INVESTIGATION ON SPECTRAL EFFICIENCY AND LATENCY OPTIMIZATION SCHEME FOR CLOUD-BASED RADIO ACCESS NETWORK

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2019

Investigation on Spectral Efficiency and Latency Optimization Scheme for Cloud-Based Radio Access Networks”

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A report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled "Investigation on Spectral Efficiency and Latency Optimization Scheme for Cloud-Based Radio Access Networks" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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APPROVAL

I hereby declare that I have checked this report entitled "Investigation on Spectral Efficiency and Latency Optimization Scheme for Cloud-Based Radio Access Networks" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

First and foremost, I would like to express my heartfelt gratitude to my academic institution Universiti Teknikal Malaysia Melaka (UTeM) for giving the opportunity to me to undertake my Final Year Project in partial fulfilment for Bachelor of Mechatronics Engineering.

I would like to express my deep and sincere appreciation to my research supervisor, Dr. Nur Ilyana binti Anwar Apandi who continuous support and encouraged me along this semester of this research. Her prompt patience, motivation, and erudite knowledge have motivated me in all the time of research and completion of my report. I am glad to have such a great advisor and mentor for my Final Year Project.

The deep gratitude also goes to my family. With their love, support and encouragement, I am tough to go through the challenges face by me. My friends, especially who has helped me in every possible way to complete this report also very appreciated by me.

ABSTRACT

With the adaption of fifth generation (5G) wireless network system in to Industry 4.0, the data transfer efficiency and speed will show a significantly improvement manner by providing a real-time information and solving capacity problem. Cloud-Based Radio Access Network (C-RAN) represents a key technology for 5G wireless network system, where the information processing is centralized to a “cloud” or central unit instead of several base stations. C-RAN is able to increase the spectral efficiency and lower the transmission latency compare to 4G wireless network system. Moreover, the used of C-RAN in future can decrease the capital, operational and maintenance expenses of mobile operator. This study aims to investigate and validate the joint of spectral efficiency and latency optimization in term of power consumption by using quantization process of uplink signal at the remote radio head (RRH) of the C-RAN network. The quantization process is used to convert the received radio frequency signal from user equipment into in-phase and quadrature baseband sample. We proposed a simulation environment-based scheme to compute the uplink power and the number of quantisation bits in a way that the performance of spectral efficiency and latency of the RRHs are simultaneously optimised. Simulation results presented the trade-off ratio between spectral efficiency and latency improvements in term of power consumption.

ABSTRAK

Dengan penyesuaian sistem rangkaian tanpa wayar yang genarasi kelima (5G) ke Industri 4.0, kecekapan dan kelajuan peminda data akan meningkat dengan care yang menakjubkan yang menyediakan maklumat masa nyata dan masalah kapasiti penyelesaian. Rangkaian Akses Radio Bersaskan-Awam (C-RAN) mewakili suatu teknologi yang penting terhadap sistem rangkaian tanpa wayar 5G, hal ini demikian kerana proses maklumat pemprosesan telah dikumpulkan ke satu “awam” atau unit pusat yang menggantikan beberapa stesen pangkalan. C-RAN dapat meningkatkan kecekapan spektrum dan merendahkan penghantaran latensi berbanding dengan sistem rangkaian tanpa wayar yang genarasi keempat (4G). Selain itu, dengan penggunaan C-RAN pada masa akan datang dapat mengurangkan perbelanjaan modal, operasional dan penyelenggaraan pengendali mudah alih. Kajian ini bertujuan untuk menyiasat dan mengesahkan gabungan kecekapan spektrum dan pengoptimuman latensi dari segi penggunaan kuasa dengan menggunakan proses kuantisasi isyarat uplink di rangkaian radio jauh (RRH) rangkaian C-RAN. Proses kuantisasi digunakan untuk menukarkan isyarat frekuensi radio yang diterima daripada peralatan pengguna yang diubah menjadi fasa dalam-fasa dan kuadratur baseband. Kami mencadangkan skim berasaskan persekitaran simulasi untuk mengira kuasa uplink dan bilangan bit kuantisasi dengan cara prestasi kecekapan spektral dan latensi RRHs dioptimumkan secara serentak. Hasil simulasi menunjukkan nisbah perdagangan antara kecekapan spektral dan peningkatan latensi dari segi penggunaan kuasa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the era of mobile internet, mobile operators are facing pressure on increasing capital expenditures and operating expenses with much less growth of income. Global network user was explosive with no sign of retardation and it is expected to keep its rapid seed of growing. Wireless network statistics reveal that 976.4% growth from year 2000 to 2017 and 51.7% among the population of the world using the wireless network [1]. Fourth generation (4G) wireless network is not able to meet this explosive growth in traffic demand. Therefore, this has giving birth to fifth generation (5G) mobile networks to support a wide range of innovative new services across different industries in the fast growing technology world.

Group Special Mobile Association (GSMA) is cooperate with its members, Huawei, and its university toward the vital shaping of 5G wireless network and they have blended the different research by industries and academia, eight major requirements of coming 5G wireless network. Firstly, 10 times increase data rates in real networks from the traditional LTE network, 100 times reduction latency, higher bandwidth, enormous number of connected devices, perceived 99%, complete coverage irrespective of users' location, higher battery life, and increase the energy of efficiency [2, 3]. Cloud-Based Radio Access Network (C-RAN) is expected to be a candidate of next generation access network techniques that can meet operators' expectation.

1.2 Motivation

Cloud-based Radio Access Network (C-RAN) is the groundwork for the "5G" networks of the future. C-RAN is a new architecture to centralize the base stations (BS) and provide a cooperative solution between multiple operators [4]. This technology comes with many advantages such as minimal cost, high energy efficiency, and centralized network architecture that are irresistible to everyone. It bring a big improvement to the next-generation wireless communication systems.

Meanwhile, the quantization process in C-RAN has to be performed after the discrete signal was sampling wherein the signal amplitudes are rounded off to a nearest value to obtain discrete amplitudes. The quantization process able process the signal in low complexity computation by converts the time-varying signal into a discrete-time signal.

In this study, we focused on survey different aspects of C-RAN innovation in term of simulation of uplink spectral efficiency and with the latency optimization as the objective in term of power consumption. Meanwhile, the optimization of the C-RAN scheme will be simulate based on quantization process. This study can be seen as an analysis of survey papers [9].

1.3 Problem Statement

According to the research [5], [6], [7] and [8] has been listed in the literature that tries to document C-RAN architecture in terms of components, structure, advantages, virtualization technologies, resource allocation, scheduling, and platform implementation to solve its current challenges and have deployed platform that can be used by industrial companies.

In [5] and [6] where the variable is energy efficiency optimization of uplink power at user equipment by formulate the joint optimization of the transmit pre-coding matrices of the mobile user and the CPU cycles/s assigned by the cloud to each mobile user is proposed, the number of quantization bits for each RRH is fixed, eliminating the potential reduction in transmission latencies.

Similarly, in [7] and [8] only uplink spectral efficiency is used as the optimization objective with the maximum allowable transmission latency as the constraint and power user equipment as the optimization variable. However, it neglects the negative impact of lowering latency to the received SINR and spectral efficiency and user equipment.

Also, the calculation of resource optimization are all done in a series connection where RRHs take turns in optimizing their resources, leading to a high computational complexity. In parallel connection of RRHs, the optimization calculation will be optimizing their received resources at the same time and more adequate to the computation in real situation.

The relevant papers do not include both uplink spectral efficiency and latency as the objective. This study aims to survey and discuss the spectral efficiency joint with latency optimization scheme of C-RANs in term of power consumption by quantize the received radio signal from user equipment to RRHs.

1.4 Objective

Two objectives that are required to be achieved during this project:

1. To investigate and formulate the joint optimization of spectral efficiency and latency subject to energy consumption for C-RANs system.

2. To validate the joint optimization of spectral efficiency and latency scheme in C-RANs system based on quantization process.

1.5 Scope and Limitation

There are some scope and limitation in this simulation project:

1. The spectral efficiency and latency optimization of C-RAN is simulated by using MATLAB.

2. The spectral efficiency and latency that simulated in this project was based on the uplink transmission baseband signal.

3. There are 5, 7, 9 units of remote radio head (RRH) was used in this project and at fixed location.

4. The number of user equipment (UE) was used in this project was same as number of RRHs used and distributed randomly in a target area.

5. The project is simulated according in an urban area.

1.6 Organization of Report

Chapter 1 is the introduction, motivation and objectives of the project. The introduction is to give a basic image of the 5G and Cloud-Based Radio Access Network and their importance. Thus motivation is based on current problem statement that needs to be solved.

Chapter 2 is literature review which described the basic knowledge needed in this project. Comparing between previous works and products which are related to the project. Identifying the requirement of the C-RAN in this projects from the literature review.

Chapter 3, methodology gives guidelines of the overall investigation of the C-RAN in term of software stimulation. Method of the experiments that's should be conducted to validate the spectral efficiency and latency of C-RANs.

1.7 Summary

In conclusion, the introduction has provided the trend, importance and basic image of 5G and C-RAN. The objectives and scope that are stated based on problem statement are defined. The project is briefly explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the background of the project will be explained briefly for better understanding of the research. A review of previous related works will be discussed to obtain some useful information by synthesizing their work to make this research successful.

2.2 Spectral Efficiency

The term Spectral efficiency is used to describe the rate of information being transmitted over a given spectrum or bandwidth in specific communication systems from transmitter to receiver [10]. Spectral Efficiency is usually expressed as bits/s/Hz, which is “bits per second per hertz”. Common definition is the net data rate in bits per second (bps) divided by the bandwidth in hertz [11].

2.3 Latency

Latency is the time of central unit (CU) takes for a message, or a signal, to travel from its remote radio heads (RRHs) [12]. It is depend on the physical distance that data must travel through cords, networks and other transmission channel to reach its destination [13]. It also described as delay. Latency optimization is the process to reduce the time of data or signal latency in signal transmitting process. Currently, 4G round trip latencies are about of 10ms [2], that is based on the 1ms sub a frame time with necessary overheads for resource allocation and access. Moreover, the 5G will able to provide round trip latency with 1ms, which is faster than 4G. In this study, the latency was the number of quantization bits used by the RRH for transmission.

2.4 Cloud-Based Radio Access Networks

Cloud-Based Radio Access Networks (C-RAN) refers to the visualization of base station functionalities by means of cloud computing [30] for next-generation wireless communication systems. C-RAN also emerged as a promising solution to improve wireless network capacity [29].

C-RANs provide a promising architecture that is based on the separation of distributed remote radio head (RRH) with base station (BS) and centralized information processing nodes [15, 16]. The resource allocation and computation signal processing for a BS is moved to a central unit (CU).

The task of the BS, referred to as a remote radio head (RRH) [30], is then to down convert the received radio frequency signal from user equipment (UE) into in phase and quadrature baseband samples.

It has been proposed as a cost-efficient way of deploying small cells [14], the proposed architecture can realize high-speed multiservice data transmission in a simplified and flexible way [17] and reduce the capital and operating cost of deployment and maintenance [30]. This make C-RAN well positioned to be one of the key technologies in the development of 5G systems. Figure 2.1 shows the schematic diagram of C-RAN.:

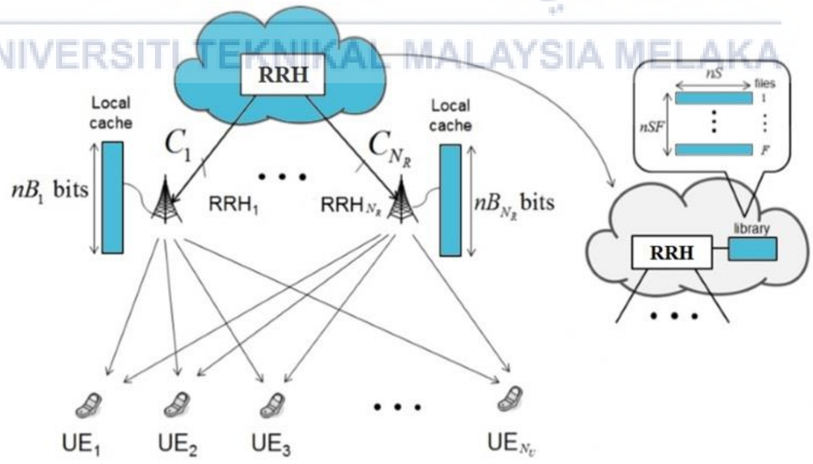

Figure 2.1 Schematic Diagram of C-RAN

Where BBU represent the baseband processing unit that can perform joint baseband processing on behalf of the remote radio heads (RRHs), UE is user equipment. Then C is denotes Common Public Radio Interface (CPRI) [33].

2.5 Fifth Generation (5G) Wireless Network System

The combination effect of emerging mm-wave spectrum access, hyper-connected vision and new application specific requirements is started to trigger the next evolution in wireless network system – the 5G [19 – 21]. Figure 2.2 shows that the wireless network envision greatness of increase in wireless data rates, bandwidth, coverage and connectivity, with a great reduction in round trip latency and power consumption.

GSMA (Group Special Mobile Association) is working with allies towards the ultimate shaping of 5G wireless network system. Blending the different research advantages by industries and academia, eight major requirements [18, 22 and 23] as follow:

1. Higher data rates in real networks.
2. Reduction latency.
3. Higher bandwidth in unit area.
4. Enormous capacity of connected devices.
5. High perceived availability.
6. Coverage for anytime and anywhere.
7. Increase battery life for smart devices.
8. Reduction in power consumption.

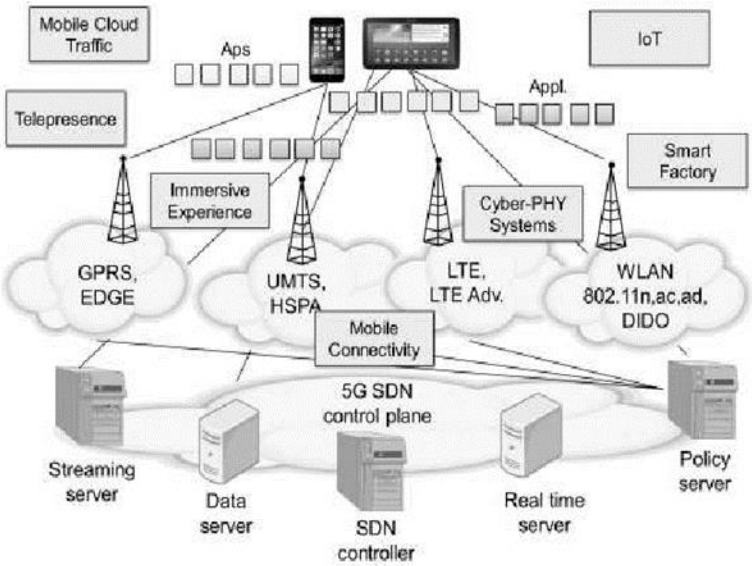

Figure 2.2 Schematic Diagram of 5G Wireless Network System

2.6 Data Rate

Data rates in wireless network system is unquestionably the main driver in 5G network, since the global network users always expected for high speed timing in future. Data rate can be measured in three ways which are service assurance and application performance management, AP/controller and network management systems [2, 32]. Firstly, aggregate data rate is refer to the total amount of data the network can be served, characterized in bit/second per unit area. The general improving is that this quantity or data rates will need to increase by roughly 100 times from 4G to 5G. Secondly, edge rate or 5% rate is the worst data rate that a user can be reasonably expect to receive when in a range of the network. For the 5G edge rate from 1 Mbps to 100 Mbps. Meeting 100 Mbps for 95% of user will be extraordinary challenging, even with major technological improvement. This requires about 100 times advance since current 4G system gave a typical 5% rate of 1 Mbps [2]. Lastly, peak rate also one of the goal target in 5G network. Peak rate is the best case data rate can be reach by a user under any conceivable network configuration. For 5G, it is likely to be in the range of 10 Gbps peak data rate [2].

2.7 Bandwidth

Bandwidth is indicated as the size of data that can be transmitted in a fixed amount of time. For digital devices, the bandwidth is usually expressed in bits per second (bps) or bytes per second. For analogue devices, the bandwidth is expressed in cycles per second, or Hertz (Hz) [18]. 5G with higher bandwidth will be able to connect with larger number of devices for longer duration in specific area.

2.8 Base Stations

Base stations (BS) are usually envisioned as big high-power tower or cell sites. The most important characteristics of BS are: it must be able to initiate and provide accommodations impulsive request for communication channels with mobile users in its coverage area. Secondly, it has to give a dependable backhaul connection to the core network. Thirdly, BSs need to have a supportable power source. Commonly, this is a traditional wired power connection system, but it could in principle be workable with the renewable solar energy, wind-powered, or fossil fuel generated [24]. There are 3 types of BS was chosen to use in this simulation which are Pico-cell, Micro-cell and Macro-cell.

2.8.1 Pico-cell Network

Pico-cells offer a capacities and coverage areas to supporting up to 100 users over a radius of less than 200m. Pico-cells are commonly installed in indoors to increase poor wireless and cellular coverage within a building, like office floor or retail space. Power output of Pico-cell is between 0.25W to 1.0W. It is almost 40 times less power consuming than macro-cells [37].

2.8.2 Micro-cell Network

Micro-cells are difficult exactly distinguish from Pico-cells, but their coverage area is the principle delineator. Microcells can coverage the radius less than a kilometre and uses power control to limit this radius. Micro-cells can be install temporarily in anticipation of high-traffic in a specific area, such as a sporting event, but are also installed as a lasting feature of mobile cellular networks. Power output of Micro-cell is between 1W to 10W [37].

2.8.3 Macro-cell Network

Macro-cell different from Micro-cell by providing a larger coverage area and high-efficiency output. The service coverage radius of a Macro-cell usually between 8 km to 30 km. Macro-cell must be properly mounted on ground-based masts or other existing structures and at heights for an unhindered, clear view of the surroundings. Power output of Macro-cell is between 10W to 50W [37]. Figure 2.3 shows the different coverage areas between Pico-cell, Micro-cell and Macro-cell. And the Table 2.1 show the summarized the property of different base station as presented in [37]. In this thesis, we consider the Pico-cell as the simulation network, with a minimum cell radius coverage.

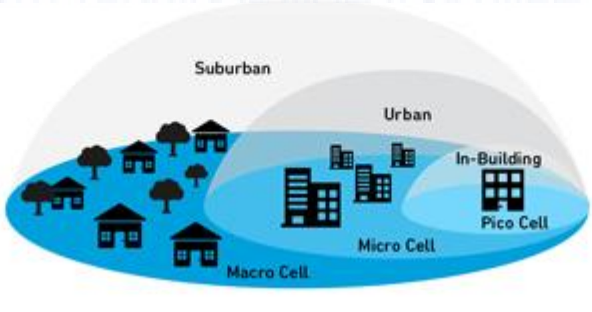

Figure 2.3 Coverage Area of Pico, Micro & Macro cell

Table 2.1 Sizing-Up Base Staion [37]

Cell Type	Output Power, W	Cell Radius, km	Amount of Users	Plant Location
Pico-cell	0.050 – 1.000	0.05 – 0.2	30 – 100	Indoor / Outdoor
Micro-cell	1.000 – 10.000	0.2 – 2.0	100 – 2000	Indoor / Outdoor
Macro-cell	10.000 – 50.000	8.0 – 30	> 2000	Outdoor

2.9 Urban Area

An urban area includes the city town, as well as suburbs its surrounding areas. Most inhabitants of urban areas have non-agricultural jobs. Urban areas are very developed, meaning there is a density of human structure such as houses, commercial buildings, roads, bridges, and railways [25]. Qualification of population size of urban center was expanded to 10,000 - 24,999 per 1 km^2 according to research in 1991 [26].

2.10 Additive White Gaussian Noise

Additive White Gaussian Noise (AWGN) is a basic noise model used in Information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics [27]:

1. The noise is additive. This means that the received signal, r (do a math annotation) is equal to the transmitted signal, s plus noise, w. It shows a widely used equality in communication systems – r = s + w [28] and shown in Figure 2.3.

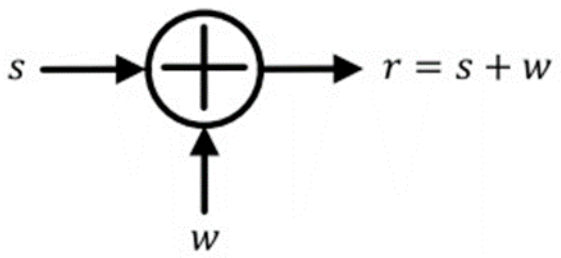

Figure 2.4 Equation of Noise Sample [28]

Note that the equation is highly simplified due to neglecting every single imperfection a T_x signal encounters, except the noise itself.

2. White noise shows that it has uniform power across the whole frequency band and is composed of all frequencies in the visible spectrum. As a result, the spectral density of white noise is ideally flat for all frequencies ranging from -∞ to +∞ [28]. The Figure 2.4 shows the frequency of noise sample.

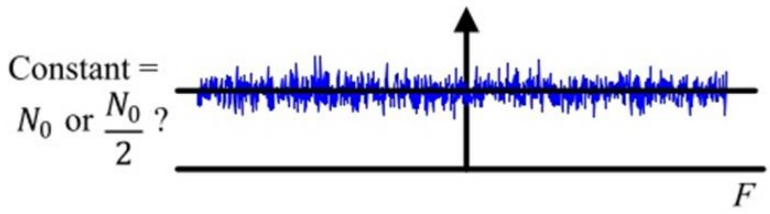

Figure 2.5 Frequency of Noise Sample [28]

3. Gaussian is refer to the probability distribution of the noise samples. According to the Figure 2.5, be acquire both negative and positive values in time domain. Besides that, the values far away from zero are less likely to appear while the values close to zero have a higher chance of occurrence [28]. In conclusion, the time domain average of a large number of noise samples is zero.

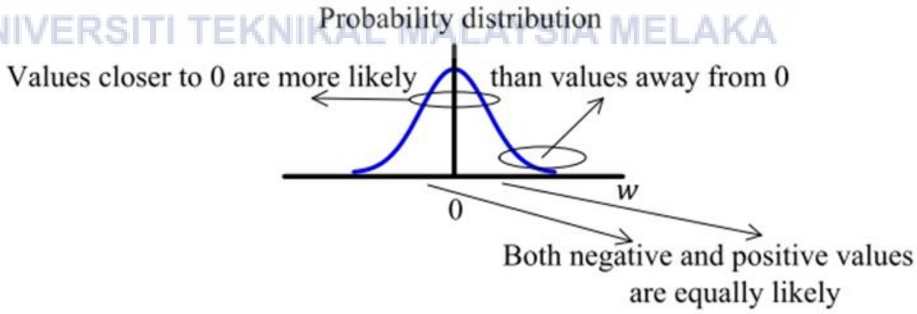

Figure 2.6 Probability Distribution of Noise Sample [28]

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, many aspect of the project to achieve the objectives for this research is shown. The method is show in terms of project flow chart, experimental test method and stimulation method to analyze the spectral efficiency and latency optimization of the C-RAN. The methodology provide guideline and idea to proceed the project smoothly.

3.2 Simulation Environment

In this simulated C-RAN system, the RRHs are assume to be mounted or located on the top of a building and engage with the Small-Cell Network (SCN) to receive the signal sending from UEs to BSs and provide the down conversion services the received radio frequency signal from UE into in-phase (I) and quadrature (Q) baseband samples.

In this study, the number of RRHs used is set as 5, 7 and 9 units with a fixed serving radius and located in systematic arrangement. At the same time, the number of UEs is set as same with the number of RRHs and distributed randomly. The proposed example of simulation environment was shown in Figure 3.1 as we increase number of RRH, this implies to a dense environment.

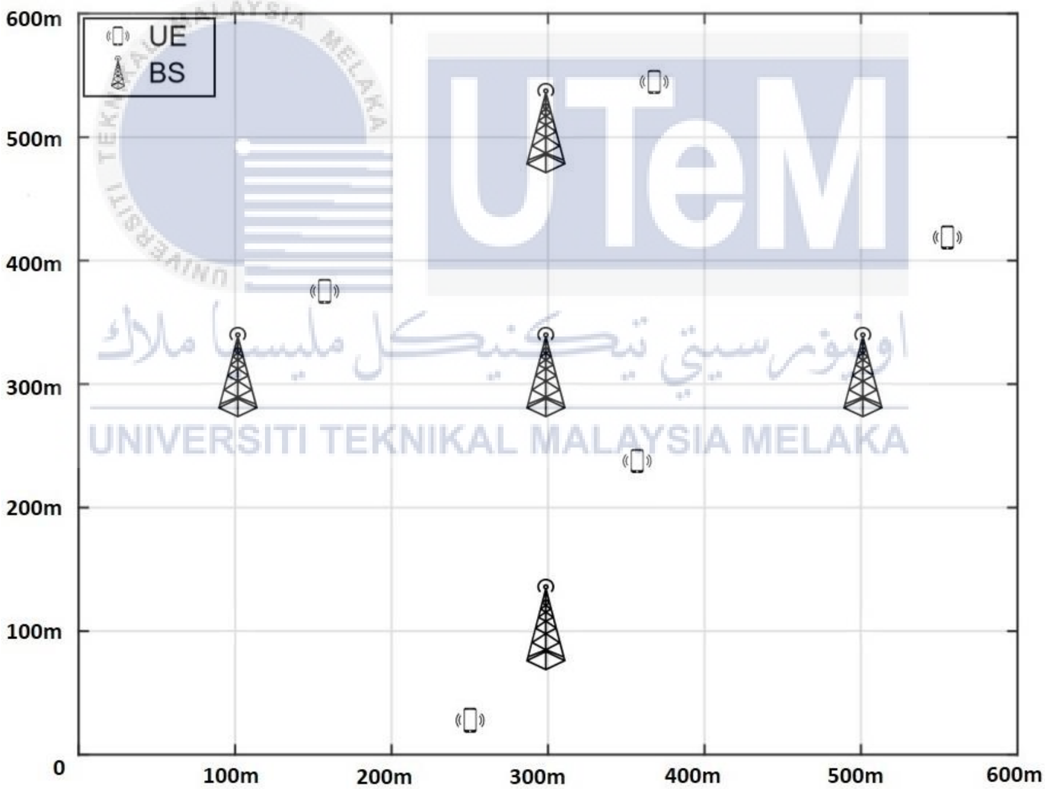

Figure 3.1 Example of Simulation Environment

3.3 System Model

In this section, we provide a general system model that consider a transmission for a C-RAN system. To formulate this system model, we assume that a power adjustment was involved between a pair of a UE and RRH nodes for any uplink transmission. We consider an uplink transmission between the numbers of UEs denoted by N_U and the RRHs, N_R in the system.

3.3.1 Wireless Channel

We suppose that a frequency reuse of 1 where each RRH $j, j \in N_R$ uses the same channel to serve its respective UE $j, j \in N_U = \{1, \ldots, N\}$. According to the Chapter 3.4, the UE is distributed uniformly across the geographical target area and connected to the closest RRH $j, j \in N$.

Therefore to express a transmission, symbols are applicable for simplicity and clarity. Assume for the pair j, the associated UE i sends packets to the target RRH j with power, $\mathcal{P}_j$. Each UE j sends a modulated symbol $\mathcal{x}_j$ to the RRH j. The set of adjacent RRHs to RRH j is defined as $\mathcal{N}_j = \{i \neq j \mid i \in \mathcal{N}\}$. Then the uplink transmit power of UE j, $p_j \in \mathcal{W}_j$, $\mathcal{W}_j = \{p_{j,i} \mid i = 1, \ldots, W\}$ is selected from W possible transmit power values.

Then, the wireless channel between RRH j and UE k is modelled as:

$$\boldsymbol{g_{jk} = h_{jk} 10^{0.1\mathcal{F}(d_{jk}, \beta)/2}} \quad (1)$$

Where h_{jk} represents the complex Gaussian coefficient with zero mean and a unit variance that represents a short term fading. The $\mathcal{F}(d_{jk}, \beta)$ is denotes a large scale fading component in dB where $\mathcal{F}(d_{jk}, \beta) = 139.5 + 10\beta \, log_{10}\left(\frac{d_{jk}}{1000}\right) + \chi$. d_{jk} is the distance between RRH j and UE k in meter, where β is path loss exponent and $\mathcal{X}$ is the random log-normal shadowing coefficient in dB [34].

3.3.2 Additive White Gaussian Noise (AWGN)

The additive white Gaussian noise (AWGN) used to mimic the effect of many random process that occur in nature at RRH j is represented as $\mathcal{Z} \sim \mathcal{C}\bar{\mathcal{N}}(0, \sigma_j^2)$where σ_j^2 is its variance.

3.3.3 Uplink Received Baseband Signal Formulation

Based on the system model used in this study, the uplink received baseband signal at RRHs after RF down-conversion is shown as below:

$$\boldsymbol{\mathcal{Y}_j = g_{jj}\sqrt{\mathcal{P}_j x_j} + \sum_{i \in N} g_{ji}\sqrt{\mathcal{P}_i x_i} + \mathcal{Z}_j = \mathcal{Y}_j^I + i\mathcal{Y}_j^Q} \tag{3}$$

$\mathcal{Y}_j$ in (2) is a complex number with its real and imaginary part representing the in-phase (I) and quadrature (Q) received samples at RRH j, $\mathcal{Y}_j^s$, s = $\{I\ ,\ Q\}$. Table 3.1 shows the input and output for the Equation 2 to calculate RF down-conversion of uplink received baseband signal at RRH.

Table 3.1 Validation of TL estimation with time series load flow simulations based on results obtained from local power utilities

Equation 2	RF Down-Conversion of Uplink Received Baseband Signal at RRH
Input:	g_{jj} = gain between RRH j and UE j $\mathcal{P}_j$ = power consumption of RRH j x_j = modulated symbol send by UE j $\mathcal{Z}_j$ = AWGN of the system
Output:	$\mathcal{Y}_j$ = uplink received baseband signal

3.3.4 Three Sigma Rule

In statistics, Three Sigma Rule also known as empirical rule. It state that, for many reasonably symmetric unimodal distributions, the percentage of values that lie within one, two and three standard deviations of the mean, almost all of the population lies within three standard deviations of the mean [31].

To calculate the range of possible values for each received random *I* and *Q* samples, denoted by $[-\eta_j^s, \eta_j^s\ ]$, we use three sigma rule [35]. In this scenario, this rule states that η_j^s is set as the value of three times standard deviation of the random *I* and *Q* samples, then the received samples will lie in this interval 99.75% of the time.

We use the standard deviation of the received signal $\mathcal{Y}_j^s$ to calculate the $[-\eta_j^s, \eta_j^s\ ]$ as described in [36]. From (2), η_j^s is given by:

$$\boldsymbol{\eta_j^s = 3\sqrt{(|g_{j,j}|^2\mathcal{P}_j + \sum_{i\in N, i\neq j} |g_{i,j}|^2\mathcal{P}_i + \sigma_j^2)/2}} \tag{2}$$

3.3.5 Selection of Quantized Signal Representation

We now assume $\breve{\mathcal{Y}}_j^s$, *s* = {*I*, *Q*} be the quantized signal representations for the received *I* and *Q* samples and q_j^s be the number of quantization bits. $\breve{\mathcal{Y}}_j^s$ is chosen by comparing the received signal $\mathcal{Y}_j^s$ with $2^{q_j^s}$ possible quantized signal representation of *I* and *Q* samples.

Then, we choose the *I* and *Q* representation that are the closest to the received signals based on the Euclidean distance. These quantized signal representations for *s* = {I, Q} can be written as:

$$\boldsymbol{W_j^s(k_j^s, l_j^s\ ) = \frac{k_j^s\eta_j^s(2l_j^s + 1)}{2^{q_j^s}}} \tag{3}$$

Where $k_j^s = -1, 1$ and $l_j^s = 0, 1, \ldots, \frac{2^{q_j^s}}{2} - 1$ are the variables that control the value of the quantized signal representations. The inclusion of η_j^s, k_j^s and l_j^s in (4) assure the W_j^s are distributed uniformly within $[-\eta_j^s, \eta_j^s\ ]$ as described in [36].

The process to select the quantized signal representations for *I* and *Q* samples are then shown as:

$$\breve{\boldsymbol{\mathcal{Y}}}_j^s = \boldsymbol{W}_j^s(\bar{\boldsymbol{k}}_j^s, \bar{\boldsymbol{l}}_j^s), (\bar{\boldsymbol{k}}_j^s, \bar{\boldsymbol{l}}_j^s) = \min_{\bar{\boldsymbol{k}}_j^s, \bar{\boldsymbol{l}}_j^s} ||\boldsymbol{W}_j^s(\boldsymbol{k}_j^s, \boldsymbol{l}_j^s) - \boldsymbol{\mathcal{Y}}_j^s||_2 \tag{4}$$

From (5), the selected $\bar{k}_j^s$ and $\bar{l}_j^s$ for both *I* and *Q* samples, *s* = {I, Q} are then sent to the CU as a binary signal sequence by RRH *j*, referred to as bits (*j*), for further signal processing.

The first binary signal sequence in bits (*j*) represents the direct binary conversion from $\bar{k}_j^s$ .The first bit of bits (*j*) is 0 if $\bar{k}_j^s = -1$ and 1 otherwise. Then, the remaining binary signal in bits (*j*) denotes $\bar{l}_j^s$. Being a positive integer, $\bar{l}_j^s$ can be converted directly to a binary signal with a length of $\frac{2^{q_j^s}}{2} - 1$.

3.3.6 Variance of Quantized Signal Sample

The error between the received symbol of $\mathcal{Y}_j^s$ and its quantized representation, $\breve{\mathcal{Y}}_j^s$, denoted by e_j^s, *s* = {*I*, *Q*}, is then shown as:

$$\boldsymbol{e}_j^s = \breve{\boldsymbol{\mathcal{Y}}}_j^s - \boldsymbol{\mathcal{Y}}_j^s \tag{5}$$

The equation (6) is assumed distributed uniformly between $[-\eta_j^s, \eta_j^s]$ with its variance, ρ_j, given by:

$$\boldsymbol{\rho_j} = (\underline{\boldsymbol{a}}) \; \frac{\int_{-\frac{\eta_j^I}{2^{q_j^s}}}^{\frac{\eta_j^I}{2^{q_j^s}}} \left(e_j^I\right)^2 de_j^I + \int_{-\frac{\eta_j^Q}{2^{q_j^s}}}^{\frac{\eta_j^Q}{2^{q_j^s}}} \left(e_j^Q\right)^2 de_j^Q}{\eta_j^s 2^{1-q_j^s}},$$

$$= (\underline{\boldsymbol{b}}) \; 3\left(|\boldsymbol{g}_{j,j}|^2 \boldsymbol{\mathcal{P}}_j + \sum_{i \in N, i \neq j} |\boldsymbol{g}_{i,j}|^2 \boldsymbol{\mathcal{P}}_i + \boldsymbol{\sigma}_j^2 \right) \boldsymbol{2}^{-2q_j^s} \tag{6}$$

Where $(\underline{a})$ and $(\underline{b})$ are obtained by following the Widrow Theorem in [36] and substituting η_j^s according to (3).

3.4 Efficiency Optimization Formulation

In this section, the resource allocation optimization formulation will be developed for the efficiency ratio with uplink power $\mathcal{P}_j$ and binary representation of *I* and *Q* samples, q_j^s, *j* = 1, . . . ,*N* as its variables. RRH *j* quantizes *I* and *Q* samples into quantization bits q_j^s and thus it transmits $2^{q_j^s}$ bits to the CU.

3.4.1 Signal-to-Interference-plus-Noise (SINR)

Now let $v_j = (\mathcal{P}_j, q_j^s)$, *s* = {*I*, *Q*} be the uplink power for UE *j* and the number of quantization bits of RRH *j*. by defining $\bar{v}_j = \{v_i, | i \neq j,\ i \in \mathcal{N}\}$ for adjacent RRHs to RRH *j*, a Signal-to-Interference-plus-Noise (SINR) for RRH *j* is given as:

$$\boldsymbol{\gamma_j(v_j, \bar{v}_j)} = \frac{|\boldsymbol{g_{j,j}}|^2 \boldsymbol{\mathcal{P}_j}}{\boldsymbol{\rho_j} + \sum_{\boldsymbol{i \in N, i \neq j}} |\boldsymbol{g_{i,j}}|^2 \boldsymbol{\mathcal{P}_i} + \boldsymbol{\sigma_j^2}} \quad (7)$$

Equation (8) is calculated at the CU based on the combination of short and long term fading coefficients, sent by RRHs to CU.

3.4.2 Uplink Spectral Efficiency

Based on (8) the uplink SE at RRH *j* is:

$$\boldsymbol{R_j} = \frac{\boldsymbol{B}}{\boldsymbol{N}} \boldsymbol{log_2}\left(\boldsymbol{1} + \boldsymbol{\gamma_j(v_j, \bar{v}_j)}\right) \quad (9)$$

Where *B* dedicated to the uplink transmission bandwidth, which is subdivided into *N* channels and each UE is allocated one channel to transmit.

3.4.3 Efficiency Ratio

The efficiency ratio is used to calculate the ratio between the uplink SE and the number of quantization bits used to represent I and Q samples at RRH j, given as:

$$\boldsymbol{I_j(\upsilon_j, \bar{\upsilon}_j) = \frac{R_j}{2q_j^s}} \tag{10}$$

The efficiency ratio optimization for RRHs with variables $\upsilon_j = (\mathcal{P}_j, q_j^s)$, s = $\{I, Q\}$ is given as:

$$\max_{\upsilon_1,\dots,\upsilon_N} \sum_{j\in\mathcal{N}} \boldsymbol{I_j(\upsilon_j, \bar{\upsilon}_j)}$$

$$\text{subject to } \boldsymbol{\upsilon_j = (\mathcal{P}_j, q_j^s), \mathcal{P}_j = \{\mathcal{P}_{j,1}, \dots, \mathcal{P}_{j,W}\}}$$

$$\boldsymbol{q_j^s = \{q_{j,1}^s, \dots, q_{j,M}^s\}, \forall j \in \mathcal{N}} \tag{11}$$

Where $q_j^s = \{q_{j,1}^s, \dots, q_{j,M}^s\}$ denotes M choices the number of quantization bits for RRH j to represent the received samples, $\mathcal{Y}_j^s$, s = $\{I, Q\}$. The optimal solution for (11) can be obtained by exhaustively searching the optimum joint transmit power and the number of quantization bits combinations, $\upsilon_j, j = 1, \dots, N$ that has very high computational complexity at the CU.

As the summary of methodology have been shown in the project flow chart as in Figure 3.2.

3.5 Project Flow Chart

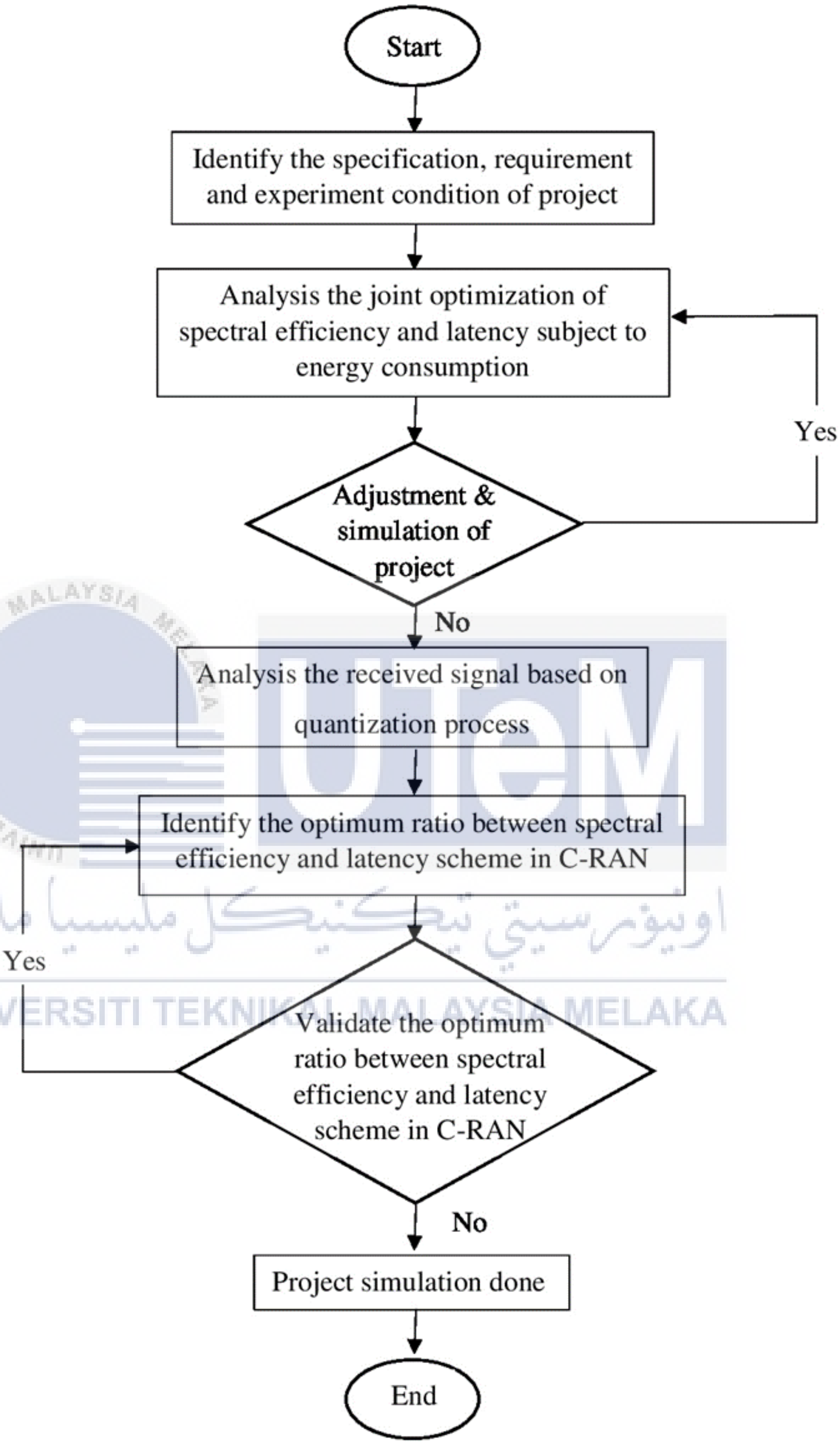

Figure 3.2 Project Flow Chart

The flow chart shown in Figure 3.2 describe the overall project flow to investigate and validate the spectral efficiency and latency optimization of C-RAN. It could use as a project guideline. Firstly, the requirement and the experiment condition need to be identified to set-up the simulation environment to carrier on next phase. Then, we need to analyze the spectral efficiency and latency optimization of C-RAN subject to power consumption before joint them together. After that, the received signal will be analyze based on quantization process and then substitute into the joint optimization equation before it. The optimum ratio between spectral efficiency and latency scheme will be identify and validate to find a best trade-off ratio after the quantization process is done.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter cover simulation result for of C-RAN based on Chapter 3. The complete simulation coding by using MATLAB is shown in Appendix B.

4.2 Simulation Set-up

In this simulation, we consider the system parameters of LTE-A and the wireless channel parameters for our model is set as the Table 4.1, we set-up the simulation of SINR performance to establish the spectral efficiency by assuming the network parameters is fixed at the certain possible value and substitute the parameter into (8). All results are evaluated over 500 independent trials.

Table 4.1 Assumed Network Parameter Values

Symbol	Description	Assumed Value
β	Path loss exponent	3.7
r	Cell radius	200m
$\mathcal{X}$	Log normal shadowing	10dB
W	Uplink transmission power	0 / 23dBm
$\mathcal{P}_{j,2}$	Maximum uplink power of UE	23dBm
B	Bandwidth of system	20MHz
N_0	Thermal noise power density	-174dBm/Hz

In the simulation, equation (1) was used to obtain the gain between each pair of UE and RRH. Then, we use efficiency ratio optimization shown in (10) to establish the ratio between the uplink SE and the number of quantization bits used to represent I and Q samples at RRH j.

There are several scenario have been proposed and simulate in the efficiency ratio optimization performance. First scenario is the simulation was set-up with different types of BS in used. The second scenario is simulation with different uplink transmission power of UEs in used. Besides that, the third scenario is increase the number of RRHs and UEs in used.

4.3 Simulation Results and Discussion

4.3.1 The Spectral Efficiency for Different Quantization Levels

We assume that each RRH only chose one bits from the number of quantization bits of each I and Q samples, $q_j^s = \{q_{j,1}^s\}$ that results in a total of $2q_j$ transmitted bits to analyze the impact of shifting the number of quantization bits to SE.

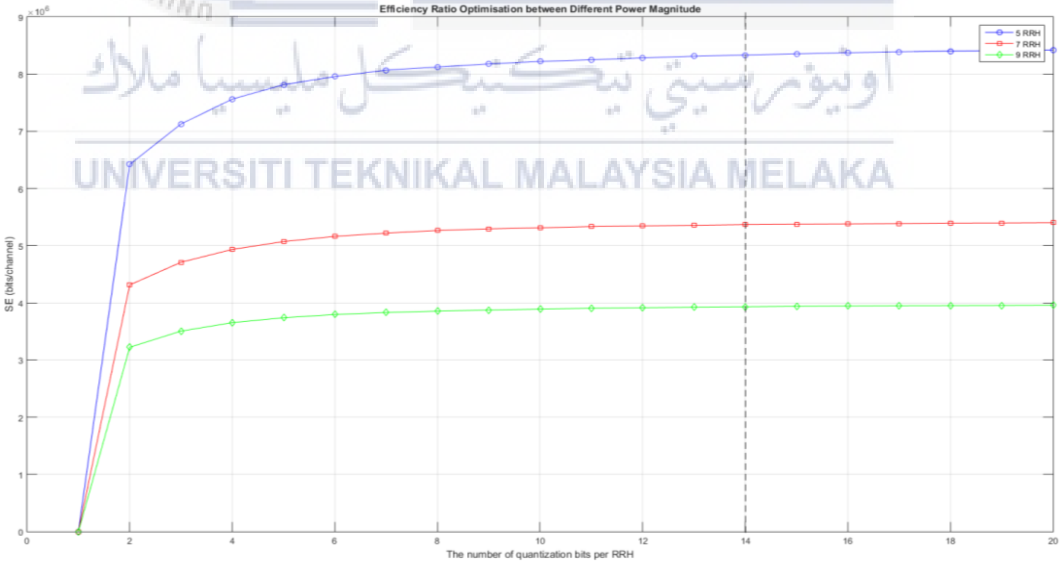

Figure 4.1 Spectral Efficiency for different RRH's Quantization Levels

From Figure 4.1 shows that increasing of the total number of quantization bits to represent I and Q samples per N RRHs, $2q_j^s, j = 1, \ldots, N$. The SE does not increase when the bits is beyond 14 bits. Therefore, we can assume that 14 bits of quantization levels is the satisfied number of bits that can be used under this simulation setting.

4.3.2 The Efficiency Ratio Optimization between Different Types of RRH

Figure 4.2 shows that the cumulative distribution function of the efficiency ratio of the different type of RRH with the different cell radii. The RRH that was chosen in this simulation is Pico-cell with the cell radius between 50 m to 200 m, Micro-cell with 200 m to 2 km as its cell radius and the Macro-cell with the cell radius between 8 km to 30 km. The number of RRH that used in this simulation was fixed as five and for simplifier the calculation the number of quantization bits at this simulation was various between 1 bits to 14 bits.

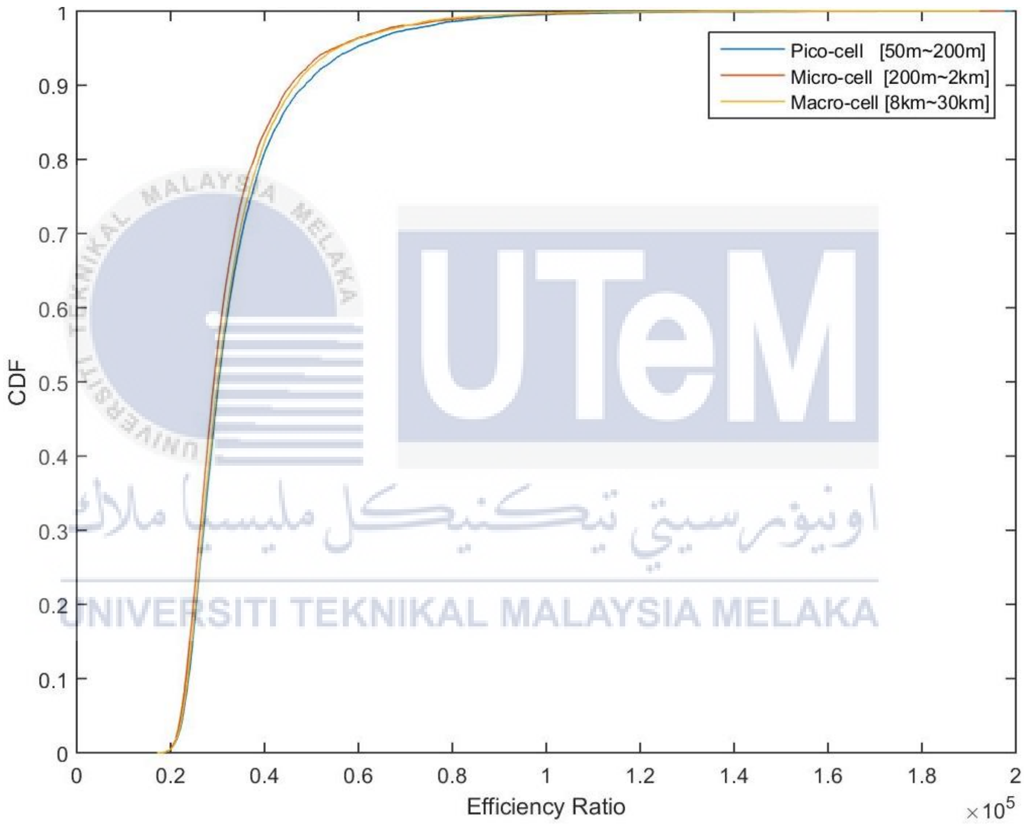

Figure 4.2 Efficiency Ratio Optimization between Different Types of RRH

Figure 4.2, show the simulation of the different cell radii does not bring a significant difference to the efficiency ratio of optimization. Therefore, this simulation show that the efficiency ratio optimization equation that proposed in this report is suitable and capable to work with the different type of RRH.

Table 4.2 Correlation of Data

	Pico-cell	Micro-cell	Macro-cell
Pico-cell	1		
Micro-cell	0.01916791	1	
Macro-cell	0.04049814	0.02448071	1

Table 4.2 show the correlation of data between 3 types of cells. From the table below, it show that 3 types of RRH were in a very weak uphill (positive) linear relationship between each other. Therefore, the different services radii provided by each type of RRH does not affect each other and does not giving huge impact to the efficiency ratio of optimization.

4.3.3 The Efficiency Ratio Optimization between Different Uplink Transmission Power

As we know based on UE class category. It cannot transmit more than its maximum UE power which is commonly 23 dBm for most LTE UEs in the uplink transmission. In this simulation we set 23 dBm as higher end of the maximum power of UE allowed to transmit and 21 dBm as lower end of the maximum power of UE allowed to transmit [38].

Therefore, Figure 4.3 shows the cumulative distribution function of the efficiency ratio of the different max-min uplink transmission power level of UEs in the simulation. Two level of transmission power have been chosen that is 0 dBm and 23 dBm, second is 0 dBm and 21 dBm and the last is 21 dBm and 23 dBm. There are five Pico-cells were used in each scenario and to simply the calculation all the power have been converted to dB and the quantization level is was various between 1 bits to 14 bits.

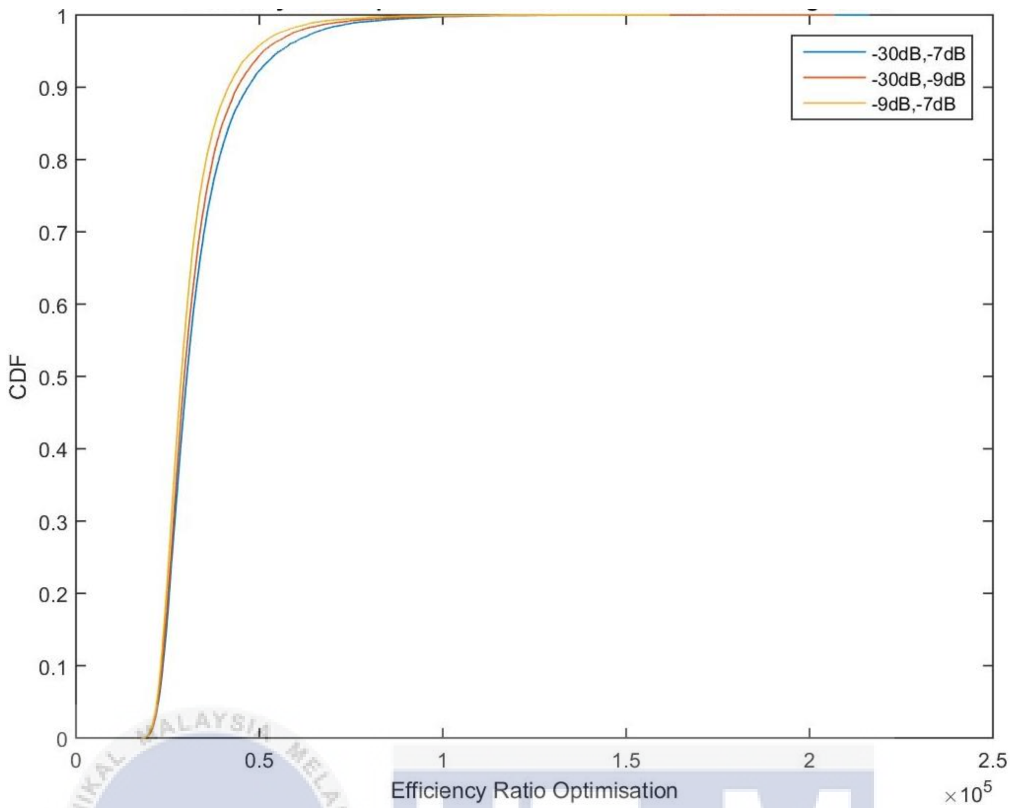

Figure 4.3 Efficiency Ratio Optimization between Different Power Magnitudes for 5 RRH

Figure 4.3 shows the significant difference on the efficiency ratio of optimization between each max-min uplink transmission power. The -30 dB as minimum and -7 dB as maximum power show the best efficiency ratio in this simulation compare with the other two max-min uplink transmission power. Therefore, the benchmark of max-min uplink transmission power of UE is recommended as 0 dBm and 23 dBm to perform a better efficiency ratio of optimization.

4.3.4 The Efficiency Ratio Optimization between Different Number of RRHs

In Figure 4.4 shows that the cumulative distribution function of the efficiency ratio of the different number of RRHs that services in the simulation. The number of RRH that have been chosen to use is 5 RRHs, 7 RRHs and 9 RRHs. In this simulation, the uplink transmission power of UEs was set as 0 dBm and 23 dBm and the Pico-cell was chosen to use in services and the quantization level was various between 1 bits to 14 bits.

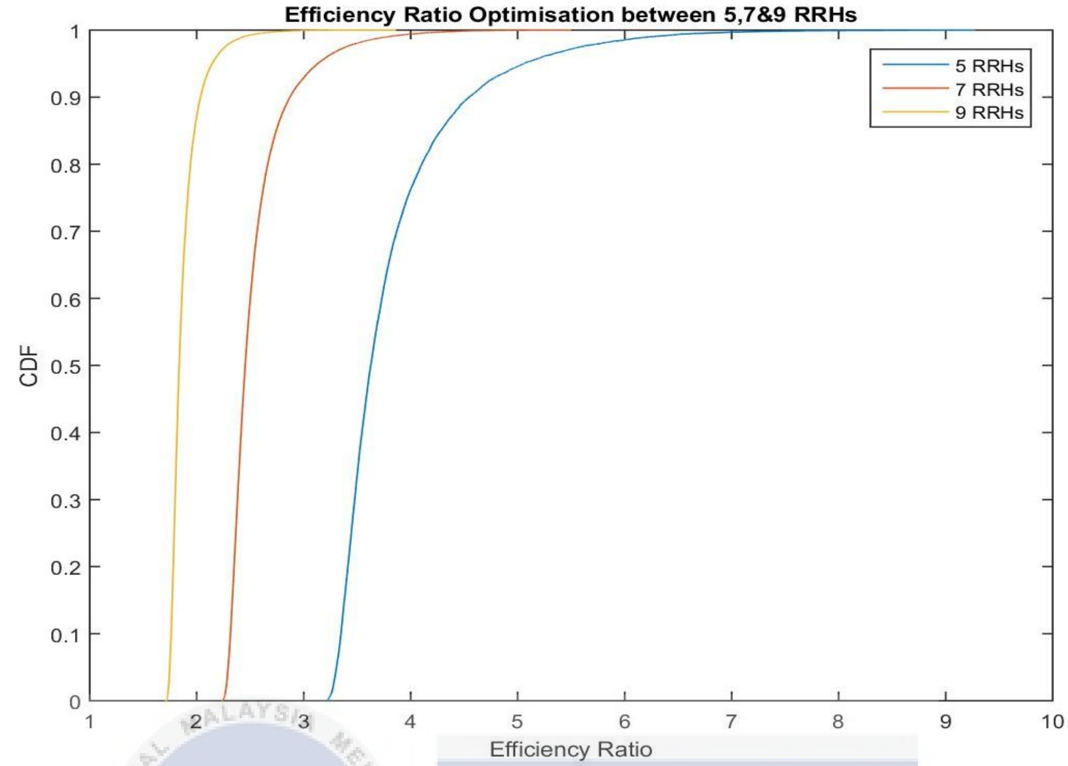

Figure 4.4 The Efficiency Ratio Optimization between Different Numbers of RRHs

Figure 4.4 shows the different number of RRH using have shown the significant different on the efficiency ratio optimization. Note that we set the $q_j^s =$ 1 to 14, this implies that every RRH was various between 2 bits to 16384 bits. As we increase the number of RRH, the interference is increasing due to the environment become denser that shown in (8) and the ratio is decreasing due to maximum number of bits per RRH, which align with (10).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Cloud-based radio access network brings a significant impact in the spectral efficiency and latency in the data transmission. In this thesis, we have clearly show that optimization of spectral efficiency subject to energy consumption for C-RANs system have been investigated and formulated. Besides that, the joint optimization of spectral efficiency and latency scheme of C-RAN system based on quantization process have been analyzed and validated and the optimum ratio between them also have been investigated.

The optimum ratio between uplink SE and latency optimization scheme that simultaneously optimizes the average uplink rate and latency of RRHs and the number of quantization bits for representing *I* and *Q* samples at RRHs as optimization variables in C-RANs also have been proposed in this thesis.

As a recommendation, we can set a various quantization bits to the transmission and also set a minimum requirement to the quantization bits for further study. Besides that, the proposed solution of this study can be upgrade into software that applicable to data processing system and wireless communication system. The advancement knowledge through this study will be a reference design that could be potentially enhanced energy-efficient for wireless traffic in Malaysia.

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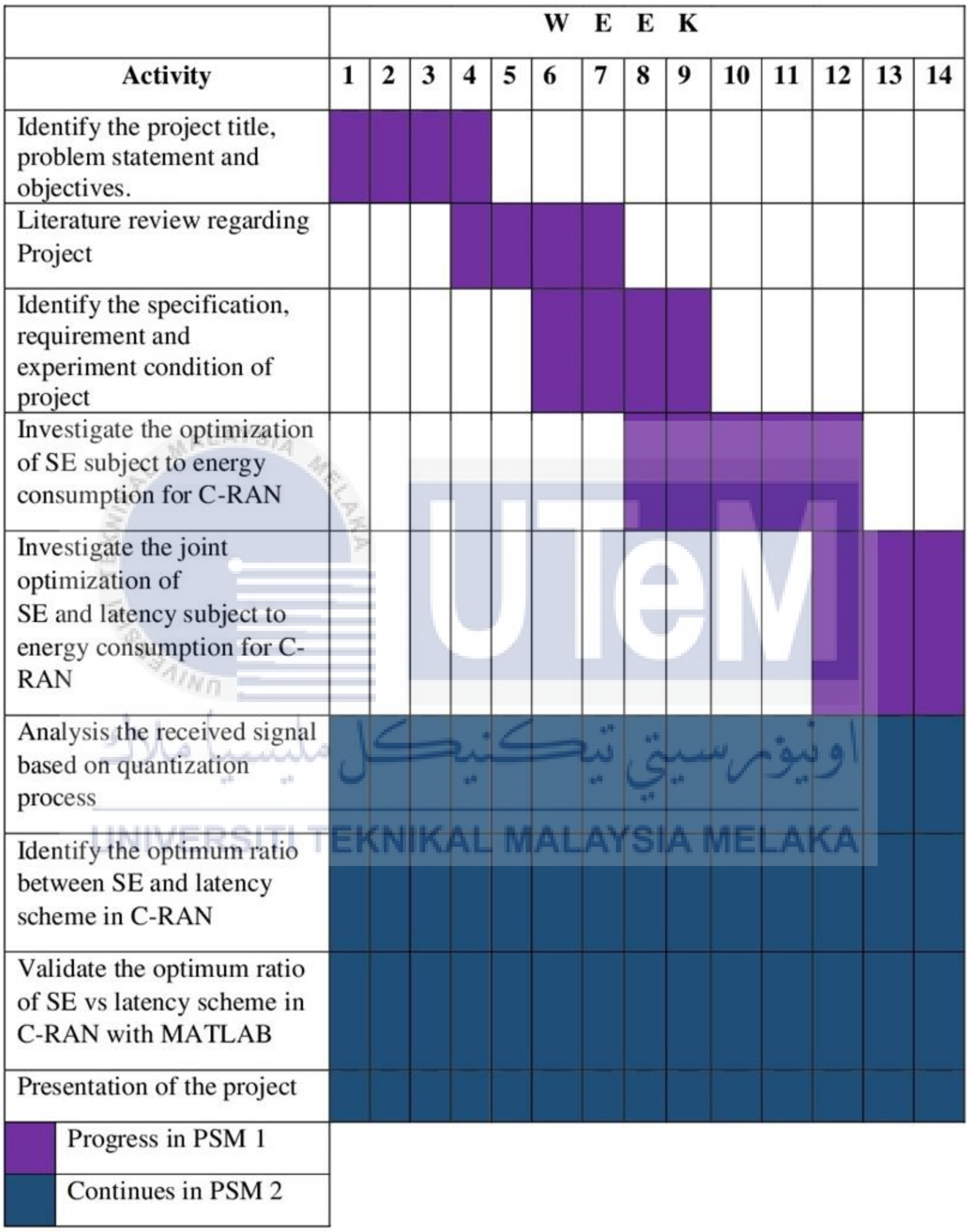
APPENDICES

APPENDIX A Project Gantt Chart



APPENDIX B MATLAB Sample Code

```
clear all
clc

%Pico Cell Radius
t = 500;                                            %Number of iteration
bl = 1;
B1 = 20000000;                                      %Bandwidth (Hz)
nUE1 = 5;                                           %Number of User Equipment
nBS1 = nUE1;                                        %Number of Base Station
rmax1 = 200; rmin1 = 50;                            %Max & min cell radius (m)
dist1=(rmin1+(rmax1-rmin1))*((rand(nBS1,1))/1000);  %Distance between UE and BS
F1 = (0.1*(149.5+37*(log(dist1)/2)));               %Short-term fading
P1 = permn([-30 -7],nUE1);                          %Power in dB
P1 = P1.';                                          %tranpose matrix
qq1 = 2.^nUE1;q1 = qq1;
q = [1 14];
qj = randi(q);                                   %Quantization bits

for n1 = 1 : t;

    a1=0;
    h1 = (0.5)*((randn(1,nUE1))+1i*(randn(1,nUE1)));
    G1 = ((10.^F1)*h1);
    G1 = G1.^2;
    G1 = abs(G1) + imag(G1);
    G1 = G1.';                                      %Tranpose matrix

%Calculate gain
        for N1 = 1:nBS1
            for pp = 1:q1
            g1(pp,:) = G1(:,N1).*P1(:,pp);
            end
          %Compute signal
          sgn1 = g1(:,N1);
          %Compute noise
                for i1 = 1:q1
                    noi1(i1) = sum(exclude(g1(i1,:),[N1]));
                    noi1 = reshape(noi1,[],1);
                end
            %Compute interference
                    itf1 = (3 * (sgn1+noi1) * 2.^(-2*qj)) + noi1 + 1;

            %Compute SINR
                        a1 = a1+1;
                        sinr1([b1:b1+q1-1],a1) =sgn1 ./ itf1;
        end

```

```
b1=b1+q1;

end

%Compute uplink spectral efficiency
for c1 = 1: size(sinr1,1)
    for d1 = 1:nUE1
        R1(c1,d1) = (B1 * log2(1+sinr1(c1,d1))) / nUE1;
    end
end

%Ratio betwwen uplink SE and no. of quantised bits
Qq = [1 10];
%for e1 = 1:size(R1,1)
    %for f1 = 1:nUE1
        I1 = sum(R1,2);
        %I11 = mean(I1,2);
        %I1 = sum(I1,2);
        II1 = I1 ./(2*(randi(Qq)+randi(Qq)+randi(Qq)+randi(Qq)+randi(Qq)));
    %end
%end

%Plot graph
figure(1)
cdfplot(II1);
grid
legend('5 RRH');
title('Efficiency Ratio Optimisation between Different Power Magnitude');
xlabel('The number of quantization bits per RRH');
ylabel('SE (bits/channel')
```