \sqrt{\eta_{kN}} w_{kN} \; q_k \qquad (3.1)$$

Where ρ_d represents normalised transmit SINR, power control coefficient from base station MeNB to UE k is denoted by η_{kN}, and w_{kN} and q_k represent the precoder and unit-power of actual intended symbol of the k-th user respectively.

For the received signal, the metric of interest is the received power, modelled as follows:

$$y_k = \sum_{\psi_k, n=1}^{N} P_T h_{kn} r_{kn}^{-\beta_{kn}} + \sum_{\Phi_B - \psi_k, n=1}^{N} P_T h_{kn} r_{kn}^{-\beta_{kn}} + \sigma^2 \qquad (3.2)$$

The set of base stations Φ_B contains the cooperating set ψ_k, while P_T, h_{kn}, and $r_{kn}^{-\beta_{kn}}$ are the transmitted power, the Rayleigh power gain and distance of separation from the base station of interest to the target UE. The path loss exponent is $-\beta_{kn}$.

Using a simplified form, the received signal power from Equation (3.4) can be presented as (Rappaport, 2002):

$$P_r = {P_t G_t G_r \lambda^2}/{(4\pi R^2)} \quad (3.3)$$

Where P_t transmit power 43dB from a base station, G_t and G_r = transmit and receive gains of antennas, λ^2 = wavelength and R is the distance between the edge UE and eNodeB.

The edge user is assumed to have low mobility of about 3km/h, so that the complex channel coefficient is considered stable over the duration of one frame. We note also for the work, that the cluster coordination station receives timely and full CSI with no estimation errors.

From the received signal Equation, we can represent the Signal to Noise and Interference Ratio (SINR) as:

$$\gamma_{kn} = \frac{\sum_{\psi_k, n=1}^{N} P_T h_{kn} r_{kn}^{-\beta_{kn}}}{\sum_{\Phi_B - \psi_k, n=1}^{N} P_T h_{kn} r_{kn}^{-\beta_{kn}} + \sigma^2} \quad (3.4)$$

Achievable rate of the edge user k over an assigned Resource Block (RB) is:

$$R_k = B \log_2(1 + SINR_k) \quad (3.5)$$

It can be seen from the received signal Equation, that the SINR of an edge user k is closely related to the clustering approach for joint transmission (JT) COMP. If the base stations which generate relatively strong received signal at the edge user are selected to perform joint transmission (JT) for the target UE, the average SINR improves greatly because signals from the co-channel regions which could have constituted interferences would be converted to useful signal. This implies that average SINR enjoys a positive gradient with respect to number of coordinated base stations.

3.1.2 Distribution of User Equipment

The distribution of user equipment in the cell edge region will follow the uniform distribution pattern during the day, when most of the users in the cell area are nearer the centre of the cell or the base station (Elalem & Zhao, 2009). At night only the density of the users in the cell edge area is assumed to increase, while a uniform distribution is maintained.

3.1.3 Cluster Formation

Cluster formation is common to all types of joint transmission, including the centralised and DCEC coordination schemes, as well as in this project as depicted in Figure 3.2. Since it is the goal of the JT COMP to exploit otherwise interfering signals from co-channel regions, and convert them to useful signals, a pre-selection criterion is adopted for clustering.

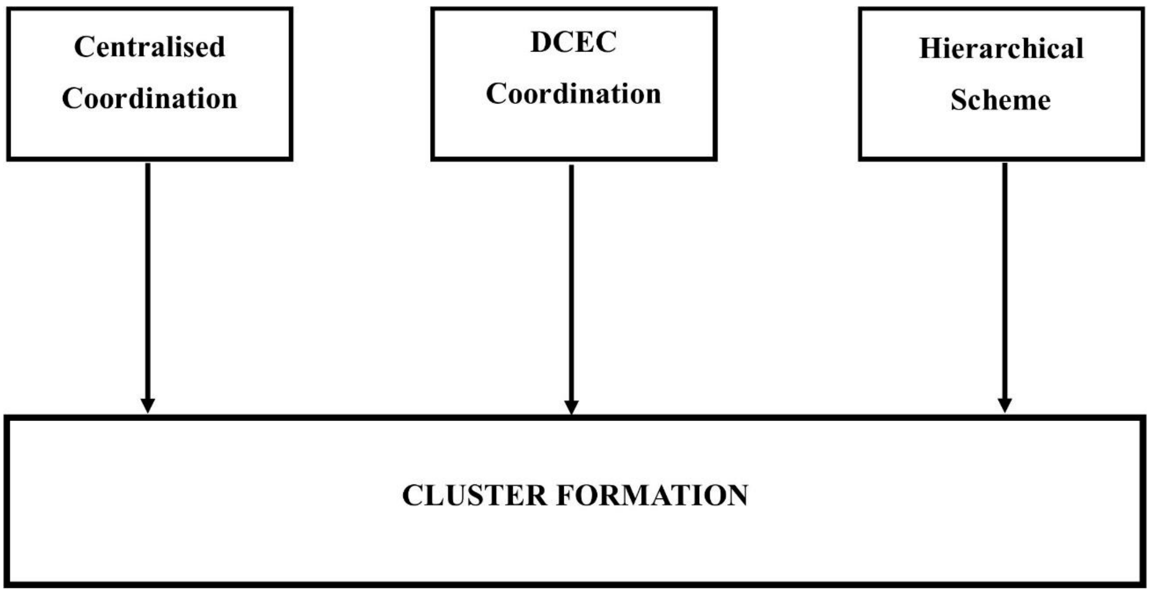

Figure 3.2: Cluster Formations Common to Joint Transmission Schemes

This pre-selection criteria will be the received signal strength (RSS) of received powers. The adjacent base station *Bi* whose pilot signal is reported to be within the threshold value will become a member of that cluster. Referring to 2.4.1 on the reason for threshold, let the threshold $CoMP_{th}$ be taken as 6dB for this work. That is:

$$CoMP_{th} \geq RSRP_{max} - RSRP_{Bi} \tag{3.6}$$

Where RSRP means reference signal received power. If the COMP-threshold is set to 6dB for instance, for an adjacent base station to be a member of the cluster, the RSRP of the adjacent base station *Bi* must not be more than 6dB less than $RSRP_{max}$ received from the main base station MeNB.

So let the set of base stations be $\Phi_B = \{B_i, \forall\ i = 1, \dots, N\}$ (3.7)

Let the set of UEs served by each base station be $U_k^{B_i}, \forall k = 1, \dots, K,\ B_i \in \Phi_B$

3.2 Introducing Weighting Criteria and Cluster Head Hierarchy

In this section, the weighting criteria developed for this project is explained, as well as the build-up of the Cluster-head Hierarchy.

3.2.1 The Weighting Criteria

Earlier on, the received signal strength was used to determine which base stations can be admitted to jointly transmit to an edge user, before the coordination station is even considered.

This work combines metrics of both network performance and COMP performance to develop a weight for each base station. These metrics are namely Throughput and Satisfaction Index, and they are used to determine network (Kazi and Wainer, 2020) and COMP performance (Bassoy *at al.*, 2019) respectively. This weight is used to determine which base station qualifies to be the cluster head for the purpose of coordination of joint transmission. The work shall reward the base station with the highest throughput and COMP gains.

3.2.1.1 The Throughput

The throughput of a base station is one of the key determinants of the performance of that cell. To calculate the throughput, the formula is given in Equation 3.8 as follows:

$$Throughput\ (Th) = TBS \times 1000 \times Mimo \qquad (3.8)$$

Where TBS is called the Transport Block Size, as specified in table 38.214 of 3GPP Release 15 technical specifications (ETSI, 2018). The TBS values can be used to determine the maximum throughput for different qualities of channel state.

For simplicity, the project assumes that MIMO is 1 x 1, and three values of information bits are selected for three hypothetical base stations X, Y and Z from the 3GPP release 15 table for TBS as can be seen in Table 3.1.

Table 3.1: Throughput Calculation Using 3GPP Release 15 MCS Index Tables

MCS Index	TBS	$(\boldsymbol{Th}) = \boldsymbol{TBS} \times \mathbf{1000} \times \boldsymbol{Mimo}$
61	1,288	1.288Mb/s
62	1,320	1.32Mb/s
63	1,352	1.352Mb/s

3.2.1.2 The User Satisfaction Index

The "user satisfaction index" is derived from the cell load-aware analysis developed in Bassoy *et al* (2019). This satisfaction index shows the impact of user density on a base station. Given the same data rates, different user densities will present different loads and therefore different outcomes in terms of user satisfaction.

Cell load analysis is one of the key methods that can quantify the COMP gain of a network (Bassoy *et al.*, 2019), and is given in Equation 3.9 as follows:

$$\hat{l}_{B\iota} = \sum_{k \epsilon U_i} \hat{r}_K / R_{tot} \quad (3.9)$$

Where $\hat{l}_{B\iota}$ is the satisfaction index, r_K is the average physical resource block (PRB) per edge user and R_{tot} is the total number of resource blocks in a base station.

The average PRB r_K can be further obtained as follows:

$$r_k = d_k / y_k B_{PRB} \quad (3.10)$$

$$r_k = d_k / R_k \quad (3.11)$$

$d_k$is the guaranteed bit rate for the UE k in the cell, $y_k B_{PRB}$is the achievable channel capacity, where B_{PRB} is the bandwidth of a physical resource block and

$$y_k = log_2(1 + SINR_k) \quad (3.12)$$

In IMT-2020, a UE which is capable of video streaming and voice calls has a guaranteed bit rate of $60kbps$, for a PRB in LTE, B_{PRB} is $360khz$.

SNR values can be safely estimated given that quality SNR values for voice and internet should be greater than or equal to $20dB$, for this example we use $25dB$.

AWGN plus inter-cell interference levels (Pouria *et al.*, 2018) can be taken as $10^{-13} Watts$

Converting 25dB SINR from logarithmic value to normal figures, we use Equation 3.13 below:

$$dB = 10\log_{10} SINR \quad (3.13)$$

Making SINR the subject of the formula, we have:

$$SINR = 10^{dB}/_{10} \tag{3.14}$$

Putting the logarithmic value of SINR, we have:

$$SINR = 10^{25}/_{10}$$

$$SINR = 316.23$$

For Equation 3.12, having obtained SINR value, we solve for $y_k$as follows:

$$y_k = log_2(1 + 316.23)$$

$$y_k = log_2(317.23)$$

$$y_k = 8.31$$

Then, $y_k B_{PRB}$ can be calculated thus:

$$y_k B_{PRB} = 8.31 \times 360kHz$$

$$y_k B_{PRB} = 2991.6kHz$$

Average PRB for the user k then is:

$$r_k = {}^{60kbps}/_{2,991.6kHz}$$

$$r_k = {}^{1}/_{50}\ bps/Hz$$

If n_k is the total number of UEs in that cell, then the average PRB for all UEs in the cell can be described as follows:

$$\hat{r}_K = r_k \times n_k \tag{3.15}$$

Assume there are 1,000, 1,500 and 2,000 users in base stations X, Y and Z in LTE, the average PRB for all users in the cells would be calculated as follows in Table 3.2.

Table 3.2: Calculating the Required Resource Block for Users

Number of users	PRB for all users ($\boldsymbol{bps/Hz}$)
1,000	$\hat{r}_K = r_k \times n_k = (1/50) \times 1{,}000 = 20$
1,500	$\hat{r}_K = r_k \times n_k = (1/50) \times 1{,}500 = 30$
2,000	$\hat{r}_K = r_k \times n_k = (1/50) \times 2{,}000 = 40$

The cell load, $\iota_{B\iota}$ being the expression of interest is then derived thus:

$$\iota_{B\iota} = \sum_{k \epsilon U_i} r_k / R_{tot} \tag{3.16}$$

Or

$$\iota_{B\iota} = \hat{r}_K / R_{tot} \tag{3.17}$$

Where U_i is the set of connected users in cell 'i', and R_{tot} is the total number of resource blocks in a cell. For LTE base station with 20MHz channel, there are 100 PRBs in total. Which implies that $R_{tot} = 100$.

In the Table 3.3 calculation for the cell load for two cells with users 1000, 1500 and 2000 is as follows:

Table 3.3: Cell Load Calculation

Number of Users	PRB for All Users (bps/Hz)	Cell Load, $\ell_{B_i} = \hat{r}_K / R_{tot}$
1,000	$\hat{r}_K = r_k \times n_k = (1/50) \times 1{,}000 = 20$	$\frac{20}{R_{tot}} = \frac{20}{100} = 0.2$ or 20%
1,500	$\hat{r}_K = r_k \times n_k = (1/50) \times 1{,}500 = 30$	$\frac{20}{R_{tot}} = \frac{20}{100} = 0.3$ or 30%
2,000	$\hat{r}_K = r_k \times n_k = (1/50) \times 2{,}000 = 40$	$\frac{40}{R_{tot}} = \frac{40}{100} = 0.4$ or 40%

By observation, the cell with only 1000 users can accommodate 5 times more users to reach its full satisfaction index of 100%, whereas the cell with about 2000 users can serve 2.5 times more users. This suggests that cell with 1000 users is more preferred to host edge users from additional cells, than the cell with 2000 users with respect to load impact.

The objective of every cell with respect to cell load considerations is to deliver the guaranteed bit rates of each connected user. If this is achieved, then all connected users' communication needs have been met, which implies 100% user satisfaction.

From the Equation, user satisfaction can be determined based on the value of ℓ_{B_i} being less than or equal to 1 or 100%. If ℓ_{B_i} has value of 200%, it would imply that only ½ of total users are satisfied.

3.2.1.3 The Cluster-Head Table

This project intends to reward jointly the base stations that have the highest throughput and best satisfaction scores, using the COMP weight in Equation 3.16 as follows:

$$W_{COMP} = \frac{Th}{l_{Bi}} \quad (3.18)$$

Where Th is the throughput and l_{Bi} is the user satisfaction index

The dividend W_{COMP} is the COMP weight. An example has been setup in Table 3.4. It can be seen that although base station X does not have the highest throughputs in the hypothetical cluster of base stations X, Y and Z, its load impact figure is the least. This means that the base station X can bear the load of more users and satisfy their data requests due to sufficient resource blocks. Base station X becomes the cluster coordination station for the JT session, and Table 3.4 is known as the Hierarchical Table for the JT session.

Table 3.4: COMP Dividend Calculation for Hierarchical Scheme

Base station	Th	l_{Bi}	$W_{COMP} = \frac{Th}{l_{Bi}}$
X	1.288mb/s	0.2	6.44×10^6
Y	1.32mb/s	0.3	4.4×10^6
Z	1.352mb/s	0.4	3.38×10^6

3.3 The Hierarchical Cluster-head Table Algorithm

The following algorithm is used to implement the developed system:

1. K*th* cell edge UE intercepts Received Signal Strengths (RSS) of adjacent base stations, and forwards CSI report to serving base station, MeNB for pilot signals in the downlink

2. MeNB processes the CSI feedback to determine UE position in the cell area, and also COMP cooperation set for the k*th* UE based on predefined RSS threshold criteria
    a. RSS threshold limits base stations with received power lower than 6dB from the MeNB received power.
    b. If eNodeB has signal strength within 0 – 6dB of the main eNodeB, that base station will pre-qualify to join the JT COMP cluster for the K*th* cell edge UE.
3. MeNB declares itself as the Coordination Station (CS) for the specific kth cell edge UE
4. The self-declared CS sends a CS-declaration message along with its achieved throughput and measured user satisfaction index to other base stations that have pre-qualified for Joint Transmission (JT) for the cell edge user, along with the expected clustering set.
5. The other base stations will compare the indices of the MeNB with their own and forward same to the main base station,
6. Main base station will use the method of weighting to determine the rank of the cluster coordinating base stations.
7. If the cluster coordinating station, throughput or satisfaction index changes, the MeNB sends command for cell edge user to transmit CSI to next higher rank in coordinating station set.
8. If UE enters cell centre, end JT COMP processes.

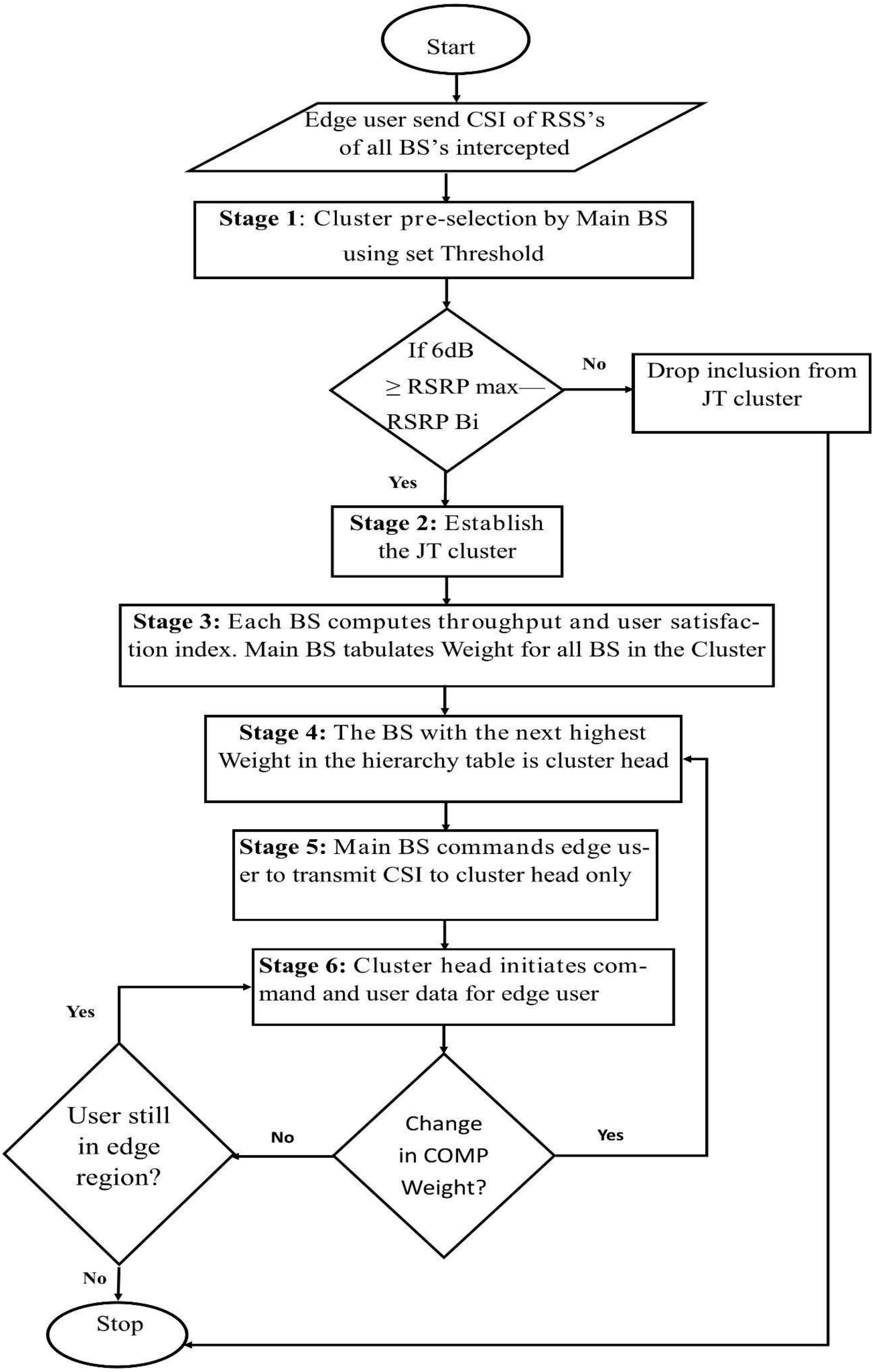

Figure 3.3: Flow Chart of the Hierarchical JT COMP Scheme

Pseudocode

Initialise,

Fetch MBS; [main base station]

ABS; [adjacent base station]

UE; [edge user equipment]

C=0; [cluster]

Edge region = radius {300…,500}

CSI=0; [channel state information]

Enter CSI

MBS;

ABS= {1, 2,…,N}

Calculate RSS

BS= {1, 2…,N}

Let max RSS = MBS

If MBS – BS <= 6dB [for all BS]

Add to set C;

Else

Discard

For all elements in set C:

Calculate

Throughput;

Satisfaction index;

COMP Weight;

Print descending order of COMP Weight;

If element in set C = max COMP Weight;

Then max COMP Weight = cluster head;

If UE in edge region:

Let Cluster head = MBS

Else let max RSS = MBS

3.4 Calculating the Number of Control Messages

It is very desirable to develop and implement JT COMP schemes which are able to perform coordination with less control data signalling. The interest of this work is to reduce the required capacity of the backhaul in the scheme when compared with any state of the art scheme.

According to the technical specifications in 3GPP TS 36.213, each CSI report is composed of the Channel Quality Indicator (CQI), the Precoding Matrix Indicator (PMI), the Precoding Type Indicator (PTI) and/or the recommended Rank Indicator (RI) of the UE. One scheme that can be used to effectively determine backhaul capacity in the JT COMP network developed is the wideband feedback scheme (Kazi & Wainer, 2020).

$F_{WB_k} = CQI_t + RI_t + PMI_t$

(3.19)

$F_{WB_k} = Nb_{CQI_t} + Nb_{RI_t} + Nb_{PMI_t}$

(3.20)

Where Nb is the number of bits, k is the edge user, t is the time of estimation of bandwidth.

Each CQI is a 4-bit transmission which occurs in one slot. For 2 slots to give 1ms, the UE needs (2)4 number of bits. CQI also includes considerations for number of transmit antennas. We assume that each base station uses 2 antennas to transmit to the UE by beam-forming, and for this scheme the cell edge UEs communicate with only one base station at any point in time.

From Equation 3.19, for any edge user k in JT COMP, the number of control messages taken up is calculated for any time, t at t = {0,1,2, 3,…,T}

3.5 Impact on Network Latency

While reducing the number of control messages, one important result from the process is the reduction in latency since the channel is expected to be freer and experience less bottlenecks in the X2 interface. The Equation 3.21 estimates the delay in the given communication channel:

$$t_{delay_k} = t_t + \left(t_{air} + \frac{P}{r_{up}}\right) + \left(t_{rout} + \frac{P}{r_{X2}}\right) + t_b \quad (3.21)$$

$$t_{delay_{total}} = n\left(t_t + \left(t_{air} + \frac{P}{r_{up}}\right) + \left(t_{rout} + \frac{P}{r_{X2}}\right) + t_b\right) \quad (3.22)$$

Where t_t is the delay in compressing feedback, t_{air} is over the air delay, t_{rout} is propagation delay, t_b is pre-coding delay, r_{up} is uplink rate, r_{X2} is the data rate over the X2 interface, P i packet size, n is the number of edge users

$$t_{delay_{average}} = {t_{delay_{total}}}/{n} \tag{3.23}$$

Given by eq. 3.23, the average delay can be obtained by dividing the total delay in seconds by the total number of edge users in the cluster.

In Figure 3.4, the flow of COMP JT command for the developed Hierarchical scheme can be seen. The UE on the cell edge sends its CSI to the MeNB (or the main Base Station). The main Base Station forwards a COMP message to eNB2 and eNB3 which are adjacent base stations, if both of them are in a COMP JT cluster. The adjacent Base Stations eNB2 and eNB3 return throughput and satisfaction indexes to the main Base Station, which then calculates COMP weights and announces the Cluster Coordination Station, CCS for the cluster. The main Base Station also directs the edge user to transmit CSI to the new CCS. Afterwards, the edge UE can be seen to transmit directly to eNB3 which was announced as CCS for the cluster.

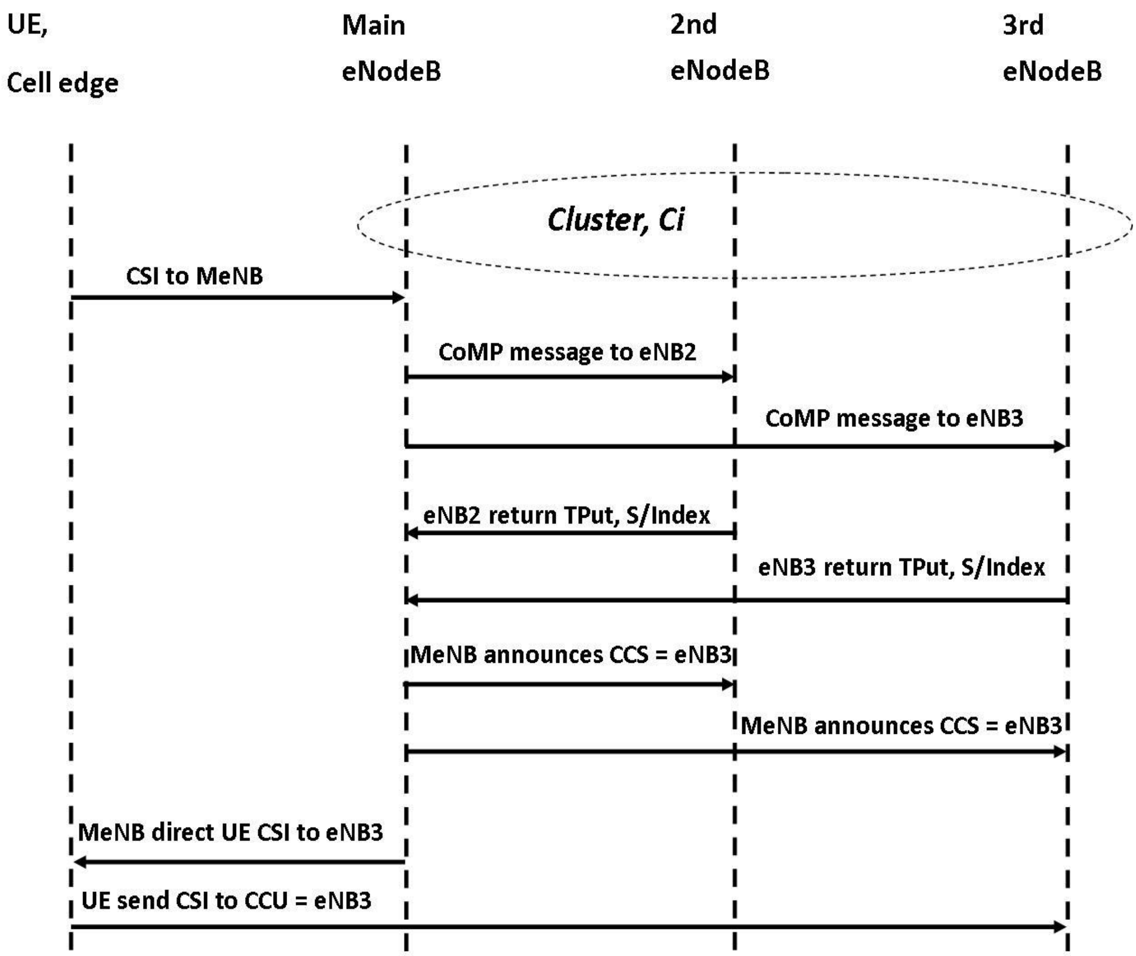

Figure 3.4: Flow of COMP JT Command for the Hierarchical Scheme

3.6 Measuring Relative Performance

In order to measure relative performance of the developed Hierarchical scheme, a well-known formula for percentage reduction adapted from Study.com (2021) can be used, as follows:

$$\%\, decrease = {initial\ value - final\ value}/_{initial\ value} \times 100 \qquad (3.24)$$

With Equation 3.24, the reduction in control data and the latency performance, as well as the SINR reduction can be mathematically analysed.

3.7 Benchmark Joint Transmission Scheme

The work will benchmark results obtained against the **DCEC** which is an improved centralised architecture in which control data signalling is significantly minimised (Kazi & Wainer, 2020) to assess its performance. Performance metrics is the number of bits, for the control data, and milliseconds for the network delay assessment.

3.8 Simulation of Hierarchical JT COMP

The algorithm for the Hierarchical JT COMP was simulated on MATLAB 2019 software. Table 3.5 is a summary of parameters which are used in simulation and analyses of the network model and the joint transmission scheme developed in this work.

We obtain parameters for base station frequency, bits for feedback, number of resource blocks (PRBs), bandwidths of UE and base station, user mobility and CSI periodicity from ETSI (2018) and ITU (2020). Other parameters such as power of transmission and path loss exponent were obtained from Bassoy *et al.*, 2019 and Rappaport, S. T. (2002) respectively. Table 3.5 captures the summary of parameters used as follows:

Table 3.5: Simulation Parameters

Parameters	Values
Macro cell transmit power	43dBm
Cell radius	500m
Frequency of carrier	5000MHz
UE arrival and departure	Uniform random and poisson
CSI report periodicity	10ms
RB bandwidth	180kHz
Path loss exponent	4
Cell edge user mobility	3km/h
Bandwidth of UE	20MHz
Number of PRBs	100
Guaranteed bit rate for the work	60kbps
CoMP threshold	6dB
Number of bits for the CQI	4 bits

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Preamble

In this chapter, the parameters used for all formulas and algorithms introduced earlier in the methodology will be tested and simulated. The results from this simulation will be analysed and compared with an existing state of the art joint transmission scheme. The network parameters are defined, the configurations for the edge user, the base station and coverage layout. MATLAB plots for Control Data, Network Latency and SINR are presented in the chapter.

4.2 Results for Lowering Number of Control Data

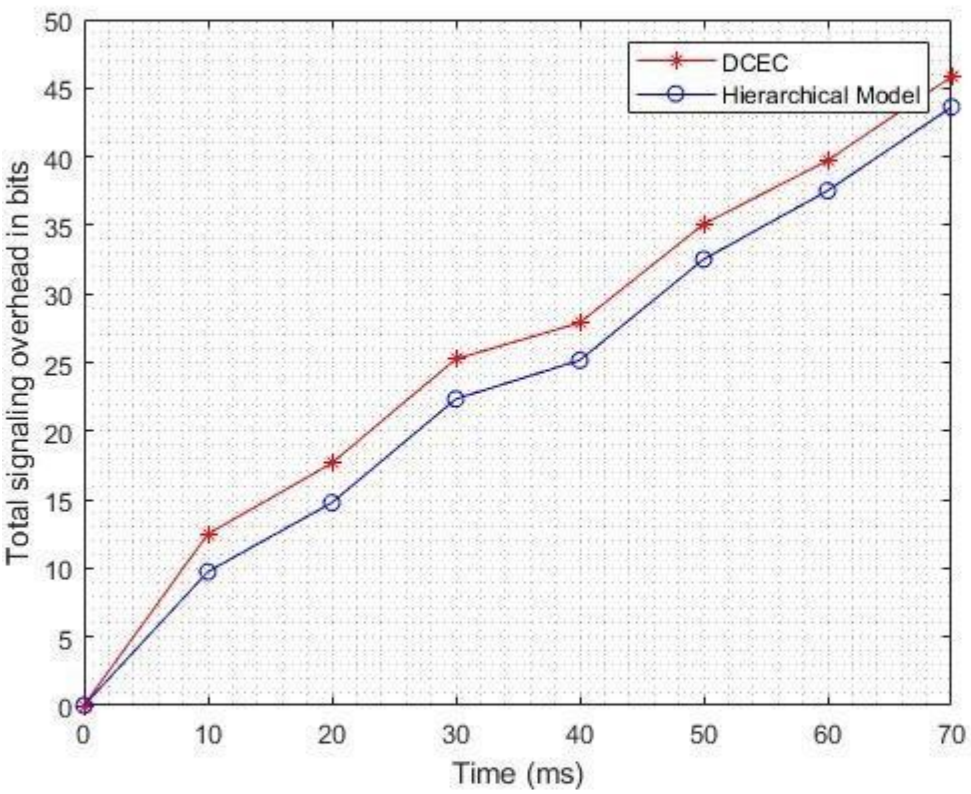

Figure 4.1: Cumulative Count for Control Data Over Time

The graph in Figure 4.1 shows the cumulative of control data signalling in bits for the DCEC model and the developed hierarchical model. It is obtained using the Equation 3.20. The total wideband bandwidth for Hierarchical JT COMP is a sum of the number of bits of the channel quality indicator CQI, the number of bots of the Rank Indicator RI and the number of bits of the Precoding Matrix Identifier PMI for any edge user k at time t.

Initially at t =0, the edge UE enters JT COMP for both DCEC and the developed Hierarchical model. The amount of total signalling overhead in bits is measured at various time intervals of 10ms. The Hierarchical JT COMP approach is seen to generate marginally lower amounts of signalling overhead compared to the DCEC JT COMP.

We assume the DCEC JT COMP is the reference and initial value, while the final value is the Hierarchical JT COMP which is being assessed. If the value is negative, it implies that an increase rather than a decrease occurred.

Table 4.1: Computing Control Data Performance in JT COMP

Time (t in ms)	DCEC	Hierarchical
0	0	0
10	12.5	9.5
20	17.5	14.5
30	25.4	22.0
40	28.0	24.5
50	35.0	32.0
60	39.7	37.0
70	46.0	43.0

Total control data	204.1	182.5

Using Equation 3.24 the total percentage decrease can be found to be

$$\% \, decrease = {}^{204.1 - 182.5}/_{204.1} \times 100$$

$$\% \, decrease = 10.5 \, \%$$

4.3 Analysing Network Delays with Daily Traffic Patterns

According to Heike Young (2014), mobile user activity begins to peak from 10:00am, and all through to between 2:00pm and 3:00pm. Based on this user activity, traffic density was increased randomly and uniformly about the given period, and the total number of control messages exchanged per hour is represented on the graph in Figure 4.2.

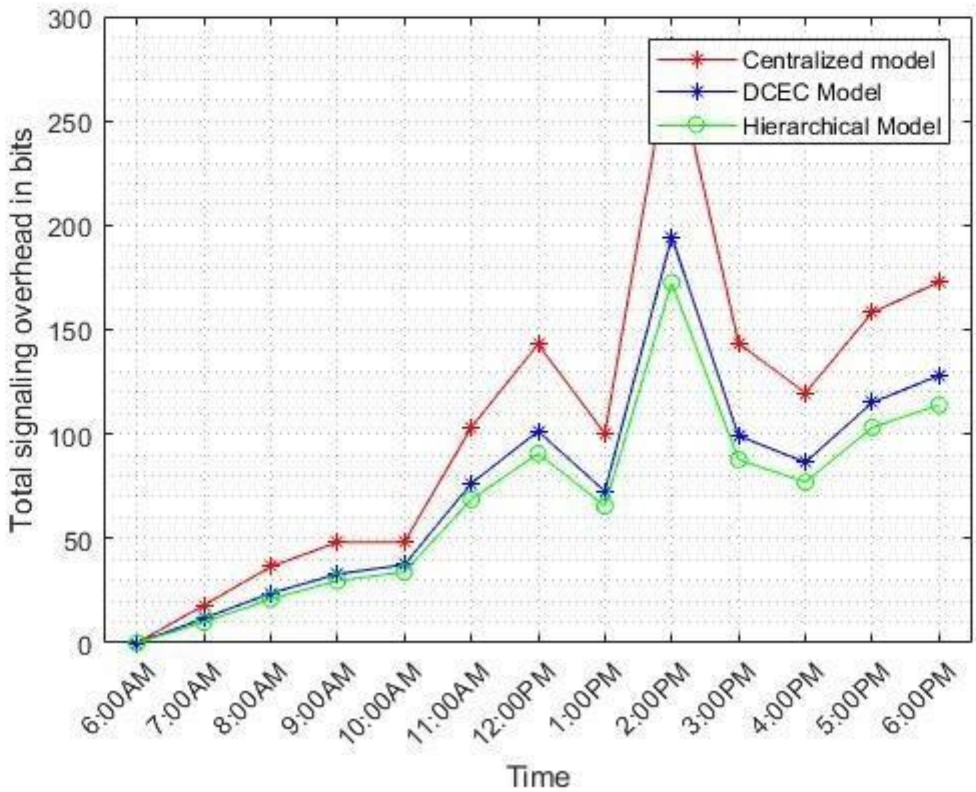

Figure 4.2: Control Data Response to Mobile Edge User Traffic Pattern

From the representation, it can be seen that control data started to peak from 10:00am to about 3:00pm, representing the more active period when active mobile edge users populated the cell edge region. For the purpose of a wider contrast, the Centralised JT COMP described earlier in **Section 1.1.3** of the work was also plotted. However, performance improvement of the Hierarchical JT COMP Scheme over the DCEC JT COMP Scheme remained consistent as computed by table 4.2**.**

Table 4.2: Computing Control Data Performance in Mobile User Traffic Pattern

Time	Centralised JT	DCEC JT COMP	Hierarchical JT
6:00am			
7:00am	20	12	10
8:00am	40	21	20
9:00am	50	32	30
10:00am	50	43	40
11:00am	105	78	70
12:00pm	140	100	90
1:00pm	102	72	65
2:00pm	285	190	170
3:00pm	140	100	90
4:00pm	120	88	75
5:00pm	160	110	100
6:00pm	170	122	110

Using Equation 3.24, we take the DCEC JT COMP Values as the initial values, and the Hierarchical JT COMP Values as the final values, a percentage decrease in total control data of up to 16.6% was determined.

4.4 Analyses for Delay in the Network

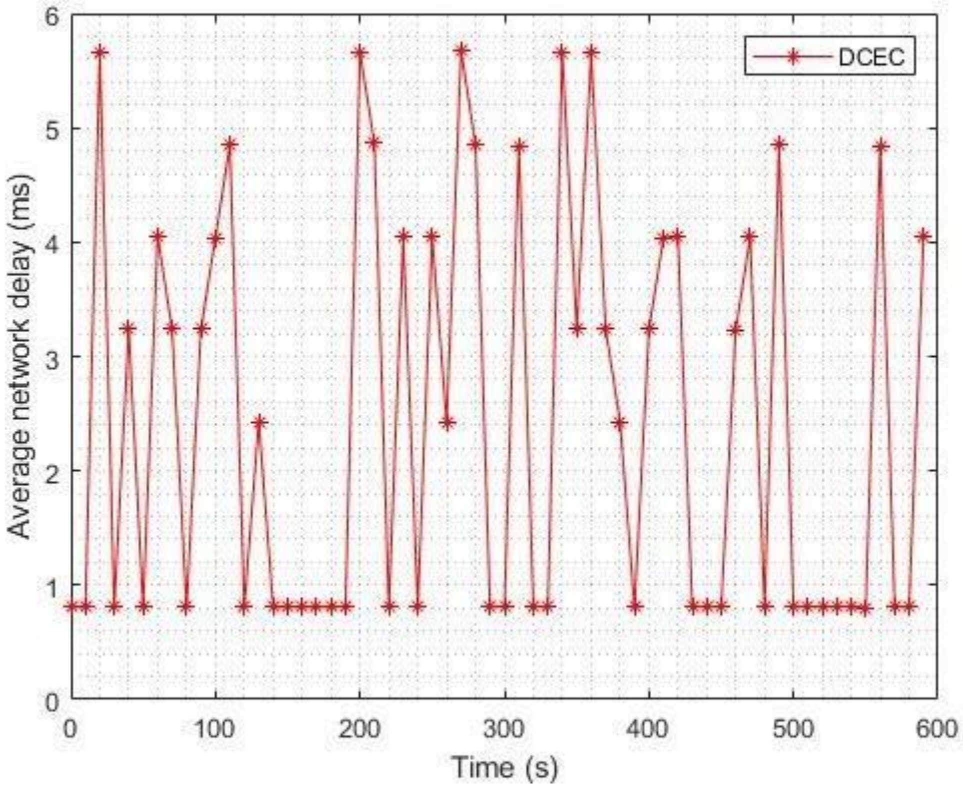

Figure 4.3: Delay Observed in the DCEC Centralised Architecture

Whenever an election for the cluster head of the JT session occurs, the data request made by the affected edge user suffers some delay. When the process of election is completed the latency drops significantly because the edge user is now able to communicate seamlessly after the coordination structure for its communication is established.

For a given number of edge users *n*, latency can be calculated using Equation 3.22. In Figure 4.3, we achieve a plot of time (or the duration of JT COMP for various n numbers of edge UEs) against Average Network Delay. At time 0s, COMP JT is initiated, and various high peaks of instantaneous network delays can be seen at t = 20s, 200s, 270s, 330s, and 360s, suggesting that edge users crossed into and out of the cell edge region at various times. Every peak however is a representation of the amount of delay for various traffic situations of edge users at various specific times t from the moment JT COMP is initiated.

In Figure 4.4, it can be seen by observation that the Hierarchical JT COMP Scheme introduced by this work achieves relatively lower network latency indices. Using Equation 3.24, and counting every hundred seconds of JT COMP analysed, the DCEC JT COMP values are taken as the original values and the Hierarchical JT COMP Scheme values as the final values, the percentage performance of the Hierarchical JT COMP Scheme will be calculated.

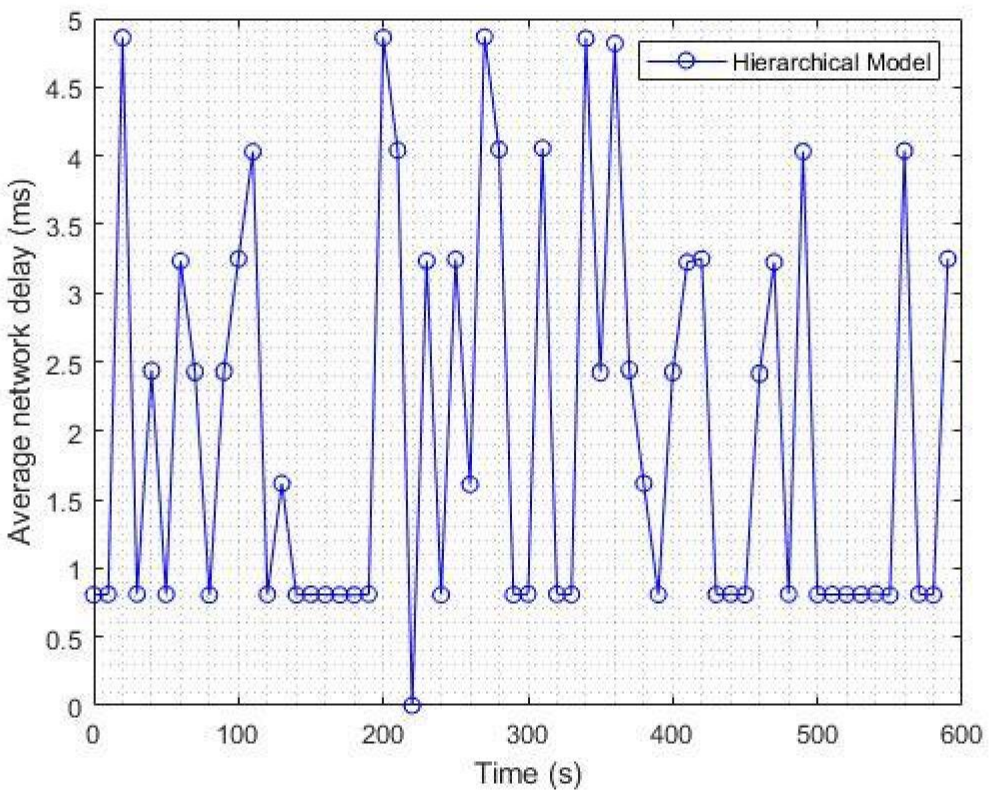

Figure 4.4: Delay Observed in the Developed Hierarchical Scheme

For the developed hierarchical model in Figure 4.4, after the first election at t = 0, a spike can be noticed in the delay experienced by the edge user. Subsequent elections occur in the lifetime of the base station communication, but these spikes are considerably lower than that of the DCEC model for the same time period. This is so because the main base station refers to the hierarchical table developed based on COMP weights computed for the base stations in the cluster. Based on this reference which requires the base station with the next highest COMP weight to become the cluster head, the main base station simply commands the edge user to transmit CSI to the new cluster head. This means that in the developed scheme, no election is required to hold after the first cluster head election holds.

Additional time is required to compute not only the throughput but also the satisfaction index for the base stations. Delay is also incurred in also fetching the information for base station with the next highest COMP weight from the processor unit, and in updating the COMP weight table.

Although these are very significant delays, the developed scheme still outperforms the DCEC model in the area of latency.

Calculating the Percentage Decrease in Average Network Delay

Extracting data from the graphs in Figures 4.2 and 4.3 at 100s intervals for simplicity and ease of computation, we have:

Table 4.3: Computing Delay Performance in DCEC and Hierarchical JT COMP

T (s)	DCEC JT COMP	Hierarchical JT COMP
100	4.0	3.2
200	5.6	4.8
300	0.8	0.8
400	3.2	2.4
500	0.8	0.8
600	4.0	3.2
Total	18.4	15.2

Using Equation 3.2 to calculate percentage performance, we take the DCEC JT COMP values as the initial values, and the Hierarchical JT COMP as the final values as follows:

$$\%\ decrease = {}^{initial\ value\ -\ final\ value}/_{initial\ value} \times 100$$

$$\%\ decrease = {}^{18.4\ -15.2}/_{18.4} \times 100$$

$$\%\ decrease = \ 17.39\%$$

Figure 4.5 shows the combined graphs for both DCEC model and the developed scheme, where delay occurs due to cluster head election. Every time an election for cluster head occurs, due to entrant of new edge users or a change in the throughput of a cluster base station such as a change in the throughput of the cluster-head, higher average network delays can be seen in red for the DCEC JT COMP, while marginally lower values can be seen in blue for the Hierarchical JT COMP which has a table of reference that avoids the need for an election.

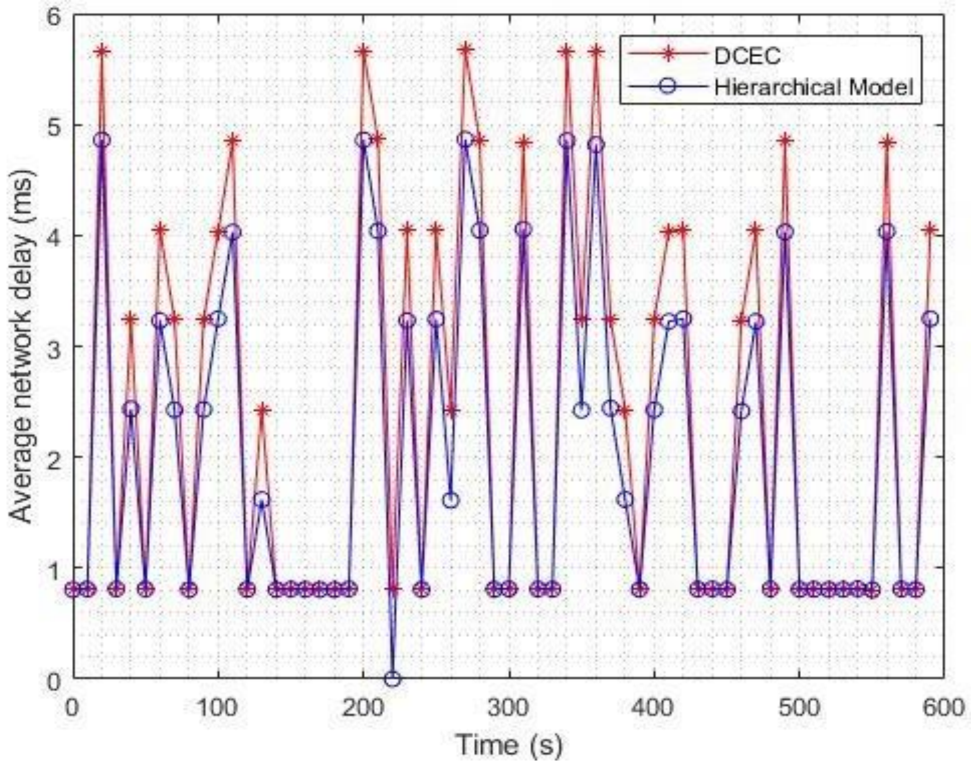

Figure 4.5: Comparative Graph Analyses for Both Schemes

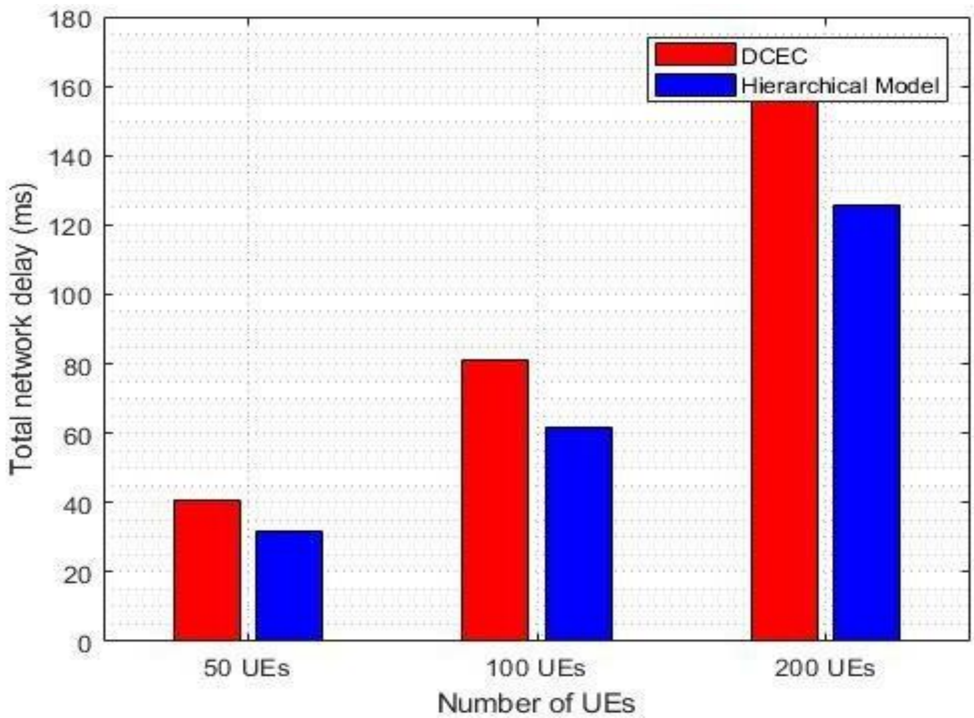

Figure 4.6: Total Network Delay Measured for Different Groups of Users

For a given number of users, the total network delay experienced by the edge users can be seen in the Figure 4.6.

Using Equation 3.2 to determine percentage performance of the two schemes as compared in different edge user densities we obtain the following results:

Table 4.4: Computing Delay Performance in Various User Densities

Number of edge users	DCEC JT COMP Scheme delay	Hierarchical JT COMP Scheme delay	Percentage reduction in Hierarchical Scheme
50	40	32.5	18.75%
100	80	62.5	21.87%
200	155	125	19.35%

The results obtained for the three traffic situations are within the calculated total delay of 17.39% obtained earlier for the Average Network Delay. This is an important metric for network quality, and it corresponds with the expectation that fewer control messages in the network will reduce the delays experienced by users since more bandwidth is available for user data. Also the joint transmission hierarchy is determined quickly and the edge user is able to communicate with its cluster head, thus experiencing shorter wait times.

4.5 SINR in Hierarchical JT Scheme Versus Non-Joint Transmission Approach

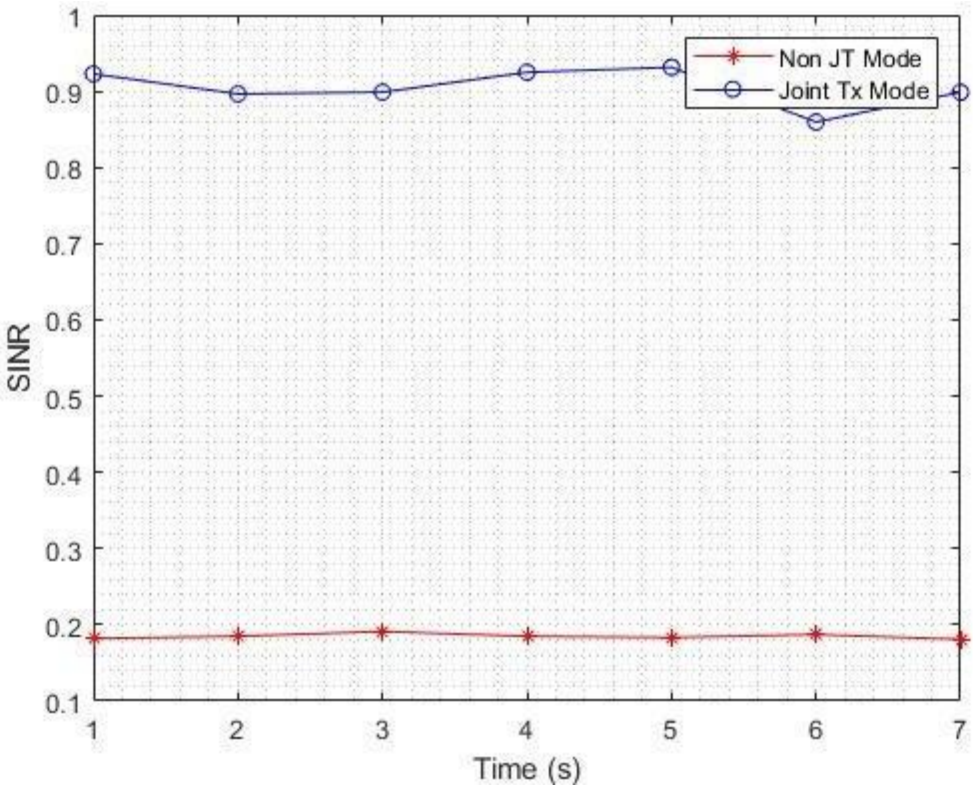

Figure 4.7: SINR Comparison with Non-Joint Transmission Scheme

The SINR of the developed scheme was placed against a non JT transmission mode, where the edge user communicates with only its main base station and suffers significant adjacent base station interference. It is seen in Figure 4.7 that the JT mode clearly outperformed the non-JT mode due to a much lower levels of interference from adjacent base stations and co-channels in the communication environment. This highlights one of the major advantages of joint transmission.

In Figure 4.7 SINR for an edge UE tracked at different times within the cell edge. This yielded the following values for JT COMP and non-JT COMP transmission modes:

Table 4.5: Computing SINR in JT COMP and Non-JT COMP edge UE

T (s)	Non-JT COMP Mode	JT COMP Mode
1	0.18	0.92
2	0.19	0.88
3	0.2	0.88
4	0.19	0.92
5	0.18	0.92
6	0.19	0.86
7	0.18	0.88
	1.31	6.26

Using Equation 3.2, the percentage performance of JT COMP can be calculated, taking the non-JT COMP transmission SINR values as the initial values, and the JT COMP transmission SINR as the final values:

$$\%\ decrease = {}^{initial\ value - final\ value}/_{initial\ value} \times 100$$

$$\%\ decrease = {}^{1.31 - 6.26}/_{1.31} \times 100$$

$$\%\ decrease = -377.86\%$$

The negative value signifies in fact an increase. Thus indicating a 377% improvement in SINR received at the edge user.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research work focused on improving the state-of-the-art joint transmission scheme which suffers a very significant problem of large amounts of control data. This control data takes up a large chunk of the bandwidth available for communication, therefore leaving whatever remains for user data transfer. Too much control data for coordination means too little available space for edge user data and would result in lower quality of service perceived by the user.

The scheme developed in this work develops a method that ensures that the amount of control data required for joint transmission for users at the edge of the cell is minimised. The developed scheme develops a table in which a ranking for base stations is entered. This table replaces the need for election of cluster coordinating heads whenever the throughput or satisfaction index or both changes.

5.2 Recommendations

More work can be done in reducing the need for real-time computation of the COMP weight and in reducing the need for frequent updating on the COMP weight table by employing some measure of machine learning which can map consistent behaviours of the base stations and establish general performance ranges. This would mean much less computation time can be achieved, and it will improve the latency parameter.

5.3 Contributions to Knowledge

One outstanding contribution to knowledge made in this research is the development of the COMP weight, which enabled the joint transmission scheme reward the base station that has the most throughput with respect to the user traffic in its cell area. Based on all surveyed literature, this is the first attempt at using network and COMP metrics jointly in joint transmission to determine suitability of the base station which must be the cluster head.

Another contribution of the work is also to evaluate the performance of the scheme. The hierarchical table introduced to joint transmission scheme in this work was shown to be a significant factor in reducing the amount of control data needed for COMP joint transmission. The hierarchical table is shown to be responsible for reducing the number of control messages by up to 10.5% compared to the DCEC method which only selected cluster heads by means of an election among base stations with the highest received signal strengths. Due to this reduction in overhead based on the hierarchical JT COMP approach, average network delay was also reduced to 17.39%, while an expected gain was seen in SINR index due to the interference mitigation of JT COMP.

REFERENCES

Ali M. S., Nadira P., & Md. F. U. (2017). Optimal Scheduling of Coordinated Multipoint Transmissions in Cellular Networks. International Journal on Communication Systems, DOI:10.1002/dac.3431

Anatolij, Z., Ahmad, R., & Suzan, B. (2020). On Practical Cooperative Multi Point Transmission for 5G Networks. Computer Networks. DOI: 10.1016/j.comnet.2020.107105

Antti, T., Hadi, G., Jarkko, K., Petri, K., Mats, B., Mikael, S., Michael, H., Eeva, L. H., Esa T. & Kari, P. (2018). Distributed Coordinated Transmission with Forward-Backward Training for 5G Radio Access. Retrieved from https://arxiv.org/abs/1802.04309 on January 4th 2022

Baccelli, F., & Giovanidis, A. (2014). A Stochastic Geometry Framework for Analysing Pairwise-Cooperative Cellular Networks, IEEE Trans. on Wireless Communications, 14(2), 794–808. DOI: 10.1109/TWC.2014.2360196

Bao, W., & Liang, B. (2018). Optimizing Cluster Size through Handoff Analysis in User-Centric Cooperative Wireless Networks. IEEE Transactions on Wireless Communications, 17(2), DOI: 10.1109/TWC.2017.2771343

Bassoy, S., Farooq, H., Imran, M. A., & Imran, A. (2017). Coordinated Multi-point Clustering Schemes: A Survey. IEEE Communications Surveys and Tutorials, 19(2), 743-764, DOI:10.1109/COMST.2017.2662212

Bassoy, S., Imran, M. A., Yang, S., & Tafazolli, R. (2019). A Load-Aware Clustering Model for Coordinated Transmission in Future Wireless Networks. IEEE Open Access Journal. DOI: 10.1109/ACCESS.2019.2927093

Beneyam, B. H., Edward, M., & Jyri, H. (2015). Coordinated Multi-point Transmission for Relaxation of Self-backhauling Bottlenecks in Heterogeneous Networks. EURASIP Journal on Wireless Communications and Networking, 78, DOI10.1186/s13638-015-0279-4

Deghel M., Stug E. B., Assaad M., & Debbah M. (2015). On the Benefits of Edge Caching for MIMO Interference Alignment. IEEE 16th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 655- 659, 978-1-4799-1931-4/15

Denny, K. H., Bhaskara, N., & Soo, Y. S. (2019). Non-Orthogonal Multiple Access in Downlink Coordinated Multipoint Transmissions. Physical Communication, DOI: 10.1016/j.phycom.2020.101017

Elalem, M., & Zhao, L. (2009). Realistic user distribution and its impact on capacity and coverage for a WCDMA mobile network. Sarnoff Symposium, IEEE Explore. DOI: 10.1109/SARNOF.2009.4850342

Ericsson, (2015). Ericsson mobility report. Albany. Retrieved from Ericsson website: https://www.ericsson.com/en/reports-and-papers/mobility-report/reports on 4th January 2022

Etemad, S. M. (2017). Simulation of Coordinated Multipoint Using Discrete Event Systems Specification. Retrieved from https://curve.carlton.ca/system/files/etd/a36ee7f9-3777-4f6f-b462-0db28396bbda/etd_pdf/936ed68845d2250f95ad085d24e7d1a5/etemad-simulationofcoordinatedmultipointusingdiscrete.pdf on 4th January 2022

ETSI. (2018). 5G, NR; Physical Layer Procedures for data (3GPP TS 38.214), 15.3(15), 18 – 23

Faizan, Q., Kaharudin B. D., Mohammed, N. H., Kamarul A. B. N., & Ahmed M. AS. (2017). A Comprehensive Review on Coordinated Multi-point Operation for LTE-A. DOI: 10.1016/j.comnet.2017.05.003

Fumiyuki, A., Amnart, B., Tomoyuki, S., & Yuta S. (2019). Distributed MIMO Cooperative Transmission Technique and Its Performance. IEEE/CIC International Conference on Communications in China (ICCC). DOI: 10.1109/ICCChina.2019.8855832

Gaurav, N., Paolo, M., & Martin, H. (2014). Coordinated Multipoint Joint Transmission in Heterogeneous Networks. IEEE Transactions on Communications, 62(11), DOI: 10.1109/GLOCOMW.2013.6824977

Giovanni, I., Frenger P., & Erik, G. L. (2019). Scalability Aspects of Cell-Free Massive MIMO. IEEE International Conference on Communications (ICC), 1 – 6, DOI: 10.1109/ICC.2019.8761828

Hasnain, A. A., Habib, A. M., Bilal, K., & Saad, Z. (2017). Pairing and Scheduling for Large Array MIMO Using Regularized Channel Inversion Receivers over Nakagami-m Fading. Wireless Personal Communications, 96(4), 6397 – 6424

Heike Young (2014, Feb 25). Mobile Behavior Report Reveals Key Findings on Usage, Apps, Downloads and More. Retrieved from Salesforce Website: https://www.salesforce.com/content/blogs/us/en/2014/02/mobile-behavior-report.html on 4th January 2022

Irmer, R., Droste, H., Marsch, P., Grieger, M., Fettweis, G., Brueck, S., Mayer, H., Thiele, L., & Jungnickel, V. (2011). Coordinated Multipoint: Concepts, Performance, and Field Trial Results. IEEE Communications Magazine, 49(2), 102 – 111. DOI: 10.1109/MCOM.2011.5706317

ITU (2020). QoS Requirements of IMT-2020, retrieved from www.itu.int/ITU-T on 4th January, 2022

Jiaqi, C., Xiaohu, G., Yi, Z., & Yonghui, L. (2019). A Novel JT-CoMP Scheme in 5G Fractal Small Cell Networks. IEEE Wireless Communications and Networking Conference (WCNC), DOI: 10.1109/WCNC.2019.8886024

Kazi, B. U., & Wainer, G. (2020). Coordinated multi-cell Cooperation with User Centric Dynamic Coordination Station. Computer Networks, 166. https://doi.org/10.1016/j.comnet.2019.106948 on 4th January, 2022

Li, Y., Ma, Y., Wang, Y., & Zhao, W. (2013). Base Station Sleeping with Dynamical Clustering Strategy of CoMP in LTE-Advanced. IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, 2013, pp. 157 – 162, doi:10.1109/GreenCom-iThings-CPSCom.2013.48

Ling, L., Yiqing, Z., Athanasios V. V., Lin, T. & Jinglin, S. (2019). Time-domain ICIC and Optimised Designs for 5G and Beyond: A Survey. China Information Sciences, 62, 1 – 28, DOI: 10.1007/s11432-017-9477-4

Mao, Y., Clerckx, B. & Li, V. O. K. (2019). Rate-Splitting Multiple Access for Coordinated Multi-Point Joint Transmission. IEEE International Conference on Communications Workshops (ICC Workshops), 1 – 6. DOI: 10.1109/ICCW.2019.8756668

Mohamed, A. F., Babiker, A., & Mustafa, A. (2013). Functions of the X2 interface, International Journal of Science and Research (IJSR), Index Copernicus Value (2013): 6.14

Muhammad, D. Z., David, G., Paul, D. M., Tareq, M. A. S., & Nils, M. (2019). Exploiting User-centric Joint Transmission Coordinated Multipoint with a High Altitude Platform System Architecture. IEEE Access, 1 – 16, 2169-3536, DOI: 10.1109/ACCESS.2019.2905844

Pouria, P., Rezvani, S., & Mokari, N. (2018). Joint Task Scheduling and Uplink/Downlink Radio Resource Allocation in PD-Noma Based Mobile Edge Computing Networks, Physical Communication, 32, 160 – 171, DOI: 10.1016/j.phycom.2018.11.007

Ralph, T., Sarabjot, S., Jeffrey, G. A., & Friedrich, K. J. (2014). Analysis of Non-Coherent Joint-Transmission Cooperation in Heterogeneous Cellular Networks. IEEE International Conference on Communications (ICC), 5160 – 5165, DOI: 10.1109/ICC.2014.6884140

Rappaport, S. T. (2002). Wireless Communication Principles & Practice. New Jersey: Pearson Publishers

Sahrish, K. T., & Munam, A. S. (2018). Resource allocation in SDN based 5G cellular networks. Peer-to-Peer Networking and Applications, DOI:10.1007/s12083-018-0651-3

Shangbin, W., & Yinan, Q. (2018). Centralized and Distributed Schedulers for non-Coherent Joint Transmission. IEEE Globecom Workshops (GC Workshops), 1 – 6, DOI: 10.1109/GLOCOMW.2018.8644228

Shuyi, C., Tianyu Z., Hsiao-Hwa C., Zhiping L., & Weixiao M. (2019). Performance Analysis of Downlink Coordinated Multipoint Joint Transmission in Ultra-Dense Networks – A Unified Approach. IEEE/ACM Transactions on Networking, 28(1), DOI: 10.1109/TNET.2019.2957319

Study.com (2014). Percentage Decrease: Formula & Calculation. Retrieved from https://www.study.com/academy/lesson/percent-decrease-formula-calculation.html on 5th January 2022

Supratim, D., Pantelis, M., Jerzy, M., & James, P. S. (2013). Algorithms for Enhanced Inter-Cell Interference Coordination (eICIC) in LTE HetNets. IEEE/ACM Transactions on Networking, 22(1), DOI: 10.1109/TNET.2013.2246820

Yan, L., Minghua, X., & Sonia, A. (2020). Coordinated Multi-Point Transmission: A Poisson-Delaunay Triangulation Based Approach. IEEE Transactions on Wireless Communications, Retrieved from https://arxiv.org/pdf/2001.07363.pdf on 4th January 2022

Yu, X., Cui, Q., & Martin, H. (2018). Coherent Joint Transmission in Downlink Heterogeneous Cellular Networks. IEEE Wireless Communications Letters, 7(2), 274 – 277

Zakhour, R., & Gesbert, D. (2011). Optimised Data Sharing in Multicell MIMO with Finite Backhaul Capacity. IEEE Trans. Signal Process, 59(12), 6102–6111

Appendix A (MATLAB Program)

```
clc
clear all

b1=-80;
b2=-1*randi([80 90],1);
b3=-1*randi([80 90],1);
b4=-1*randi([80 90],1);
b5=-1*randi([80 90],1);
b6=-1*randi([80 90],1);
b7=-1*randi([80 90],1);

rsrp=[b1;b2;b3;b4;b5;b6;b7]; %Assumption: the UE is at the edge of 7
base stations
diff=b1-rsrp; %RSS difference between serving base station and
neighboring BS
mimo=1;


td=0;
NOB=0;
NOB1=0;
NOB2=0;
TNOB1=0;
TNOB2=0;
%NOB_after=0;
td_after=0;
time=0;
i=7;
j=0;


for k=1:i
    b1=-80;
b2=-1*randi([80 90],1);
b3=-1*randi([80 90],1);
b4=-1*randi([80 90],1);
b5=-1*randi([80 90],1);
b6=-1*randi([80 90],1);
b7=-1*randi([80 90],1);

rsrp=[b1;b2;b3;b4;b5;b6;b7]; %Assumption: the UE is at the edge of 7
base stations
diff=b1-rsrp; %RSS difference between serving base station and
neighboring BS

   for n=1:i
    if diff(n,:)<=6
        tbs=randi([336 3496],1);
        thp=tbs*1000*mimo;
        sindex=randi([50 200],1);
        compd=thp*100/sindex;
        cluster(n,1)=n;
        cluster(n,2)=thp;
        cluster(n,3)=sindex;
        cluster(n,4)=compd;
        j=j+1;
    end
```

```
   end
        PMI=[2 4];
        NB_CQI=8;
        NB_RI=1;

      for u=1:j
        m=randi([1 2],1);
        NB_PMI=PMI(m);
        NOB1=NB_CQI+NB_RI+NB_PMI+NOB1;
        TNOB1=NB_CQI+NB_RI+NB_PMI+TNOB1;

      end



 if j-1>=0
        for w=1:j-1
            m2=randi([1 2],1);
            NB_PMI=PMI(m2);
            NOB2=NB_CQI+NB_RI+NB_PMI+NOB2;
            TNOB2=NB_CQI+NB_RI+NB_PMI+TNOB2;
        end
      else
          NOB2=NB_CQI+NB_RI+NB_PMI+NOB2;
          TNOB2=NB_CQI+NB_RI+NB_PMI+TNOB2;
      end

%NOB=NB_CQI+NB_RI+NB_PMI;
%NOB1=NOB;
%NOB_after=NB_CQI+NB_RI+NB_PMI+NOB_after;
%}
  overhead1(k,1)=NOB1/j
 overhead2(k,1)=NOB2/j
 toverhead1(k,1)=TNOB1/j %cummulative overhead bits for the DCEC model
 toverhead2(k,1)=TNOB2/j %cummulative overhead bits for the
hierarchical model
% overhead2(1,1)=NOB;
 time_int(k,1)=time;

%NOB=0
NOB1=0;
NOB2=0;
%j=0;
time=time+10;
end

format long
cluster

over_a=[0;overhead1];
over_b=[0;overhead2];
tover_a=[0;toverhead1];
tover_b=[0;toverhead2];
timing=[time_int;time];


%{
figure
```

```
plot(td1,'v-r')
hold
plot(td2,'v-b')

grid minor
%}

figure

plot(timing,over_a,'*-r')
hold
plot(timing,over_b,'o-b')
xlabel('Time (ms)')
ylabel('Average signaling overhead in bits')
legend('DCEC Model','Hierarchical Model')
grid minor

figure
plot(timing,tover_a,'*-r')
hold
plot(timing,tover_b,'o-b')
xlabel('Time (ms)')
ylabel('Total signaling overhead in bits')
legend('DCEC Model','Hierarchical Model')
grid minor

%Delay
n50=50;
 for k=1:n50
     b1=-80;
b2=-1*randi([80 90],1);
b3=-1*randi([80 90],1);
b4=-1*randi([80 90],1);
b5=-1*randi([80 90],1);
b6=-1*randi([80 90],1);
b7=-1*randi([80 90],1);

rsrp=[b1;b2;b3;b4;b5;b6;b7]; %Assumption: the UE is at the edge of 7
base stations
diff=b1-rsrp; %RSS difference between serving base station and
neighboring BS
    for n=1:i
    if diff(n,:)<=6
        tbs=randi([336 3496],1);
        thp=tbs*1000*mimo;
        sindex=randi([50 200],1);
        compd=thp*100/sindex;
        cluster(n,1)=n;
        cluster(n,2)=thp;
        cluster(n,3)=sindex;
        cluster(n,4)=compd;
        j=j+1;
    end
    end

   for u=1:j
         tt=randi([1 5],1)/1000;
        tb=randi([1 5],1)/1000;
        ta=randi([1 5],1)/1000;
        TR=500;
```

```
        v=300000000;
        tp=TR/v;
        P=2; %2MB packet size
        rup=5; %data rate over the uplink channel in MB
        rx2=5;   %data rate over the X2 channel in MB
        td=(tt+(ta+P/rup)+(tp+P/rx2)+tb)+td;

    end



 if j-1>=0
        for w=1:j-1
            td_after=tt+(ta+P/rup)+(tp+P/rx2)+td_after
        end
      else
          td_after=tt+(ta+P/rup)+(tp+P/rx2)+td_after
  end



td1(k,1)=td/j;
td2(1,1)=td1(1,1);
td2(k,1)=td_after/j;


td=0;
td_after=0
j=0

end


delay1_n50=sum(td1)
delay2_n50=sum(td2)


n100=100;
for k=1:n100
   b1=-80;
b2=-1*randi([80 90],1);
b3=-1*randi([80 90],1);
b4=-1*randi([80 90],1);
b5=-1*randi([80 90],1);
b6=-1*randi([80 90],1);
b7=-1*randi([80 90],1);

rsrp=[b1;b2;b3;b4;b5;b6;b7]; %Assumption: the UE is at the edge of 7
base stations
diff=b1-rsrp; %RSS difference between serving base station and
neighboring BS
   for n=1:i
    if diff(n,:)<=6
        tbs=randi([336 3496],1);
        thp=tbs*1000*mimo;
        sindex=randi([50 200],1);
        compd=thp*100/sindex;
        cluster(n,1)=n;
```

```
        cluster(n,2)=thp;
        cluster(n,3)=sindex;
        cluster(n,4)=compd;
        j=j+1;
    end
    end

   for u=1:j
         tt=randi([1 5],1)/1000;
        tb=randi([1  5],1)/1000;
        ta=randi([1  5],1)/1000;
        TR=500;
        v=300000000;
        tp=TR/v;
        P=2; %2MB packet size
        rup=5; %data rate over the uplink channel in MB
        rx2=5;    %data rate over the X2 channel in MB
        td=(tt+(ta+P/rup)+(tp+P/rx2)+tb)+td;

    end



 if j-1>=0
        for w=1:j-1
            td_after=tt+(ta+P/rup)+(tp+P/rx2)+td_after
        end
      else
          td_after=tt+(ta+P/rup)+(tp+P/rx2)+td_after
  end



td1(k,1)=td/j;
td2(1,1)=td1(1,1);
td2(k,1)=td_after/j;


td=0;
td_after=0
j=0
end


delay1_n100=sum(td1)
delay2_n100=sum(td2)


n200=200;
for k=1:n200
 b1=-80;
b2=-1*randi([80 90],1);
b3=-1*randi([80 90],1);
b4=-1*randi([80 90],1);
b5=-1*randi([80 90],1);
b6=-1*randi([80 90],1);
b7=-1*randi([80 90],1);
```

```
rsrp=[b1;b2;b3;b4;b5;b6;b7]; %Assumption: the UE is at the edge of 7
base stations
diff=b1-rsrp; %RSS difference between serving base station and
neighboring BS
   for n=1:i
    if diff(n,:)<=6
        tbs=randi([336 3496],1);
        thp=tbs*1000*mimo;
        sindex=randi([50 200],1);
        compd=thp*100/sindex;
        cluster(n,1)=n;
        cluster(n,2)=thp;
        cluster(n,3)=sindex;
        cluster(n,4)=compd;
        j=j+1;
    end
    end

   for u=1:j
         tt=randi([1 5],1)/1000;
        tb=randi([1 5],1)/1000;
        ta=randi([1 5],1)/1000;
        TR=500;
        v=300000000;
        tp=TR/v;
        P=2; %2MB packet size
        rup=5; %data rate over the uplink channel in MB
        rx2=5;   %data rate over the X2 channel in MB
        td=(tt+(ta+P/rup)+(tp+P/rx2)+tb)+td;

    end



  if j-1>=0
        for w=1:j-1
            td_after=tt+(ta+P/rup)+(tp+P/rx2)+td_after
        end
      else
          td_after=tt+(ta+P/rup)+(tp+P/rx2)+td_after
  end



td1(k,1)=td/j;
td2(1,1)=td1(1,1);
td2(k,1)=td_after/j;


td=0;
td_after=0
j=0
end


delay1_n200=sum(td1)
delay2_n200=sum(td2)
figure
a=categorical({'50 UEs','100 UEs','200 UEs'})
```

```
a=reordercats(a,{'50 UEs','100 UEs','200 UEs'})
b=[delay1_n50 delay2_n50;delay1_n100 delay2_n100;delay1_n200
delay2_n200]
c=bar(a,b)
c(1).FaceColor='red'
c(2).FaceColor='blue'
xlabel('Number of UEs')
ylabel('Total network delay (ms)')
legend('DCEC Model','Hierarchical Model')
grid minor
N=7;
i=30;
td1=0;
td2=0;
time=0;
for t=1:i
    o=randi([1 30],1);%number of outages
    %z=randi([2 6],1);
    b1=-80;
b2=-1*randi([80 90],1);
b3=-1*randi([80 90],1);
b4=-1*randi([80 90],1);
b5=-1*randi([80 90],1);
b6=-1*randi([80 90],1);
b7=-1*randi([80 90],1);
rsrp=[b1;b2;b3;b4;b5;b6;b7]; %Assumption: the UE is at the edge of 7
base stations
diff=b1-rsrp; %RSS difference between serving base station and
neighboring BS

    for n=1:N
    if diff(n,:)<=6
        tbs=randi([336 3496],1);
        thp=tbs*1000*mimo;
        sindex=randi([50 200],1);
        compd=thp*100/sindex;
        cluster(n,1)=n;
        cluster(n,2)=thp;
        cluster(n,3)=sindex;
        cluster(n,4)=compd;
        j=j+1;
    end
    end


   for u=1:j
         tt=randi([1 5],1)/1000;
        tb=randi([1 5],1)/1000;
        ta=randi([1 5],1)/1000;
        TR=500;
        v=300000000;
        tp=TR/v;
        P=2; %2MB packet size
        rup=5; %data rate over the uplink channel in MB
        rx2=5;    %data rate over the X2 channel in MB
        td1=(tt+(ta+P/rup)+(tp+P/rx2)+tb)+td1;

    end
```

```
     for w=1:j-1
         td2=(tt+(ta+P/rup)+(tp+P/rx2)+tb)+td2;
     end
td=tt+(ta+P/rup)+(tp+P/rx2)+tb;
delay(t,:)=td;
delay1(t,1)=td1;
delay2(t,1)=td2;

%{
 if o<=3
     delay1(k,1)=td1;
     delay2(k,1)=td2;
 %}



td1=0;
td2=0;
j=0;


end


delay1
delay2
delay

delay_combined1=[delay1;delay];
delay_combined2=[delay2;delay];
delay_combined=[delay_combined1 delay_combined2]

M=sort(delay_combined)
P=size(M)
for x=1:P
    if M(x,1)==0
        M(x,:)=[]
    end
end




s=size(delay_combined);
S=s(1)
D1=randperm(S);
delay=delay_combined(D1,:);
%delay(1,1)=0;
%delay(2,1)=max(delay);
delay


for s=1:S
   % td2(s,:)=(tt+(ta+P/rup)+(tp+P/rx2)+tb);

    time_(s,:)=time;
```

```
    time=time+10;
end
%td2(1,1)=0;
%td2(2,1)=max(delay);

figure
plot(time_,delay(:,1),'*r-')



xlabel('Time (s)')
ylabel('Average network delay (ms)')
legend('DCEC Model')
grid minor

figure
plot(time_,delay(:,2),'ob-')
xlabel('Time (s)')
ylabel('Average network delay (ms)')
legend('Hierarchical Model')
grid minor



figure
plot(time_,delay,'*r-')
hold
plot(time_,td2,'ob-')


xlabel('Time (s)')
ylabel('Average network delay (ms)')
legend('DCEC Model','Hierarchical Model')
grid minor


%SINR
N=7;%number of base stations at the edge
n=size(cluster);%base stations matrix
i=0;%number of interfering base station(s)
z=0;
B=360*1000; %bandwidth
g=7;%number of iterations

for K=1:g

   for p=1:N
    if diff(p,:)<=6
        tbs=randi([336 3496],1);
        thp=tbs*1000*mimo;
        sindex=randi([50 200],1);
        compd=thp*100/sindex;
        cluster(p,1)=N;
        cluster(p,2)=thp;
        cluster(p,3)=sindex;
        cluster(p,4)=compd;
```

```
    end

    C=randi([55 70],1)*1000;
        snr=power(2,C/B)-1;%SNR of each base station
        SNR(p,:)=snr; %SNR matrix

   end
  a=sort(SNR)
 if n(1)==N
  for k=1:N
    if cluster(k,1)==0
        i=i+1;
    end
  end
end

 if n(1)<N
     for k=1:n(1)

         if cluster(k,1)==0
             z=z+1;
         end

     end
     j=n(1)-z %number of base stations in the joint transmission
cluster
     i=N-j; %number of interfering base stations

 end
  i

  if i==0
     SNIR2(K,:)=sum(a);
  end


if i>0
    for q=1:i
        ai(q,:)=a(q);
    end
     total_int=sum(ai); %total interference plus noise
     total_sig=sum(a)-total_int; %total signal in joint transmission
plus noise
     SNIR2(K,:)=total_sig/total_int; %SNIR of joint transmission
end
SNIR1(K,:)=max(a)/(sum(a)-max(a)); %SNIR of single transmission
i=0;
z=0;
end

SNIR1
SNIR2
figure
plot(SNIR1,'-*r')
hold
plot(SNIR2,'-ob')

xlabel('Time (s)')
ylabel('SINR')
```

```
legend('Single Tx Model','Joint Tx Model')
grid minor
```

Appendix B (Publication)

Ozuluonye B., Ohize H., & Achonu A. (2021). A Survey on Antenna Selection, in Proceedings of International Conference on Cyberspace (I2C) CYBERNIGERIA 2020. Pp 179 – 183.