Sudan University of Science and Technology

College of Graduate Studies

Performance Evaluation of Carrier Aggregation in Long Term Evolution-Advanced

تقييـــم أداء تقنية تجميع الموجات الحاملة في نظام التطـور طويــل الأمــد المتقــدم

A Thesis Submitted in Partial Fulfilment for the Requirements of the Degree of M.Sc. in Electronics Engineering (Communications)

Prepared by:

Wala Khalifa Mohamed Ahmed

Supervised by:

Dr.Fath Elrahman Ismael Khalifa Ahmed

MAY, 2018

Sudan University of Science & Technology

College of Graduate Studies

بسم الله الرحمن الرحيم

SUST

كلية الدراسات العليا

جامعة السودان للعلوم والتكنولوجيا

كلية الدراسات العليا

Ref: SUST/ CGS/A11

Approval Page

(To be completed after the college council approval)

Name of Candidate: Wala Khalifa Mohamed Ahmed

Thesis title: Performance Evaluation of Carrier Aggregation in Long Term Evolution Advanced

تقييم أداء تقنية تجميع الموجات الحاملة في نظام التطور طويل الأمد المتقدم

Degree Examined for: Master of Science in Electronics Engineering (Communications)

Approved by:

1. External Examiner

Name: Abdelmotaal Ebashir Ibrahim

Signature: A.Motaal Date: 4/6/2018

2. Internal Examiner

Name: Ebtihal Haider Gismalla Yousif

Signature: [signature] Date: 4/6/2018

3. Supervisor

Name: Dr. Fath Elrahman Ismael Khalifa Ahmed

Signature: Fathe rahman Date: 4/6/2018

الإستهـــــــــــلال

قَالَ تَعَالَى:

" قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنْتَ

الْعَلِيمُ الْحَكِيمُ"

البقرة الايه ٣٢

DEDICATION

From depth of my heart I dedicate this work to:

The spirit of my dear mother

I miss you in many stages of my life.

My great father

For his continuous prayers, love, patience, encouragement and support. thanks a lot Dad without you I mean nothing. Love you so much.

My sisters

Who are making my life easier, all love to you.

To my friends, colleagues and to whom I love for always being there for me at times for need.

To all I belong to I dedicate this work.

ACKNOWLEDGMENT

Firstly, all my thanks and praise is to Allah ever and forever.

I would like to send my regards and thanking to Sudan University of science and technology for the chance that have provided me to gain knowledge and experiences.

Deep thanks to supervisor **Dr.Fath Elrahman Ismael** for sharing me all his wisdom knowledge, experiences, his time and endless help throughout the research period.

Special thanks to Professor. Hussain Al-Rizzo (University of Arkansas) who is supported me and sent me the LTE-A downlink system level simulator.

Special thanks to Eng.Yousf Yaseen (Zain Company), Eng.Abd alfatah Alkhalifa (SUDATEL) and Eng.Mustafa Malek.

ABSTRACT

Carrier aggregation is one of the promising features that enables expanding the bandwidth of the Long Term Evolution-Advanced (LTE-A) system through aggregating multiple LTE component carriers (CCs) of the same or different frequency bands to support high data rate up to 1 Gbit/s. The LTE-Advanced users can transmit packets on all of the available CCs whereas the LTE users are limited to transmit packets on a single CC. But Carrier Aggregation (CA) functionality introduces new challenges for Radio Resource Management (RRM) function of network and becomes more complicated, of which one significant aspect is the requirement of CC selection method. To solve this problem CC selection method needs to be carefully designed. In this research two CC selectors implemented there are All CC selector and Cyclic CC selector, also their performance evaluated using LTE-A downlink system level simulator conducted with MATLAB. Simulation results show that All component carrier selector outperforms the Cyclic CC selector in term of average cell throughput, average user equipment (UE) throughput and spectral efficiency by 225.16%, 214.35% and 163% respectively. While Cyclic outperforms the All in term of fairness by 47%. The reduction in the fairness index in All selector implies that, the scheduler has an increased task in resource allocations due to the added component carrier.

المستخـلص

تعتبر تقنية تجميع الموجات الحاملة أحد الميزات الواعدة التى تمكن من توسيع النطاق الترددي لنظام التطور طويل الأمد المتقدم من خلال تجميع العديد من مكونات الموجات الحاملة من نفس او مختلف النطاقات الترددية لدعم معدل بيانات مرتفع يصل إلى ١ جيجا بت/ ثانية. يمكن لمستخدمي نظام التطور طويل الامد المتقدم إرسال الحزم على جميع مكونات الناقلات المتوفرة بينما يقتصر مستخدمو نظام التطور طويل الأمد على نقل الحزم على مكون موجة حاملة واحدة. لكن وظائف تجميع الموجات الحاملة تقدم تحديات جديدة لوظيفة إدارة الموارد الراديوية للشبكة وأصبحت أكثر تعقيدا. حيث يكون أحد الجوانب الهامة هو الحاجة لطريقة اختيار مكونات الموجة الحاملة. لحل هذه المشكلة يجب أن يتم تصميم طريقة إختيار مكونات الموجة الحاملة بعناية. في هذا البحث تم تطبيق اثنين من طرق إختيار مكونات الموجة الحاملة هما محدد كل مكونات الموجة الحاملة ومحدد مكونات الموجة الحاملة بصورة دورية، كما تم تقييم أدائهم بإستخدام برنامج محاكاة نظام التطور طويل الأمد المتقدم الهابط وبرنامج الماتلاب. وتبين من نتائج المحاكاة أن المحدد الكل يتفوق في الاداء على المحدد الدوري في متوسط انتاجية الخلية، متوسط إنتاجية المستخدم وكفاءة الطيف بنسبة ٢٢٥,١٦%، ٢١٤,٣٥% و ١٦٣% على التوالى في حين يتفوق المحدد دوري على الكل في الإنصاف بنسبة ٤٧%. قلة الإنصاف في المحدد الكل يدل على زيادة مهمة الجدولة في حجوزات المورد بسبب مكونات الناقلات المضافة.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
BLER	Block Error Rate
CA	Carrier Aggregation
CC	Component Carrier
CLSM	Close Loop Spatial Multiplexing
CQI	Channel Quality Indicator
CS	Circular Selection
DL	Downlink
DPCS	Dual Priority CC Selection
ECDF	Empirical Cumulative Distribution Function
EESM	Exponential Effective SINR Mapping
eNB	Evolved Node B
FDD	Frequency Division Duplex
FI	Fairness Index
GA	Greedy Algorithm
GBR	Guaranteed Bit Rate
HARQ	Hybrid Automatic Repeat Request
ICS	Improve Carrier Selection
IMT-A	International Mobile Telecommunication Advanced
ITU	International Telecommunication Union
LA	Link Adaption
LL	Least Load Selection
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Control Modified Least Load

MCS	Modulation and Coding Scheme
M-LL	Modified Least Load
OFDMA	Orthogonal Frequency- Division Multiple Access
PCC	Primary Component Carrier
PCell	Primary Serving Cell
PDCP	Packet Data Convergence Protocol
PF	Proportional Fair
PHY	Physical
PRBs	Physical Resource Blocks
PSO	Practical Swarm Optimization
QoS	Quality of Service
RB	Resource Block
RLC	Radio Link Control
RR	Round Robin
RRH	Remote Radio Heads
RRM	Radio Resource Management
RS	Random Selection
RSRP	Reference Signal Received Power
SCC	Secondary Component Carriers
Scell	Secondary Component Carrier
SC-FDMA	Single Carrier Frequency Division Multiple Access
SINR	Signal-to-Interference-Plus-Noise-Ratio
TCD	Traffic and Channel Driven
TDD	Time Division Duplex
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink

LIST OF SYMBOLS

$r_{j.k}^{(i)}(t)$	Transmission Rate of kth RB of CC j and U i
$RB_{j,k}$	Represents the kth RB of CC j
Uj	The Set of UEs Camping on CC j
$R^{(i)}(t)$	Denotes The Average Rate of UE i Up to Time t
$\mathrm{DRC}_{\mathrm{j}}^{(\mathrm{i})}(\mathrm{t}-1)$	Denoting The Actual Received Data Rate of UE i on CC_j at Time (t-1)
Cj	The Set of The CCs Allocated to UEi
$r_c^u(t)$	Instantaneous Throughput of Each User u on the CC *c*
w_c^u	Allocated Bandwidth to The User *u* on the CC *c*
$\gamma_c^u(t)$	Received (SINR) of Each User *u* Served on a CC *c* at a TTI (t)
C	Channel Capacity
n	Number of Transmit Antenna
B	Bandwidth
S/N	Signal-to-Noise Ratio
$\bar{B}(\varepsilon)$	Average Spectral Efficiency
ε	Carrier Frequency Offset
(n, k)	Resource Element Which is Devoted to Data Transmission
N_D	Number of Transmission Layers
$H_k^{(eff)}$	Channel Matrix (Precoding Included) at Subcarrier k
l	Transmission Layer Index
N_{SC}	Number of Subcarriers On Each Resource Block
$SINReff$	Effective SINR
R_{k}	Denotes The Individual UE Mean Throughput

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Preface

The global mobile data traffic has grown tremendously during the last few years and the growth is expected to continue in the future[1]. Long Term Evolution-Advanced (LTE-A) aims to support peak data rates of 1 Gbps in the downlink and 500 Mbps in uplink. In order to fulfil such requirements, a transmission bandwidth of up to 100 MHz is required. However, since current versions of broadband wireless systems make use of channel bandwidths of up to 20 MHz the availability of such large portions of contiguous spectrum is rare in practice. Therefore, a different spectrum management scheme is necessary for next generation wireless systems in order to achieve the required bandwidth [2]. LTE-Advanced uses carrier aggregation (CA) to form a larger bandwidth by collection of multiple existing carriers in order to meet the needs of higher bandwidths. Each aggregated carrier is referred to as a component carrier (CC) [2]. Carrier aggregation, where multiple component carriers of smaller bandwidth are aggregated, is an attractive alternative to increase data rate. Additional advantages are offered by carrier aggregation in terms of spectrum efficiency, deployment flexibility, backward compatibility, and more. By aggregating non-contiguous carriers, fragmented spectrum can be more efficiently utilized. With each component carrier being Long Term Evolution (LTE) compatible, carrier aggregation allows operators to migrate from LTE to LTEA-advanced while continuing service to LTE users. Both implementation and specification efforts are minimized by reusing the LTE design on each of the component carriers [3]During initial access, a CA-capable terminal behaves similarly to a terminal from earlier releases; that is, there is a single carrier, referred to as a primary component carrier (PCC). Upon successful connection to the network, depending on its own capabilities and the network configuration, a terminal may be configured with additional carriers in the uplink (UL) and downlink (DL), which are referred to as secondary component carriers (SCCs) [4].Carrier aggregation is a process where we will be sensing the unused carriers or spectrum and combine them with the Primary Component Carriers (PCC) [5].

CA permits LTE to achieve the goals mandated by International Mobile Telecommunication Advanced (IMT-A) while maintaining backward compatibility with Release-8 and 9 LTE. Release-10 CA permits the LTE radio interface to be configured with any number (up to five) carriers, of any bandwidth, including differing bandwidths, in any frequency band. Carrier Aggregation can be used for both Frequency Division Duplex (FDD) and Time Division Duplex TDD [6].

1.2 Problem Statement

The introduction of CA brings several challenges to the traditional RRM mechanisms and becomes more complicated, of which one significant aspect is the requirement of CC selection method needs to be carefully designed.

1.3 Proposed Solution

Component Carrier (CC) selection plays an important role in CA technology. An appropriate CC selection method is necessary to improve the system performance. In this thesis All and Cyclic CC selectors are selected to be evaluated.

1.4 Aim and Objectives

The aim of this thesis is performance evaluation of All and Cyclic CC selectors in different measurement:

- Increasing in average UE throughput.
- Enhancing in average cell throughput.
- Improving of Signal to Interference plus Noise Ratio (SINR).
- Increasing in spectral efficiency.
- Enhancing in fairness.

1.5 Methodology

Implementation LTE-Advanced with carrier aggregation using Remote Radio Heads (RRH) scenario, then analysing the performance using LTE-A downlink system level simulator Rel-v1-9-Q2-2016 conducted with MATLAB, the simulator consists of many files and functions. Some modifications were done in order to be able to run the CA Simulation. The main focus was on two types of component carrier selectors (all and cyclic) and evaluate their performance in term of UE throughput, cell throughput, SINR, spectral efficiency and fairness index.

1.6 Thesis Outlines

Chapter One contains short introduction, problem statement, proposed solution, aim and objectives and brief about methodology. While Chapter Two gives background about LTE-A and concept of Carrier Aggregation in addition to Radio Resource Management and related works to this research. Chapter Three describes simulation of carrier aggregation using system level simulator also explain All and Cyclic component carrier selectors and performance metrics. Chapter Four include Results and Discussions. Finally, Chapter Five contains Conclusions and Recommendations.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Third Generation Partnership Project (3GPP) LTE-Advanced can be considered as a toolbox that provides advanced features on top of existing LTE Release 8. The features can be implemented separately to the network. Such features are Carrier Aggregation, Heterogeneous Networks, Relay Nodes and Coordinated Multipoint transmission. LTE-Advanced includes also improvements to multi-antenna schemes and to Self-Organizing Networks [1].This thesis focuses primarily on Carrier Aggregation, which is covered in Section 2.3. In addition to this chapter presents overview of LTE-Advanced and Radio Resource Management (RRM) in carrier aggregation.

2.1.1 Overview of LTE-A Systems

Long Term Evolution-Advanced (LTE-A) is an evolution of 3GPP-LTE which aims to bridge the gap between Third Generation (3G) and Fourth Generation (4G) standards described in IMT-Advanced (International Mobile Telecommunications) [7].

The International Telecommunication Union (ITU) defined the IMT-Advanced requirements which included further significant enhancements in terms of performance and capability compared to legacy cellular systems, including the first release of LTE. With the aim of reaching and even surpassing these requirements, the 3GPP worked on further evolution of their first release of the LTE standard. The key goals for this evolution are increased data rate, improved coverage, reduced latency and spectrum flexibility. The key performance targets of LTE-A as compared to LTE are illustrated in Table 2-1 [8].

Table 2-1: System Performance Requirements for LTE-A [8].

Target	LTE	LTE-A
DL peak data rate	300 Mb/s	1 Gb/s
UL peak data rate	75 Mb/s	500 Mb/s
DL Peak spectrum efficiency	16 (b/s/Hz)	30 (b/s/Hz)
UL Peak spectrum efficiency	3.75 (b/s/Hz)	15 (b/s/Hz)

There are two main parts in LTE-Advanced the first is uplink that is present in Single Carrier Frequency Division Multiple Access (SC-FDMA) that is mean transmit the data of mobile from user equipment (UE) to base station (Evolved Node B), while the second is downlink that is present in Orthogonal Frequency- Division Multiple Access (OFDMA) that is mean transmit the data of mobile from Evolved Node B (eNB) to user equipment (UE)[9].

2.1.2 Carrier Aggregation

Carrier Aggregation was introduced in LTE Release 10 and it has been enhanced in the later releases. CA is considered to be the most important feature of LTE-A because it offers higher data rates, improves the DL coverage and allows operators with fragmented spectrum to utilize spectrum resources more effectively. The first commercial LTE Rel. 10 network was launched in Korea in 2013 and since then the rollout has been continuing worldwide. In September 2015, Telia Sonera achieved data speeds of 375 Mbps on live LTE network in Helsinki using three-band CA technology [10].

The maximum carrier bandwidth in LTE is 20 MHz. wider bandwidth is required to reach higher data rates. However, such spectrum is rarely available for an operator. Furthermore, if wider than 20 MHz bandwidth has to be allocated for several operators, the set of possible frequencies is very limited. Wider than 20 MHz bandwidth would also be incompatible with Release 8 capable UEs [1].

Carrier Aggregation (CA) allows scalable bandwidth extension via aggregating multiple smaller band segments, each called a Component Carrier (CC), into a wider virtual frequency band to transmit at higher rates [11].Each CC can use a particular bandwidth from the original ones defined for LTE Release 8: 1.4, 3, 5, 10, 15 or 20 MHz, each CC can take any of the transmission bandwidths supported by LTE Release, namely 6, 15, 25, 50, 75 or 100 Resource Blocks (RBs) respectively [1, 6, 10, 12]

Up to five CCs can be allocated for 100 MHz of bandwidth per user, as shown in Figure 2-1:

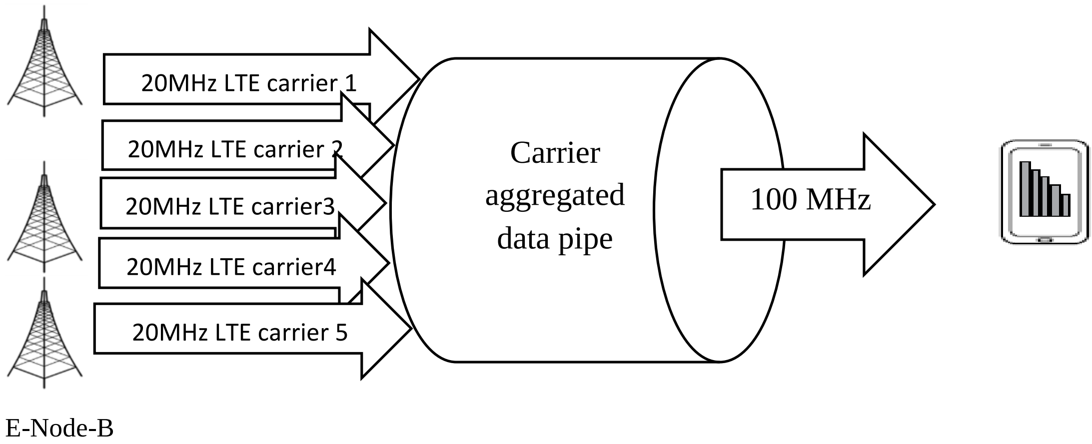


Figure 2-1: CA Combines Multiple LTE Carrier Signals [13].

There are two serving cells in CA known as the primary serving cell (PCell) and secondary serving cell (Scell). PCell and Scell each carrying at least one CC. PCell responsible for carrying the primary component carrier (PCC) and also in charge of handling radio resource control (RRC), while Scell responsible for carrying the secondary component carrier (SCC). In the configuration of CA, there is only one PCell and allowed more than one Scell [14].

2.1.2.1 FDD and TDD Aggregation

Carrier aggregation allows increased data rates and improved network performance in the uplink, downlink or both. It also supported for both frequency - division duplexing (FDD) and time - division duplexing (TDD) [2, 4],with all carriers using the same duplex scheme [4].as well as licensed and unlicensed carrier spectrum. In FDD communication links, separate frequency bands are used to transmit and receive. In TDD communication links, uplink is separated from downlink by allocating different time slots in the same frequency band [13].

In FDD the number of aggregated carriers can be different in downlink (DL) and uplink (UL) however, the number of UL component carriers is always equal or lower that the number of DL component carriers. The individual CC can also be of different bandwidths. For TDD the number of CCs as well as the bandwidths of each CC will normally be the same for DL and UL[2, 13].

2.1.2 .2 Type of Carrier Aggregation

Based on whether the component carriers are from the same band or not and whether they are adjacent to each other in frequency domain or not, carrier aggregation is classified as intra band contiguous carrier aggregation, intra band non-contiguous carrier aggregation, inter band non-contiguous carrier aggregation as shown in Figure 2-1:

- Intra-band contiguous CA

All the aggregated CCs are located within the same frequency band are contiguous one by one [11, 15].

A bandwidth wider than 20 MHz and next to other is applied for the LTE advanced. However, with the frequency allocations today, contiguous bandwidth wider than 20 MHz may not be likely possible but would be common in the near future when spectrum bands like 3.5 GHz are allocated in the various parts of the world. The spacing between centre frequencies is made to be a multiple of 300 kHz for the contiguously aggregated CCs in order to be compatible with the frequency raster of 100 kHz for release 8/9 and also preserve the subcarrier orthogonally with spacing of 15 kHz [16].

- Intra-band contiguous CA

Requires less power and lower costs than the other two types. It can be implemented without making much change to the LTE physical layer structure. Moreover, it is possible to use a single transceiver to utilize the continuous CCs for an LTE-A user [17].

- Intra-band non-contiguous CA

Are also located within the same frequency band but may not be contiguous to each other. As the CCs of the first two types are both located within the same band, the radio characteristics (e.g., the channel fading statistics) of each CC can be considered identical [11, 15].

This type of CA is more complicated as multi-carrier signal cannot be assumed as a single signal and thus two transceivers are needed. This form adds significant complexity especially in consideration of power, space and cost for the UE [16, 17].

- Inter-band CA

CCs can be located in different frequency bands, thus having different radio characteristics which should be carefully considered into the RRM framework for inter-band CA [11, 15].

The use of two carriers can greatly improve the communication throughput and the use of multiple carriers with various environments for propagations can improve stability. Mobility and robustness can also be achieved by this kind of aggregation through exploiting the various characteristics of the radio propagation of different frequency bands. This kind of CA, however, introduces complexities due to the requirements to minimize cross modulation and intermodulation from the transceivers [11, 16].

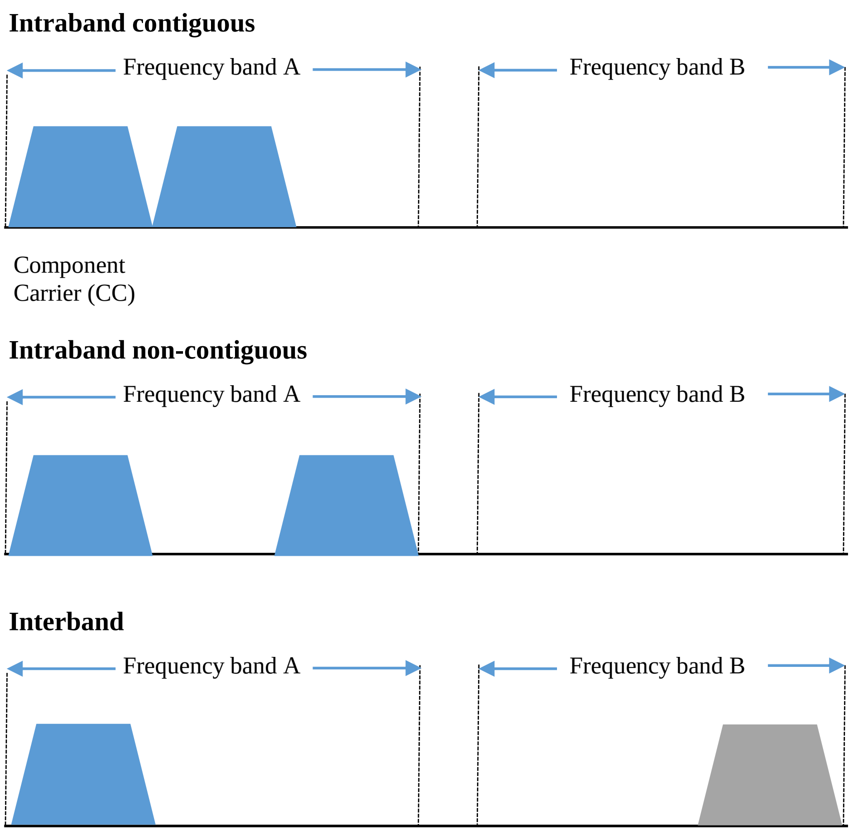


Figure 2-2: Different Type of CA Allocation in LTE-A [6].

Carrier aggregation also classified as symmetric and asymmetric carrier aggregation depending on the number of component carriers in the uplink and downlink, if the number of component carriers in both the uplink and downlink is same then it is said to symmetric carrier aggregation. If the number of component carriers in downlink is more than that of uplink or vice versa then it is said to be asymmetric carrier aggregation [15].

2.1.2.3 Deployment Scenarios

The possible CA deployment scenarios are presented in Figure 2-3. There are two frequencies, of which the frequency F1 represents the macro layer. Frequency F2 is deployed in five different ways. The first two scenarios are the most typical choices for CA deployment in a macro network. The difference is that the former scenario represents the intra-band solution and latter represents the inter-band solution, where frequency F2 is the higher frequency. The third scenario offers more homogeneous performance over the entire coverage area. The fourth scenario utilizes Remote Radio Heads (RRH), which offer the additional capacity in hotspots. Repeaters or relays are used in the fifth scenario to extend the higher frequency coverage [1, 3].

2.1.2.4 Design Principles of CA

The following subsections give a brief introduction on the CA design principles and management characteristics. The design of 3GPP LTE-A CA considers various aspects including:

1. Backward Compatibility - Backward compatibility is critical for LTE-A CA to migrate smoothly from LTE and reuse the LTE design to the most extent. Each CC in LTE-A is LTE backward compatible, i.e., accessible by the LTE UE. The complete set of LTE downlink transmissions are performed on each CC following the LTE physical procedure and specifications [3, 11, 17].

2. Minimum Protocol Modifications - From the aspect of user-plane protocols, the CCs are invisible to the Packet Data Convergence Protocol (PDCP) and radio link control (RLC) layers. The multiple CCs are only different data transmission pipes managed by a single scheduling entity at the medium access control (MAC) layer. Each CC has its own LTE-compatible hybrid automatic repeat request (HARQ) processes for the

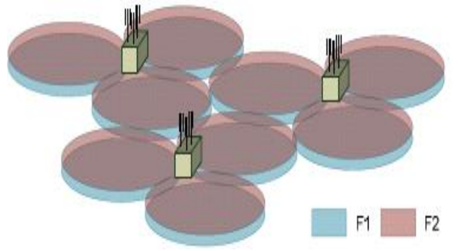
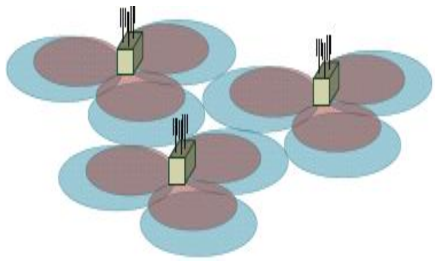
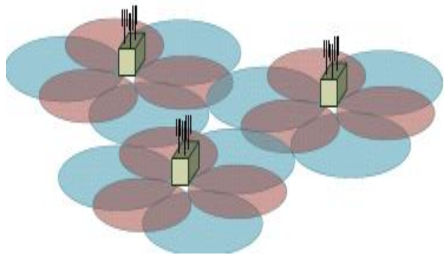
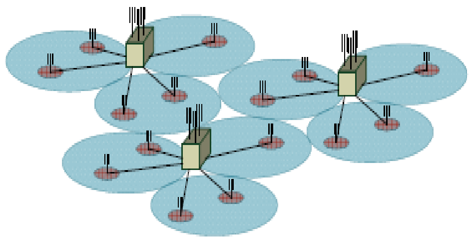
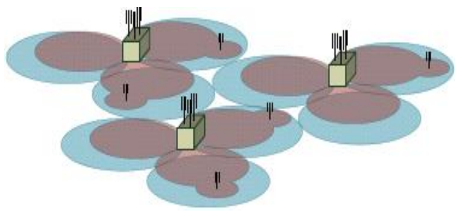
#	Description	Example
Scenario 1	F1 and F2 cells are co-located and overlaid, providing nearly the same coverage. Both layers provide sufficient coverage and mobility can be supported on both layers. Likely scenario is when F1 and F2 are of the same band.	
Scenario 2	F1 and F2 cells are co-located and overlaid, but F2 has smaller coverage due to larger path loss. Only F1 provides sufficient coverage and F2 is used to improve throughput. Mobility is performed based on F1 coverage. Likely scenario when F1 and F2 are of different bands.	
Scenario 3	F1 and F2 cells are co-located but F2 antennas are directed to the cell boundaries of F1 so that cell edge throughput is increased. F1 provides sufficient coverage but F2 potentially has holes. Mobility is based on F1 coverage. Likely scenario is when F1 and F2 are of different bands.	
Scenario 4	F1 provides macro coverage and on F2 Remote Radio Heads (RRHs) are used to improve throughput at hot spots. Mobility is performed based on F1 coverage. Likely scenarios are both when F1 and F2 are DL non-contiguous carrier on the same band. and F1 and F2 are of different bands It is expected that F2 RRHs cells can be aggregated with the underlying F1 macro cells.	
Scenario 5	Similar to scenario #2, but frequency selective repeaters are deployed so that coverage is extended for one of the carrier frequencies. It is expected that F1 and F2 cells of the same eNB can be aggregated where coverage overlaps.	

Figure 2-3: CA Deployment Scenarios [1, 2]

physical (PHY) layer transmissions. The PHY and MAC design for 3GPP LTE-A supports up to 5 CCs despite of the CA types [3].

3. Limited Control Procedure Impact - In the control-plane aspect, radio resource control (RRC) entity assigns the radio management information from the network to the UE. At a given time, instance, one UE is in either RRC IDLE or RRC connected state. One UE can transmit/receive data to/from the network only when it is RRC connected. One RRC IDLE UE shall transit to RRC connected state by establishing an RRC connection following the LTE procedure before being able to transmit on multiple CCs. Hence, LTE-A CA does not change the RRC IDLE procedures; nor does it impact the establishment procedure of an RRC connection [3, 11].

2.1.2.5 Benefits of Carrier Aggregation

- More efficient use of spectrum

Operators can combine fragmented smaller spectrum holdings into larger and more useful blocks, and can create aggregated bandwidths greater than those that would be possible from a single component carrier [11].

- Leveraging of underutilized spectrum

CA enables carriers to take advantage of underutilized and unlicensed spectrum, thereby extending the benefits of LTE Advanced to these bands.

- Increased uplink and downlink data rates:

Wider bandwidth means higher data rates.

- Network carrier load balancing

Enables intelligent and dynamic load balancing with real-time network load data.

- Better network performance

With CA, carriers provide a more reliable and stronger service with less strain on their individual networks.

- Higher capacity

CA doubles the data rate for users while reducing latency by approximately 50 percent.

- Scalability

Expanded coverage allows carriers to scale their networks rapidly.

- Dynamic switching

CA enables dynamic flow switching across component carriers (CCs).

- Better user experience

CA delivers a better user experience with higher peak data rates (particularly at cell edges), higher user data rates, and lower latency, as well as more capacity for "bursty" usage such as web browsing and streaming video.

- Enabling of new mobile services

Delivering a better user experience opens opportunities for carriers to innovate and offer new high bandwidth/high data rate mobile services [11, 13, 18].

2.1.3 The Main Function of RRM

Radio Resource Management (RRM) is a set of system level functions that control the resource allocation in LTE air interface. The objective for RRM is to maximize the spectral efficiency by restricting the interference and optimizing the resource usage. It also manages the UE mobility. RRM provides means to manage radio resources in single and multi-cell scenarios. The requirements defined for RRM in Release 8 are applicable for LTE-Advanced as well [19].

There are many similarities retained for the RRM framework of LTE Advanced from the LTE design. With carrier aggregation in LTE advanced, however, a user can possibly be scheduled simultaneously on multiple component carriers that would likely exhibit different characteristics for radio channel. Supporting operations of multiple carrier components introduces some new challenges in the RRM framework for LTE advanced network. For carrier aggregation system, the RRM structure is as illustrated in Figure 2-4 [16-18].

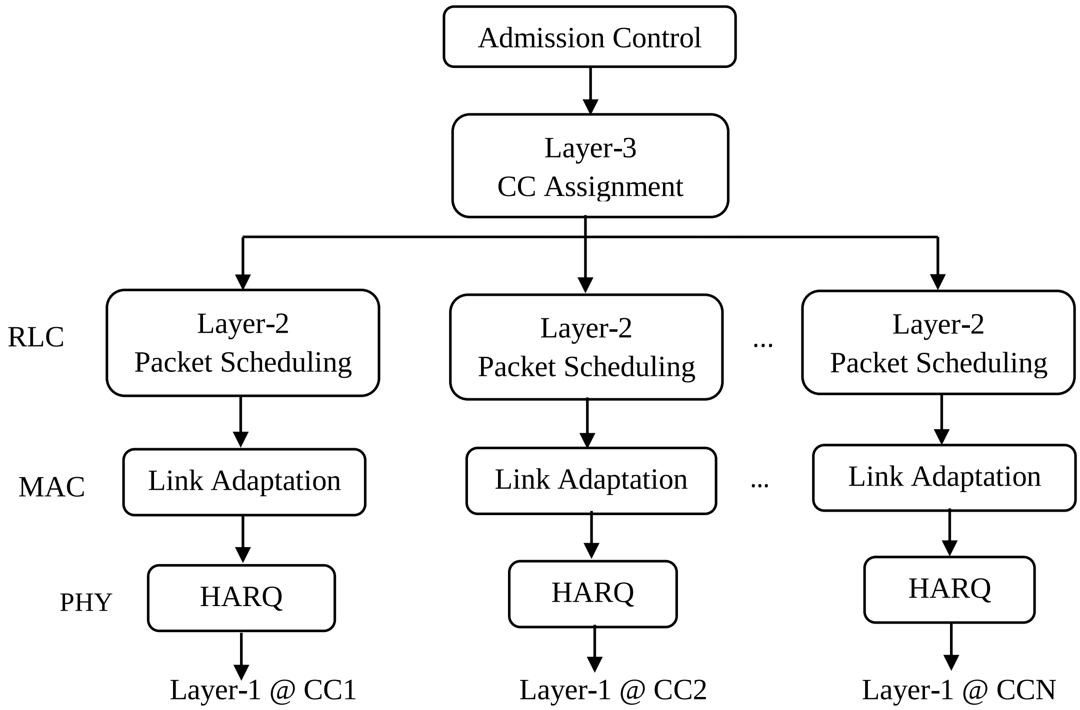


Figure 2-4: RRM Structure of LTE-A System with CA [16]

- Admission control: is performed by the eNodeB before the establishment of new radio carrier and configuration of the QoS parameters [16]. Admission decision of a user is made according to the user's channel state, Quality of Service (QoS) requirements, and the current cell load conditions [8].Moreover, each of the users will experience various channel conditions affected by geographical location and various types of noise and interference [17].The QoS parameters are the same for the LTE advanced and LTE, and are therefore CC-independent [16].

- CC Assignment: in this level, the admitted user is assigned one or more of the available CCs according to the user's terminal type and traffic requirement [8]. There are possibly different techniques in balancing the load across CCs, and this impacts the network performance [18].
- Packet Scheduling: is executed immediately after the users are allocated onto an exact CC(s) [18]. a packet scheduling process starts that allocates the available Physical Resource Blocks (PRBs) to users. The PRB is the minimum unit that can be allocated to a user at once in LTE and LTE-A systems [8] .In this perspective, the PS principally means the act of taking the task of allotting time frequency resources for every assigned user on the different CCs [18].
- Layer-1: is contained link adaptation (LA) and a hybrid automatic repeat request (HARQ) per CC to optimize transmission on dissimilar CCs conferring to qualified radio situations [18]. In the link adaptation stage, a suitable Modulation and Coding Scheme (MCS) is selected for the user to satisfy certain spectral efficiency requirements and constrained by a certain Block Error Rate (BLER) [8].

The settings of diverse transmit powers for specific CCs could provide different levels of coverage. Particularly, in inter-band CA cases, the radio channel characteristics, for example, propagation, path loss, building penetration loss, and Doppler shift, differ significantly at different frequency bands, choosing different transmission parameters comprising modulation scheme, code rate, and transmit power per CC is anticipated to be beneficial in improving user QoS further [18].

2.1.3.1 CC Selection Techniques

Layer-3 CC selection is the new RRM functionality initiated in LTE-Advanced which used the user QoS requirements, terminal capability, aggregated traffic level, and traffic load per CCs for component carrier scheduling. For optimal performance, it is advantageous to have roughly equivalent load on the different CCs and bare minimum number of CCs is allocated to UE so as to reduce signal processing complication and power over-utilization.

Different CC selection algorithms to attend to load balancing:

i. Random selection (RS)

These are CCs meant for every UE selected randomly within the obtainable CC set by eNB [18]. From the long term point of view, the number of UEs on different CCs will be the same. Thus, the load across CCs will be well balanced [20-22]

ii. Circular selection (CS)

This makes a circular selection of CCs. It offers better throughput and coverage performance compared to the RS.

iii. Least load selection (LL) or Round Robin (RR)

This does apportion user's packets to the CC with a smallest possible traffic load. It is better than RS and CS in terms of cell throughput and coverage performance [18].it tries to distribute evenly the load to all CCs. Although there might be tiny variation for the load across different CCs, it will not lead to serious load imbalance [20-22].

iv. Modified Least Load (M-LL)

Utilizes the projected future average transmission rate. While the benefits are highly dependent on the estimated accuracy of the average user rates, this approach could lead to higher complexity.

- Making a CC choice for load balancing with full consideration for diverse channel characteristics:

i. Inter-band carrier switch

UE to start with will apportion to CCs which has the high quality in some particular band. Thereafter, the load is verified in both bands for balancing of load. Therefore, if the load of an allocated band is higher compared to the other band, the users with high Channel Quality Indicator (CQI) will be moved to another band. This allows for high throughput however it could result in the boosting complexity and delay.

ii. Reference Signal Received Power (RSRP) based CC selection

This allots the better CCs to the UE whose average data rate is relatively small. It is extra ordinarily proficient for RT traffic

iii. G-factor based selection

For LTE UE, this allocates the best quality CC to cell edge UEs and the slightest load CC to other UEs. For LTE-A UEs, it could apportion all CCs. This improves the coverage performance [18].

2.1.3.2 Scheduling Algorithms

Packet Scheduling is performed after CC selection. It will decide the RBs that one UE can get within each CC.

1) Proportional Fair (PF) scheduling

Currently, PF is one of the most representative scheduling algorithms. PF can make a well trade-off between the system throughput and fairness [20]. It increases the degree of fairness amongst the user equipment's by selecting users with high relative channel quality (ratio of user’s instantaneous achievable data rate and the data rate of user i at time t). PF scheduling algorithm achieves multiuser diversity by scheduling users having peak instantaneous channel quality, to transmit during different time slots [23].

As given in, at each scheduling slot t, RBj,k should be allocated to UEi satisfying:

$$i^{*} = \text{argmax}_{i \in U_j} \frac{r_{j.k}^{(i)}(t)}{R^{(i)}(t)} \tag{2.1}$$

Where $RB_{j,k}$ represents the kth RB of CC $_j$, U_j is the set of UEs camping on CC j and $r_{j.k}^{(i)}(t)$ is the achievable instantaneous transmission rate on $RB_{j,k}$ for UE i. $R^{(i)}(t)$ denotes the average rate of UE i up to time t according to the following equation:

$$R^{(i)}(t) = \left(1 - \frac{1}{t_c}\right) R^{(i)}(t-1) + \frac{1}{t_c} \sum_{j \in C_i} DRC_j^{(i)}(t-1) \tag{2.2}$$

Where $DRC_j^{(i)}(t-1)$ denoting the actual received data rate of UE i on CC j at time (t -1) and t_c denoting the average window size, which is set to 1000 TTI in the context. Cj is the set of the CCs allocated to UEi [20].

2) RR scheduling

RR scheduling is operated more simply than PF. The basic principle of RR is to schedule the UEs on the same CC cyclically. As a result, each UE can be assigned with nearly the same number of RBs of that CC. This principle makes it easy to predict the scheduled probability of each UE, which is much helpful for the analysis of the throughput-optimized CC selection method [20].

Table 2-2 demonstrate different between Proportional Fair and Round Robin scheduling [18].

Table 2-2: Comparison Between (PF) and (RR) Scheduling [18].

Strategies	Algorithm	Advantages	Limitations
Channel independent/ unaware QoS	RR	- Simple technique. - Good fairness.	-Inefficient in terms of throughput. -It does not account channel quality variations.
Channel sensitive/ unaware QoS	PF	-Good trade-off between system throughput and data rate fairness among UE.	-Low spectral efficiency.

2.2 Related Works

The authors in [21] developed a RRM algorithm that assigns CCs to each newly-arrived UE on the basis of the average channel quality, independent of RB allocation. The improvements cover the increased average user throughput and 5th percentile worst user throughput, the reduced packet loss rate, and the better guaranteed system fairness compared with RR and Random methods.

In [24] the authors carried comparison with traditional CC selection methods i.e., random and round-robin and particle swarm optimization (PSO) iterative algorithm in terms of throughput and fairness. The results illustrated that the proposed CC selection method outperforms the other proposed ones.

The authors in [25] proposed a radio resource allocation scheme, and referred to it as Greedy Algorithm (GA). The GA considered MCS assignment jointly with CC selection and RB allocation. The authors assumed that all CCs have the same number of RBs, and all UEs have the same CA capability, however both assumptions are unrealistic. Moreover, GA is an iterative process that calculates the utility function for all possible combinations of UEs, CCs and MCSs at each iteration. An assignment with the highest value of the utility function is selected at each iteration until the algorithm converges.

In [26] the authors proposed Improve Carrier Selection (ICS) algorithm, which it takes total load and channel quality into consideration when allocation a CC to each newly arrived LTE user. Simulation results have demonstrated that the Guaranteed Bit Rate (GBR) PLR kept below 10-3 threshold, the ICS has 72.2% and 10.7% system capacity improvement over the Least-Load and Max CQI algorithms, respectively. Additionally, it was observed in the results that the ICS algorithm support 11.4% and 18.2% more users compared to the Max CQI and Least-Load algorithms when minimum user throughput of 469 kbps of GBR application is required to be satisfied.

The new CC selection scheme proposed which minimizes the inter-CC handovers while meeting user QoS requirements. Two cost functions are introduced to first select the primary cell, then the secondary cell. Simulation results showed that not only the successful handover rate has increased by almost 10% but also more load balanced cells are obtained [27].

Selective periodic component carrier assignment technique is proposed by considering behaviour of system during the component carrier assignment operations. The performances of current joint and proposed selective component carrier assignment techniques are compared by using analytic analysis based on queuing algorithm and an extensive simulation. Results showed that the proposed technique efficiently uses system resources and improves throughput rate up to 25% and average delay time up to 35% in LTE and LTE-A systems [28].

The Traffic and Channel Driven (TCD) CC selection algorithm proposed which takes the channel quality and traffic load in each CC into consideration. It was shown via simulation that the proposed algorithm can significantly improve the downlink LTE-Advanced performance as compared to the conventional CC selection algorithms [29].

The novel dual priority CC selection (DPCS) algorithm used to complement the shortage of conventional ones (Least Load (LL) and reference signal received power (RSRP)), taking CA capability, channel conditions and carrier load into consideration. Simulation results show that DPCS algorithm can achieve significantly improvements, covering the average sector throughput, the average LTE/LTE-A UE throughput and the system fairness [30].

The authors in [17] proposed a greedy-based method which can increase the system throughput and maximize the QoS of the user while ensuring better spectral efficiency and low computational complexity. The queue length of each CC is taken into account to balance the load among all CCs. A set of system-level simulations have been performed to support the proposed method. The obtained results demonstrated that the proposed method significantly improves the user throughput up to 39.40% compared to the well-known method of previous studies.

CHAPTER THREE

COMPONENT CARRIER SELECTORS

CHAPTER THREE

COMPONENT CARRIER SELECTORS

3.1 Introduction

Radio Resource Management (RRM) function of network becomes more complicated in LTE-A. The CC selector is part of the RRM. It assigns UEs to the CC. In this research, there are two different selectors implemented [31].

3.1.1 Cyclic Component Carrier Selector

This selector assigns the UEs cyclically to the active CC. Therefore, the first UE of the eNodeB will get assigned to the first active CC, the second UE of the eNodeB to the second active CC, and this continues in a cyclic fashion. This assignment is done for users served by one eNodeB [31].

Figure 3-1 illustrates flow chart for Cyclic Component Carrier selector algorithm and Appendix A as source code. The steps of Cyclic CC selector algorithm go as follow:

- Determine the number of users, number of CC and define counter for CC that assigned to the UE.
- For each user if the current CC active for UE and active for the eNodeB as well as the user is not assigned, increase the counter of CC.
- Else if the current CC active for the user and the current CC is not active for the eNodeB that means the CC active for the user but not active for eNodeB.
- Else if the current CC active for the user and the user assigned that means multiple CC activated.
- Then for each CC if the CC is not active for the eNodeB, set the counter of CC equal to not a number.

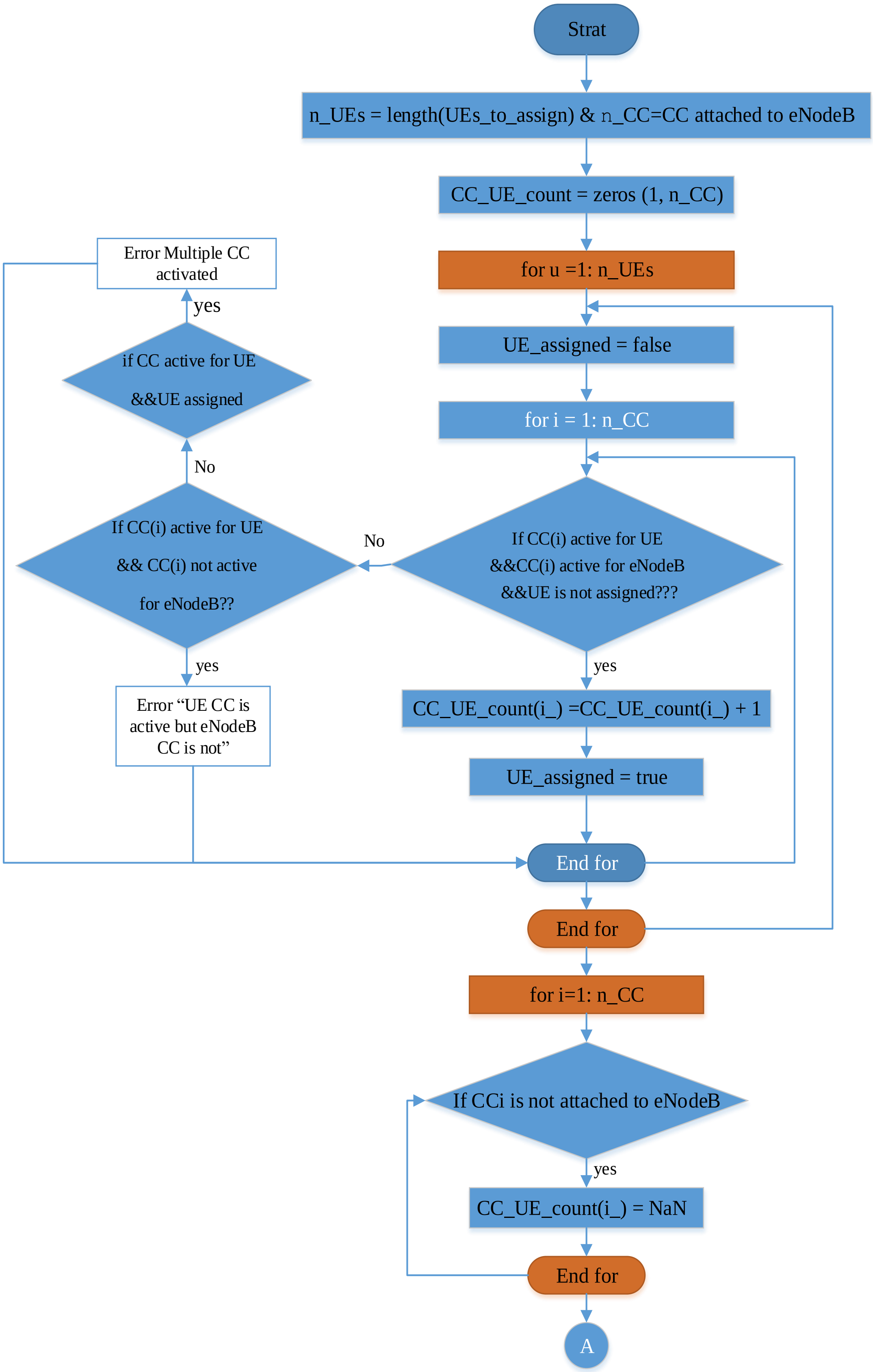
- If UE not assigned, active the CC of the minimum index to the UE as a primary CC.
- After that step of scheduling [31, 32].

3.1.2 All Component Carrier Selector

This selector assigns every UE with CA support to all active CC of the eNodeB and only to its primary CC if does not support CA [31].

Figure 3-2 illustrates flow chart for All Component Carrier selector algorithm, and Appendix A as source code. The main steps of All CC selector algorithm go as follow:

- Set the number of users and the number of component carrier attached to eNodeB.
- For each user if the user supported for CA and the first component carrier active for eNodeB as well as the first CC active for the UE that means the UE is already assigned to first CC but if the first CC is not active for the UE then activates the first CC to the UE, make scheduling and go to the next CC until finishing all available CC and after that go to the next user.
- Also if the CC is not active for the eNodeB and the CC active for the UE, do nothing. But if the CC is not active for the UE give error message "CC is not active for eNodeB".
- Else if the user is not supported for CA, only one CC assigned to the UE as primary CC [31, 32].


Strat
n_UEs = length(UEs_to_assign) & n_CC=CC attached to eNodeB
CC_UE_count = zeros (1, n_CC)
for u =1: n_UEs
UE_assigned = false
for i = 1: n_CC
If CC(i) active for UE
&&CC(i) active for eNodeB
&&UE is not assigned???
No
yes
CC_UE_count(i_) =CC_UE_count(i_) + 1
UE_assigned = true
End for
End for
for i=1: n_CC
If CCi is not attached to eNodeB
yes
CC_UE_count(i_) = NaN
End for
A
Error Multiple CC activated
yes
if CC active for UE
&&UE assigned
No
If CC(i) active for UE
&& CC(i) not active
for eNodeB??
yes
Error "UE CC is active but eNodeB CC is not"

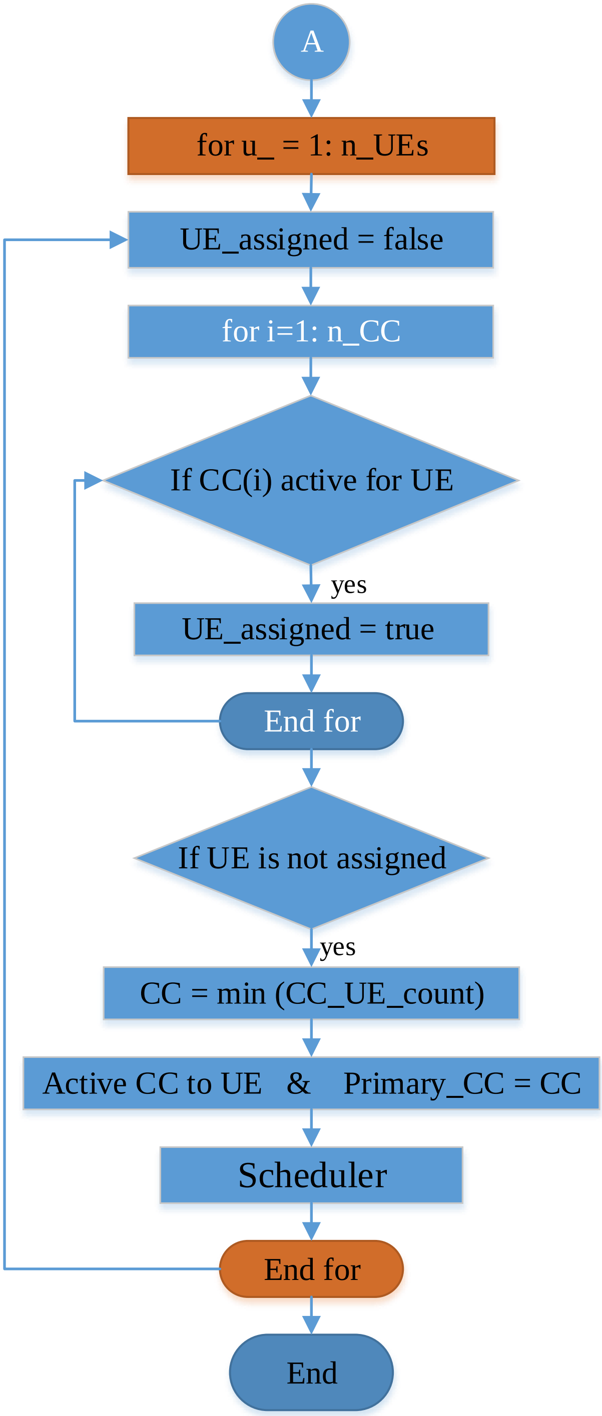


Figure 3-1: Flow Chart of Cyclic CC Selector [31, 32]

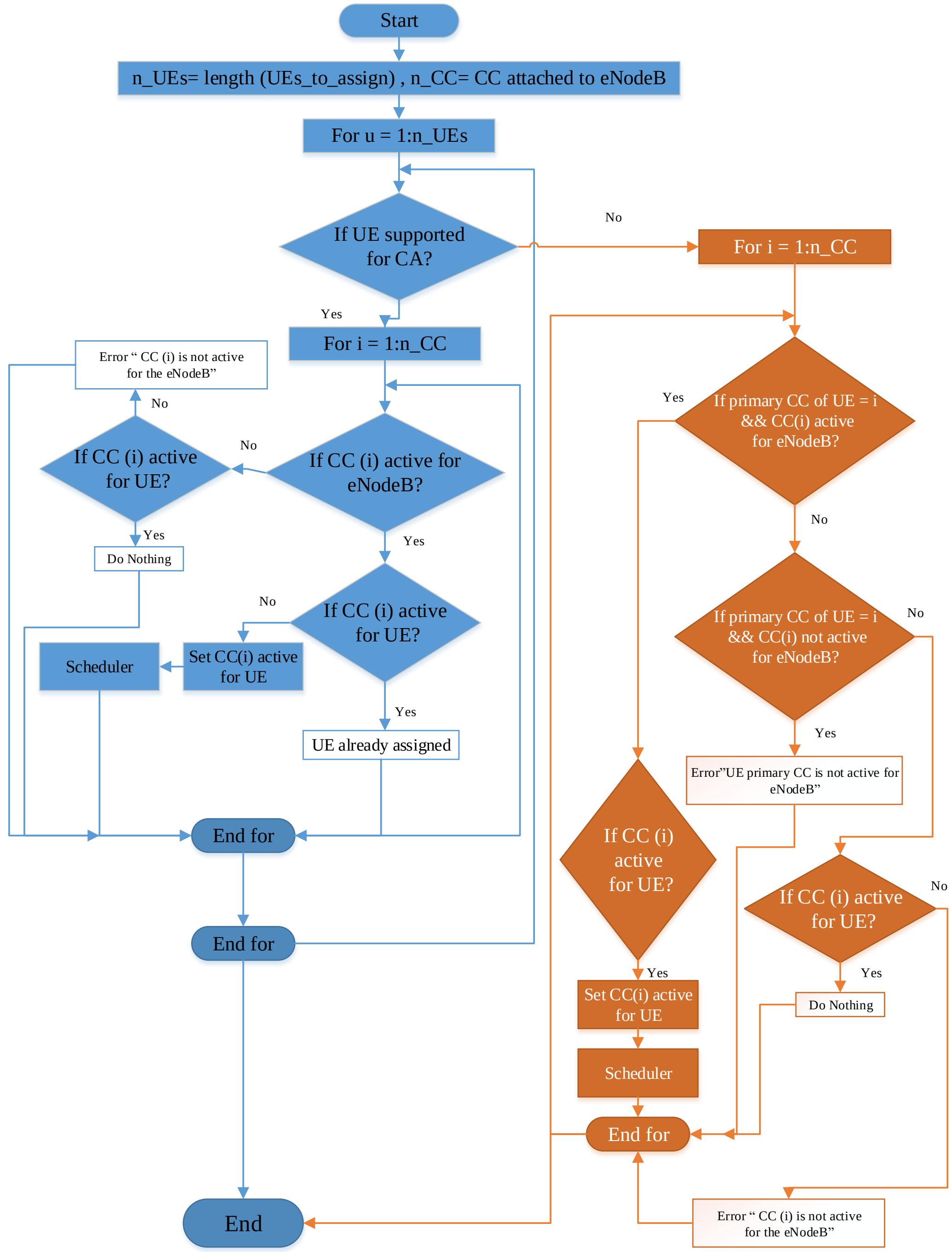


Figure 3-2: Flow Chart of All CC Selector [31, 32]

3.2 Performance Metrics

3.2.1 UE Throughput

Defined as the total number of over-the-air information bits that were successfully delivered within the transmission time for a user. This statistic is determined for all the users in the system [33].

Let w_c^u be the allocated bandwidth to the user u on the CC c. The resulting instantaneous throughput $r_c^u(t)$ of each user *u* on the CC c is thus given by:

$$r_c^u(t) = w_c^u \log_2(1 + \gamma_c^u(t)) \qquad (3.1)$$

Where $\gamma_c^u(t)$ is the received Signal-to-Interference-plus-Noise Ratio (SINR) of each user *u* served on a CC *c* at a given TTI (Transmission Time Interval) t [27].

3.2.2 Cell Throughput

Defined as the total number of over-the-air (i.e. over-the-physical-layer) information bits that were successfully delivered to or from the cell within the simulation time. This number is averaged over all the cells in the system [33].

3.2.3 Spectral Efficiency

The spectral efficiency is measured in bit/s/Hz/cell. In other words, it is the cell throughput divided by the bandwidth. The peak spectral efficiency is the highest theoretical data rate (divided by bandwidth) when all radio resources are assigned to single user [1]. The means of attaining maximum spectral efficiency is to allocate resources to the suitable user which has data to transmit within the system [18].

It is important to keep in mind that there is a hard limit to how much data can be transmitted in a given bandwidth in accord with Shannon-Hartley theorem (Shannon's Law) [34]:

$$C \approx n * B * \log_2(1 + S/N) \qquad (3.2)$$

Where C denotes to channel capacity (bits/s), n is number of transmit antennae, B bandwidth (Hz) and S/N: signal-to-noise ratio.

The average spectral efficiency that can be achieved at each transmission layer is written as [35]:

$$\bar{B}(\varepsilon) = \frac{1}{N_D N_L} \sum_{(n.k)} \sum_{l} f\ (SINR_{n.k}^{(l)}(\varepsilon. H_k^{(eff)})) \tag{3.3}$$

Where ND is the number of available data resource elements, ε is Carrier Frequency Offset (CFO), (n, k) denotes a resource element which is devoted to data transmission, N_D is number of transmission layers, $H_k^{(eff)}$ is channel matrix at subcarrier k and l is transmission layer index.

3.2.4 Signal-to-Interference-Plus-Noise-Ratio (SINR)

The wideband SINR is the ratio of the average power received from the serving cell and the average interference power received from other cells plus noise [36].signal-to-interference-and-noise ratio as far as wireless cellular LTE network is concerned as long as inter cell interference comes into play is a very good indicator for signal quality and is one of the most important factor affecting the spectral efficiency. It is a common practice to use SINR as an indicator for network quality [34].

The Exponential Effective SINR Mapping (EESM) model is used to combine the SINR on each subcarrier to obtain the PRBs' effective SINR, which is:

$$SINR_{eff=} - \ln\left(\frac{1}{N_{SC}} \sum_{i=1}^{N_{SC}} e^{-SINR_i}\right) \tag{3.4}$$

Where $SINR_i$ is the SINR of subcarrier i and N_{SC} is the number of subcarriers on each resource block [8].

3.2.5 Fairness Index (FI)

Fairness index expressed by the Jain's Fairness Index (FI), which is formulated as follows:

$$\text{Fairness Index (FI)} = \frac{(\sum_{k=1}^{K} R_{\text{k}})^2}{\text{U} \sum_{k=1}^{K} R_k^2} \tag{3.5}$$

Where U is the number of UEs in the system, R_k denotes the individual UE mean throughput. This index measures the degree of fairness in the allocated rates or throughput performance between users and it has value that falls between zero and one with more fairness achieved as we are close to one and FI=1indicates that all UEs have equal throughput in average [8].

3.3 Simulation

For CA simulation, LTE-A downlink system level simulator Rel-v1-9-Q2-2016 based on 3GPP TS 36.942 (Macrospcopic path loss models) via MATLAB R2016a is set as follows. Seven sites, each has three cells are considered, Urban area with the random user deployment in the cell is considered where users are equally distributed and scattered all over the coverage area. The number of user varies from 5 to 35 in each cell with combination of active and inactive user. In this simulation, active users are transmitting and receiving data whereas the inactive users are connected to eNB but not requesting any data. The average speed of the user is 5 kmph. Three CCs with 20 MHz bandwidth in 800MHz, 2400MHz band and 2600MHz band respectively are aggregated. In order to analyse the performances of CA deployment RRH scenario with inter-eNodeB distance 500 m, using two method of component carrier selectors there are All and Cyclic [37, 38]. Also another simulation parameter shown in table 3-1.

As it shown in Figure 3-3, the numbers from 1 to 21 indicate to cells, blue dots are users, red circles represent the 7 sites eNodeBs and grey circles are Remote Radio Heads which are connected via optical fibers to the eNodeB, thus allowing the aggregation of CCs between the macrocell and RRH cell based on the same CA framework for collocated cells. Such deployment allows the operator to efficiently improve system throughput by using low cost RRH equipment.

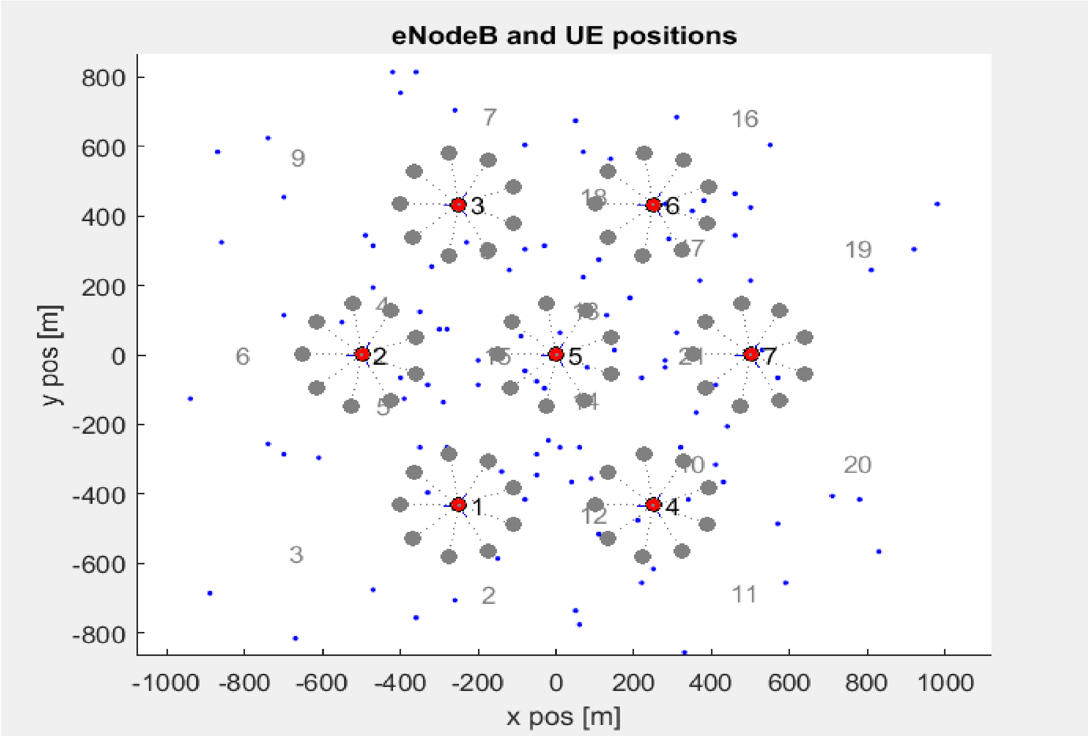


Figure 3-3: eNodeB and UE Positions

Table 3-1: Other Simulation Parameters.

Parameters	**Value**
CA deployment scenario	Scenario 4 (RRH)
Carrier frequency	800MHz, 2400MHz,2600MHz
CC Bandwidth	20MHz
Network configuration	7 sites, 3 sectors/site
Scenario	Urban (constant UEs per cell) 5,10,15,20,25,30,35 users per cell
User speed	5 Km/hours
Scheduling algorithm	Proportional Fair (PF)
Simulation Time	10 TTI
eNodeB_distances	500 m
Transmit power	40 dBm
Number of Tx/Rx antenna	1/2
Transmission mode	Close Loop Spatial Multiplexing (1x2CLSM)

CHAPTER FOUR

RESULTS AND DISCUSSION

CHPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview

To give a comprehensive performance comparison, we compare the simulation results of all and cyclic component carrier selectors in different performance metrics for two cases.

4.2 Fixed Number of Users Scenario

In this scenario constant number of users is used (5 UE/cell) to illustrate Empirical Cumulative Distribution Function (ECDF) for throughput, spectral efficiency and Signal to Interference plus Noise Ratio (SINR) for All and Cyclic component carrier selectors as it shown in Figure 4-1, Figure 4-2 and Figure 4-3. In addition to the relation between SINR and Average UE throughput which depicts in Figure 4-4 also the relation between SINR and Spectral efficiency for each user as it shown in Figure 4-5.

Figure 4-1 shows the ECDF of the average user throughput for all and cyclic component carrier selectors. As it observed in Cyclic CC selector (100% or all) of UEs experience low throughput (less or equal to 20 Mbit/s) but in All CC selector 55% of the UEs experience low throughput (less or equal to 20 Mbit/s) and the throughput enhanced for 42% of the UE as well as 3% of the UE achieve better throughput (≈77 to 177) Mbit/s. That means All CC selector outperform higher throughput with 89% compared with cyclic.

Figure 4-2 shows the ECDF of the average user spectral efficiency for all and cyclic component carrier selectors. As it observed both selectors outperform approximately same performance and as it depicted

70% of the users achieve spectral efficiency less than 3.8 bit/cu and the rest of the users (30%) achieve better spectral from ≈ (3.8 to 7.4) bit/cu.

Figure 4-3 shows the ECDF of UE wideband SINR for all and cyclic component carrier selectors. As it observed in Cyclic CC selector 38% of the user achieve SINR less than zero but in All CC selector 57% of the user achieve SINR less than zero. Also for approximately 1% of UEs both selectors achieve same maximum SINR from 9 dB to 12 dB. Cyclic method outperforms slightly better SINR by 9% compared with All.

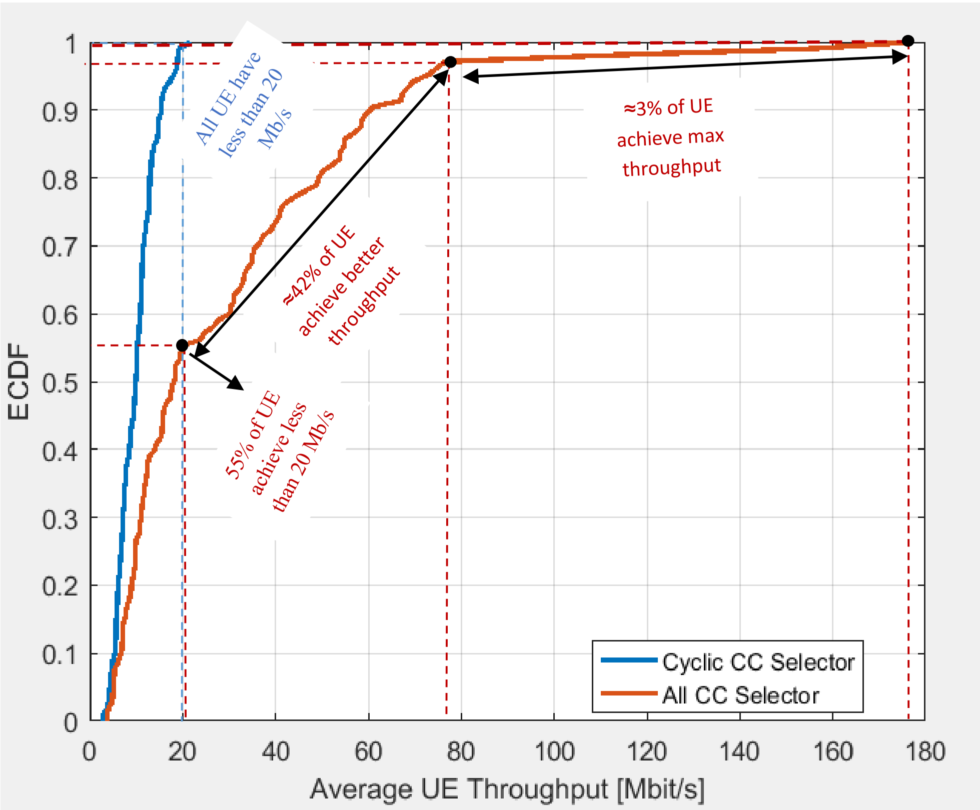


Figure 4-1: ECDF of UE Throughput

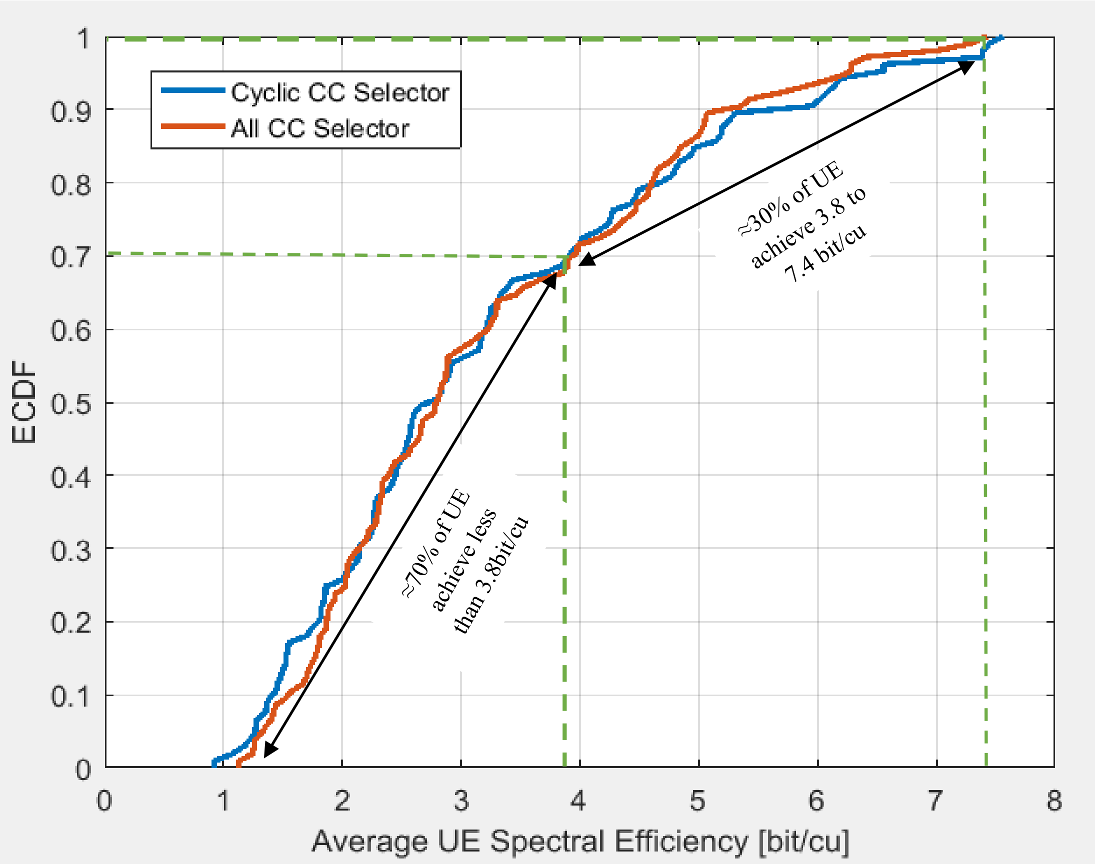


Figure 4-2: ECDF of Spectral Efficiency

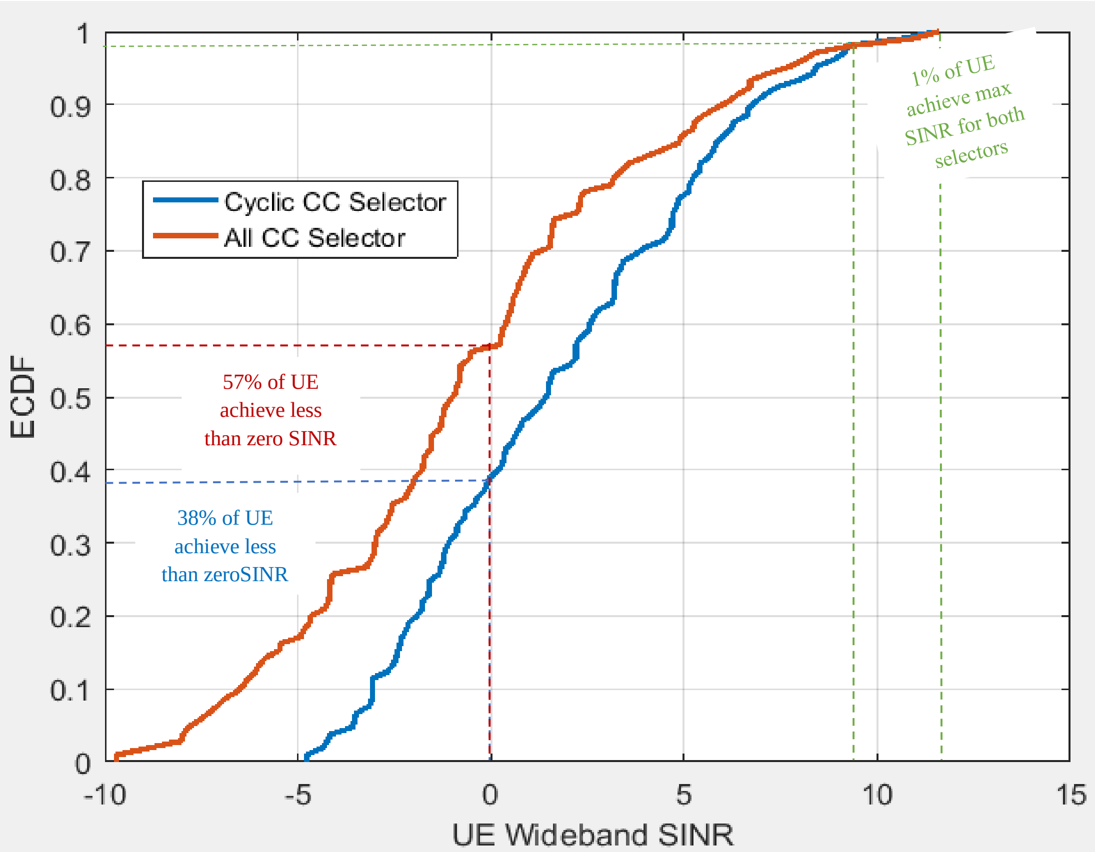


Figure 4-3: ECDF of Wideband SINR

Figurer 4-4 shown scatterplot, which depicts SINR versus average UE throughput for each user in both selectors (All & Cyclic). As it observed the All CC selector achieve better performance than Cyclic and UE throughput increase as the SINR increase in most UE but maximum throughput (approximately 180 Mbit/s) achieve for UE has SINR (approximately 4 dB). As well as Cyclic CC selector has worse UE throughput (the max less than 20 Mbit/s) versus various SINR.

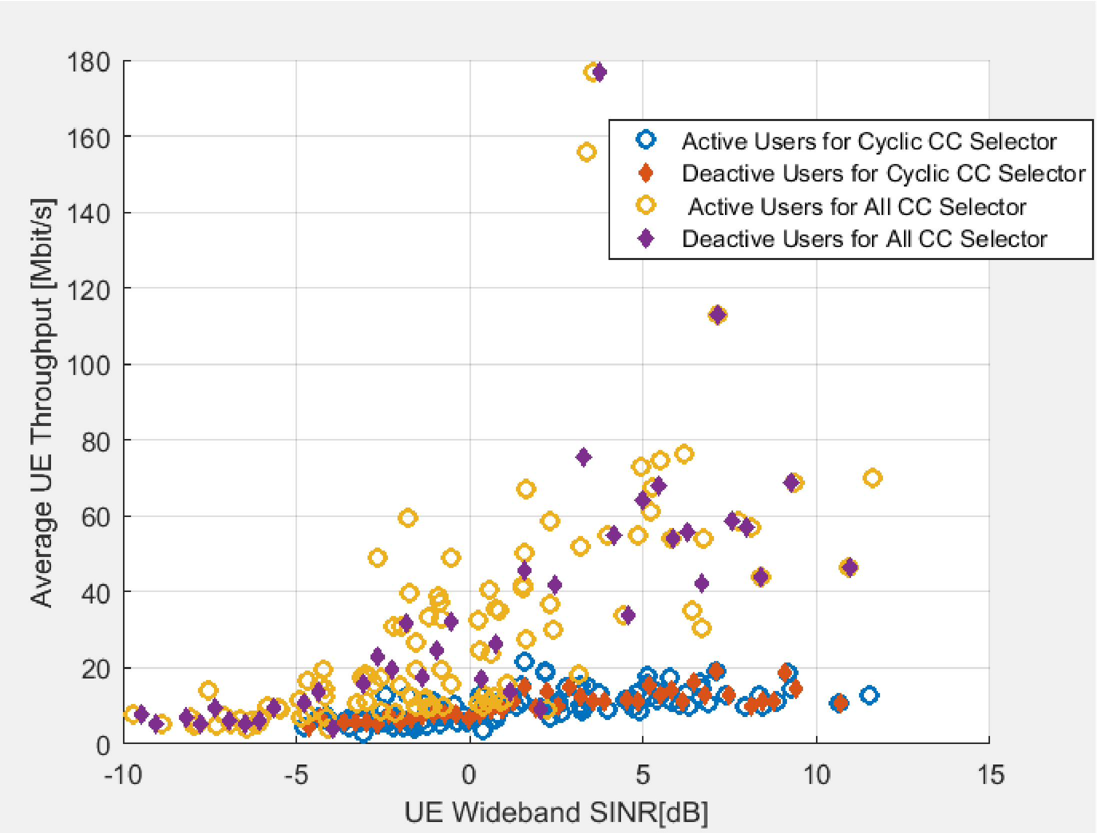


Figure 4-4: UE Throughput Vs UE Wideband SINR

Figurer 4-5 shown scatterplot, which depicts the SINR versus spectral efficiency for each user in both selectors (All & Cyclic) and as it observes the spectral efficiency increase as the SINR increase (which refer to the Shannon channel capacity according to equations (3.2) and (3.3)) in both selectors. and the Cyclic CC selector achieve slightly better SINR versus the spectral compared with All CC selector.

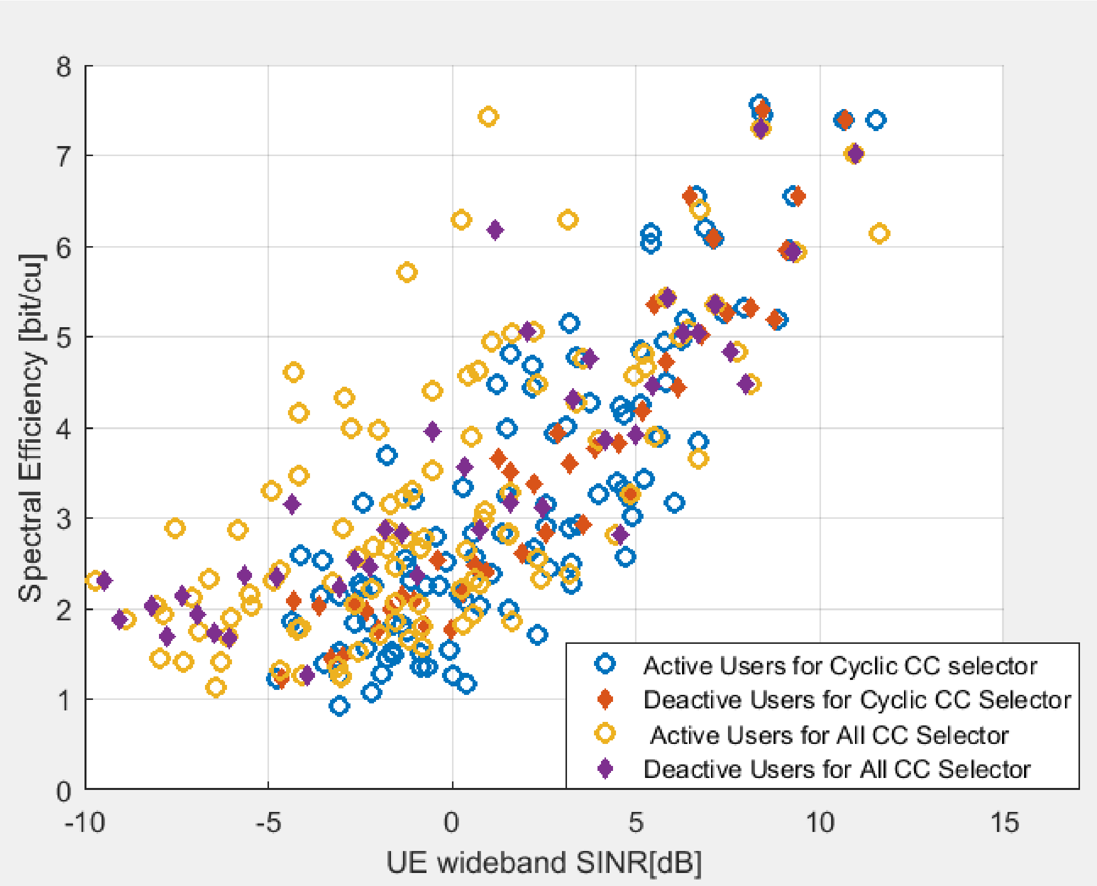


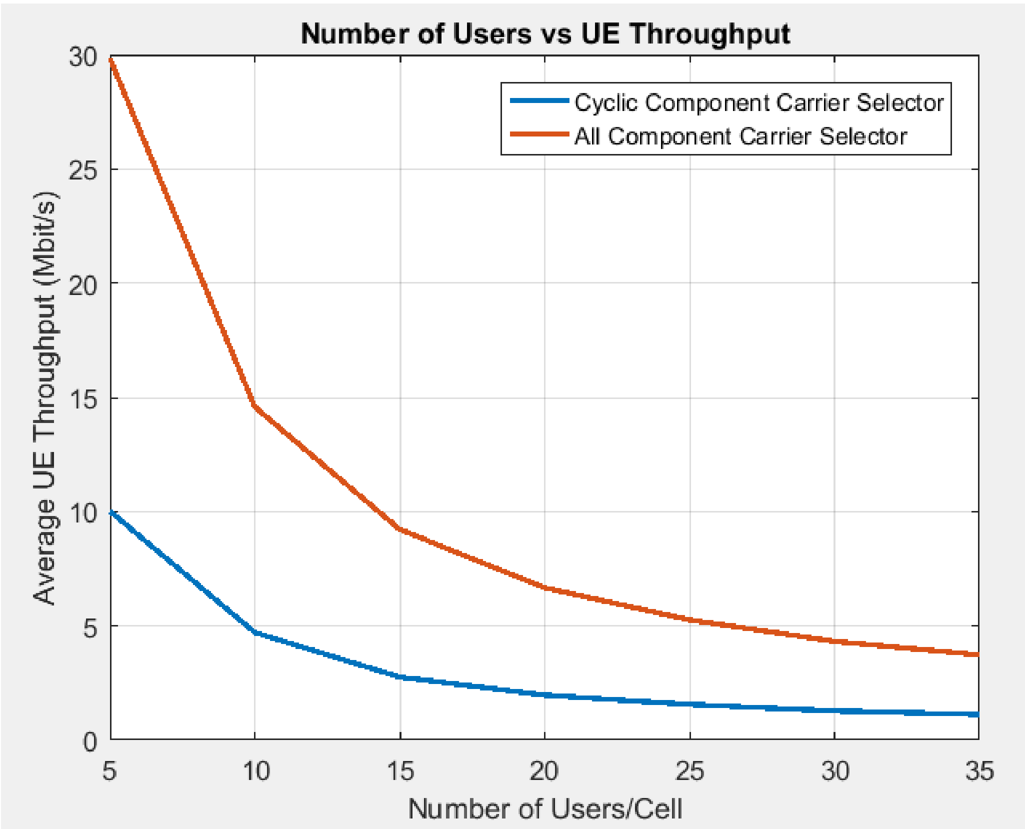
Figure 4-5: Spectral Efficiency Vs UE Wideband SINR

4.3 Different Number of Users Scenario

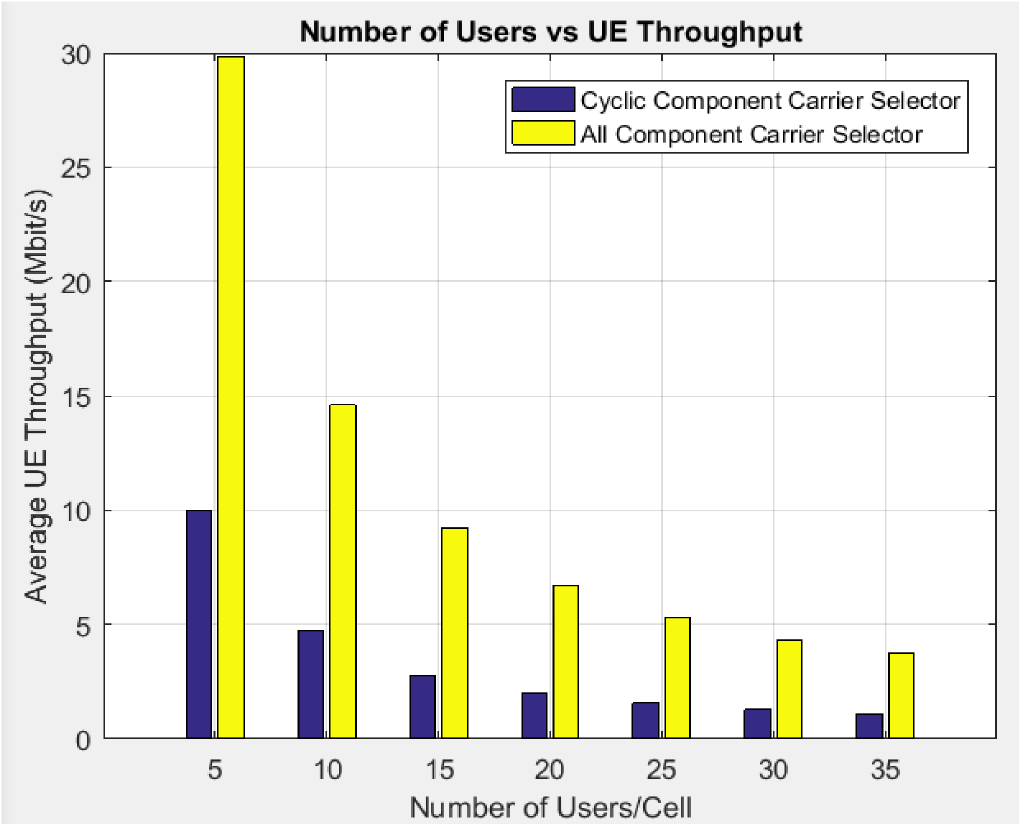
In this scenario different constant number of users per cell are used (5, 10, 15, 20, 25, 30, 35) UEs/cell to illustrate the different metrics.

4.3.1 Number of Users and Average UE Throughput

Figure 4-6 (a & b) illustrates that, average UE throughput is decreasing with the increase in number of user for both All and Cyclic methods. As the competition for the limited resources gets more and more intense by available fixed bandwidth and having a high user density, which leads to reduce the maximum achievable single UE throughput. From the figure, it can be easily seen that All component carrier selector outperforms higher UE throughput by 214.35% compared with Cyclic as it calculated from tables in Appendix B. The different between two selectors become less with increase in number of users. Figure 4-6 (b) just represent comparison of UE throughput between two methods at each number of UEs/cell.



(a)

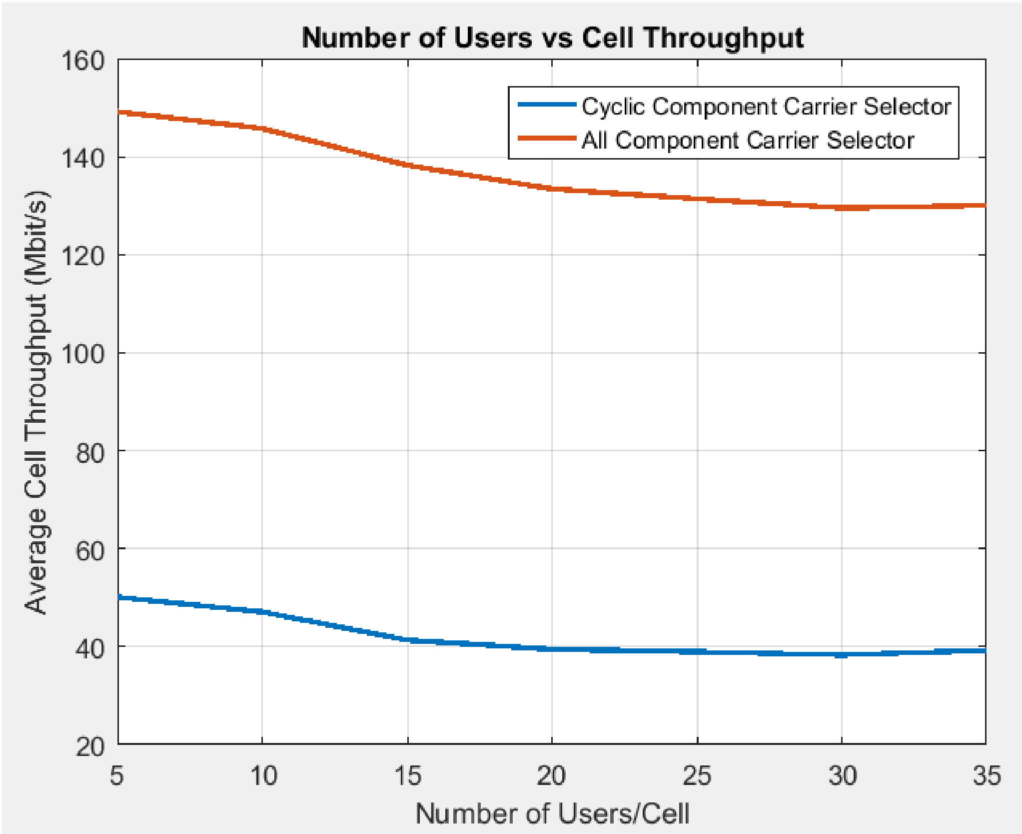


(b)

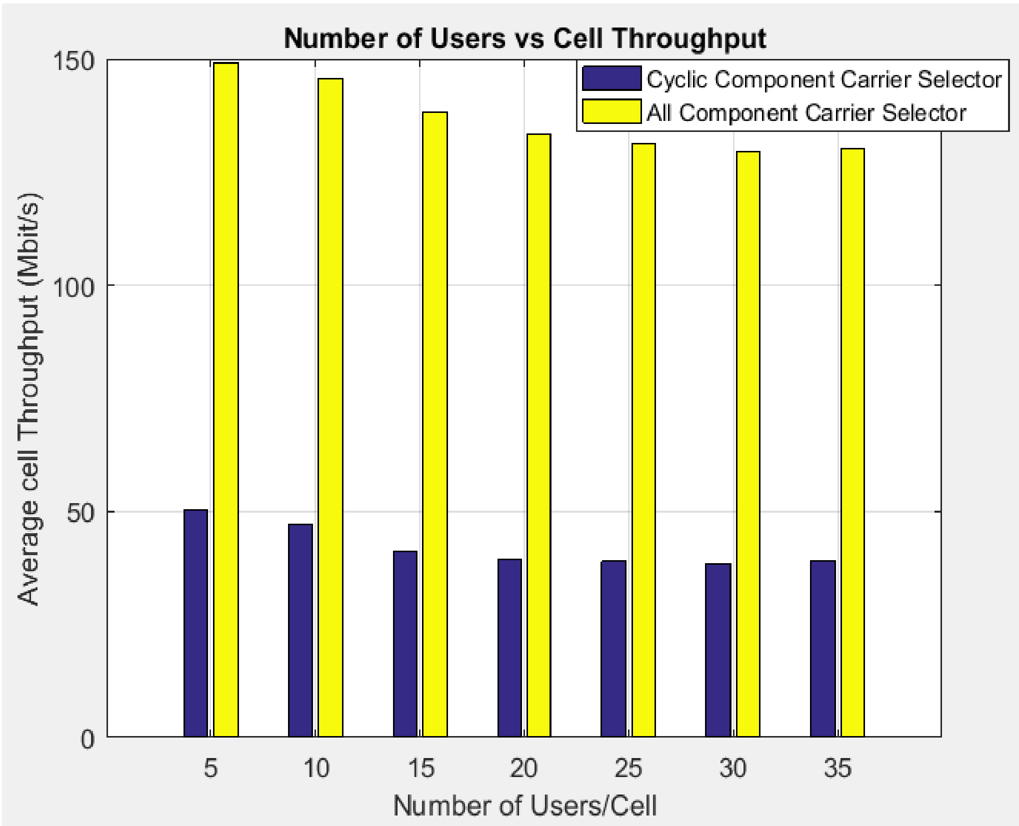
Figure 4-6: a & b UE Throughput Vs Number of Users

4.3.2 Number of Users and Average Cell Throughput

Figure 4-7 (a & b) compares the cell throughput of all and cyclic methods in different number of users per cell. The graphs show that average cell throughput slightly decrease with increase in number of users. But all component carrier selector outperforms higher average cell throughput by 225.16% compared with cyclic component carrier selector as it calculated from tables in Appendix B. Figure 4-7 (b) just represent comparison of cell throughput between two methods at each number of UEs/cell.



(a)

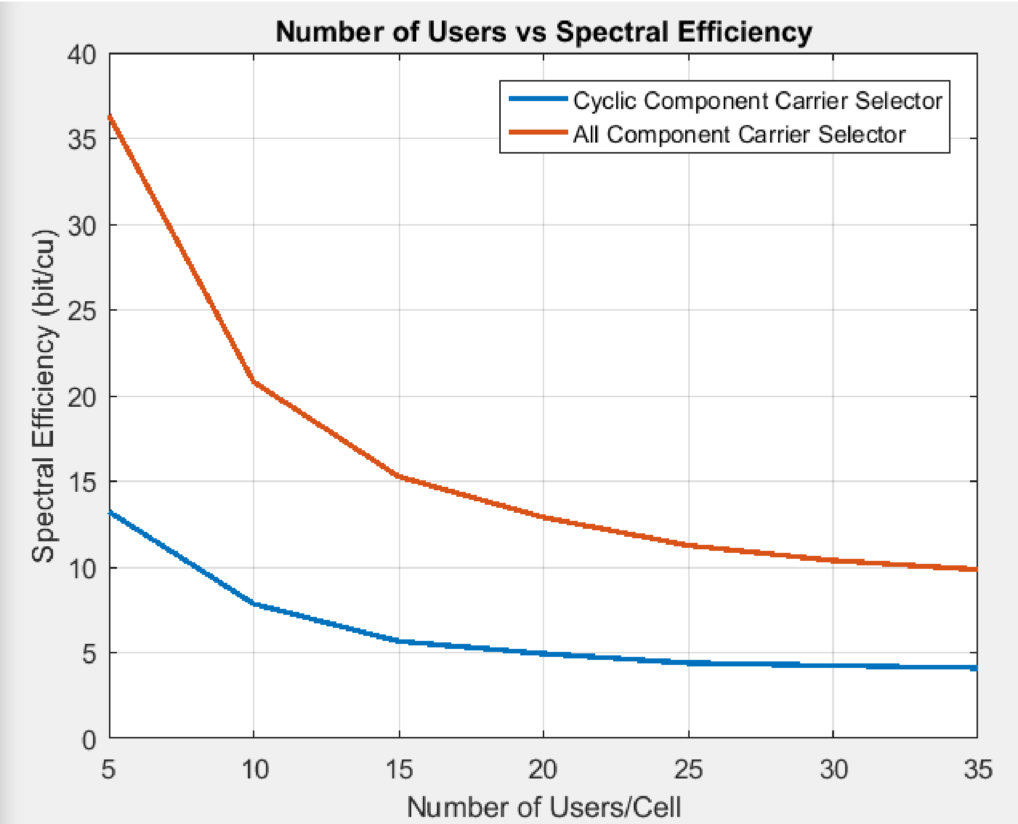


(b)

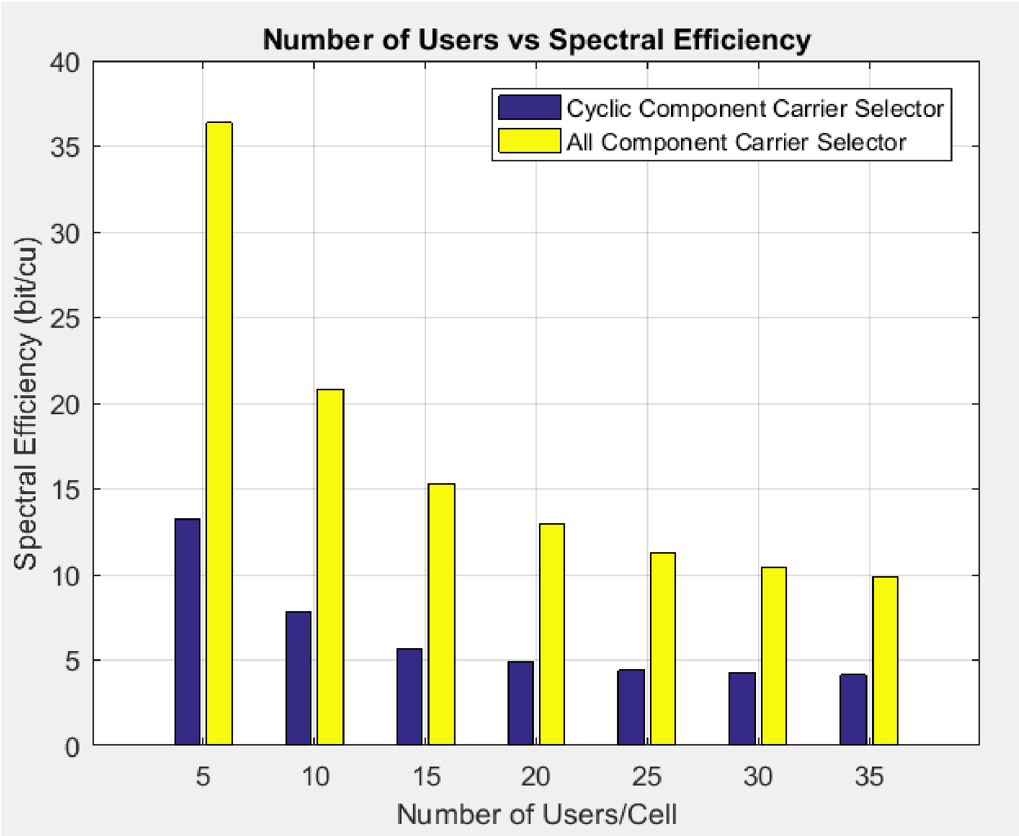
Figure 4-7: a & b Cell Throughput Vs Number of Users

4.3.3 Number of Users and Spectral Efficiency

Figure 4-8 (a & b) compares the spectral efficiency of all and cyclic methods. As it is clearly shown, all component carrier selector outperforms better spectral efficiency than cyclic by 163% as it calculated from tables in Appendix B. Also spectral efficiency decrease with increase in number of users also different between spectral efficiency of two methods become less while increasing in number of users. Figure 4-8 (b) just represent comparison of spectral efficiency between two methods at each number of UEs/cell.



(a)

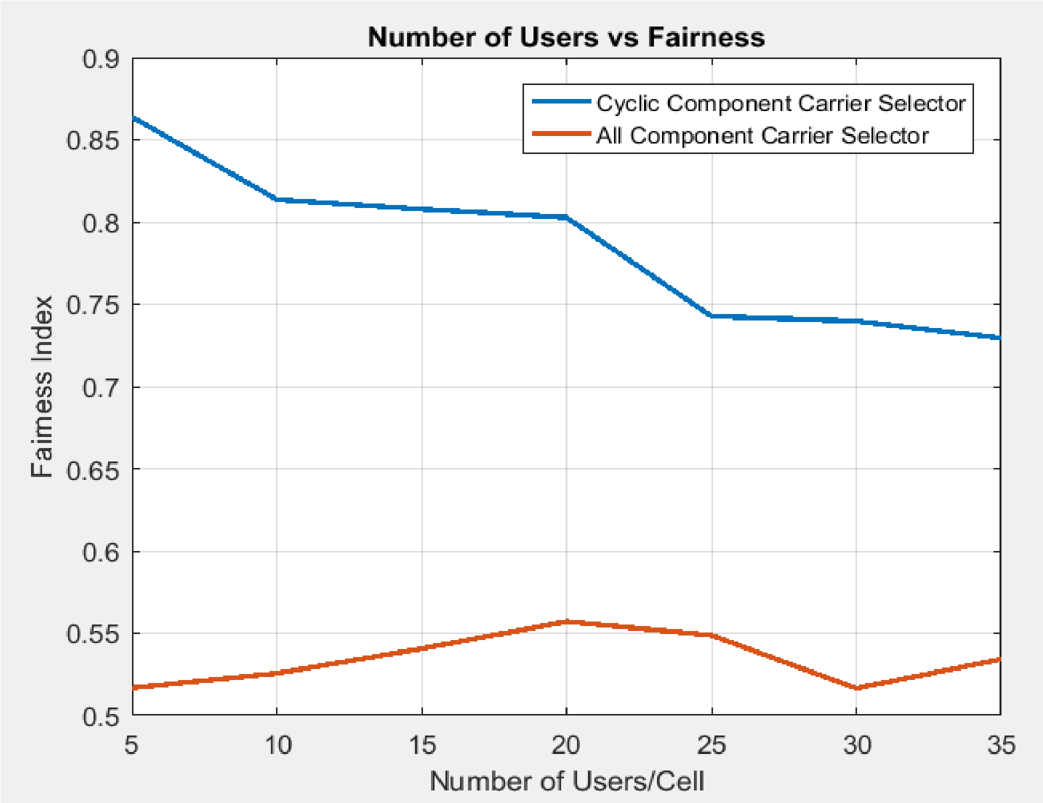


(b)

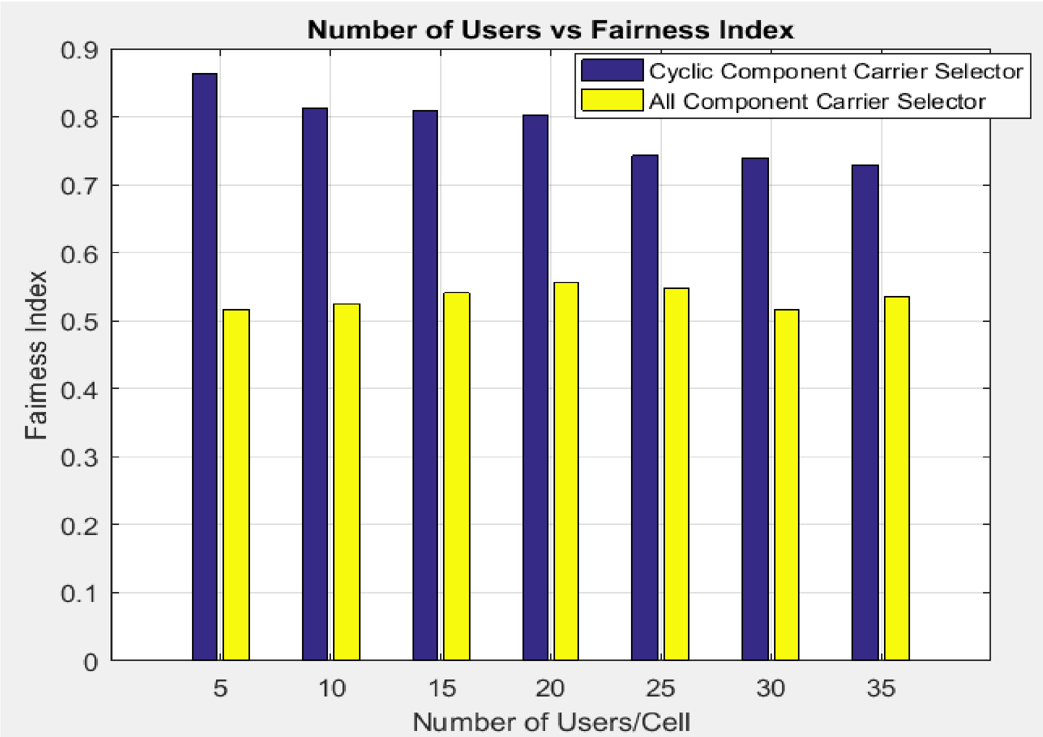
Figure 4-8: a & b Spectral Efficiency Vs Number of Users

4.3.4 Number of Users and Fairness Index

Figure 4-9 (a & b) depicts the fairness index for different number of users per cell, and it can be seen the cyclic method outperforms highly fairness index which means the system has the better fairness performance by 47% compared with the All component carrier selector method as it calculated from tables in Appendix B. Moreover, when UE number increases, the fairness of cyclic method becomes noticeably worse because of the more and more serious load imbalance across the CCs. But in All component carrier selector method although of increase number of UE the alteration in fairness is small. Figure 4-9 (b) just represent comparison of fairness index between two methods at each number of UEs/cell.



(a)



(b)

Figure 4-9: a & b Fairness Index Vs Number of Users

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This thesis introduced a brief overview of LTE-A, and concentrate on concept, type, scenarios and benefit of carrier aggregation in addition to RRM and different method to assign CC.

This work mainly aimed to evaluate the performance of two component carrier selector methods (All & Cyclic) using LTE-A downlink system level simulator and Remote Radio Heads scenario, also three component carrier are used with same bandwidth (20 MHz) for each CC (inter-band and intra-band) discontinuous CA.

Simulation results show that All component carrier selector outperforms the Cyclic CC selector in the measurement of average user throughput with 214.35%, and higher spectral efficiency by 163%. In addition to its higher average cell throughput by 225.16% compared with cyclic. But Cyclic outperform higher fairness index by 47% compared with All selector, the reduction in the fairness index implies that, the scheduler has an increased task in resource allocations due to the added component carrier.

All CC selector outperforms better UE throughput, cell throughput and spectral efficiency that is because All selector assigns every UE with CA support to all active CC of the eNodeB, while Cyclic CC selector outperforms better fairness because it assigns the UEs cyclically to the active CC according so it's fairly to assigns CC to the user.

5.2 Recommendations

In the future works, simulation can be done:

- for more frequency bands to validate the results as well as examining the performance of other parameters which were not considered in this study such as number of ignored cell and mean of resource block occupancy.
- Also for more than three component carrier and show the result.
- In addition to using different methods and algorithm to select and assign component carrier that can be trade-off between throughput and fairness.

REFERENCES

[1] A. Reinikainen, "Performance Evaluation of LTE-Advanced Carrier Aggregation," master, School of Electrical Engineering, aalto, 2015.

[2] I.-E. Puşcaş, "Carrier Aggregation in LTE-Advanced," TRANSACTIONS on ELECTRONICS and COMMUNICATIONS, vol. 59(73), p. 4, 2014.

[3] Z. Shen, A. Papasakellariou, J. Montojo, D. Gerstenberger, and F. Xu, "Overview of 3GPP LTE-advanced carrier aggregation for 4G wireless communications," IEEE Communications Magazine, vol. 50, 2012.

[4] C. S. Park, L. Sundström, A. Wallen, and A. Khayrallah, "Carrier aggregation for LTE-advanced: design challenges of terminals," IEEE Communications Magazine, vol. 51, pp. 76-84, 2013.

[5] M. DESHMUK and P. PAVALE, "Carrier Aggregation for High Speed Data in LTE Advanced System," The SIJ Transactions on Computer Networks & Communication Engineering (CNCE), vol. 1, 2013.

[6] S. K. Tiwari, "Carrier aggregation in lte-advanced," Master, Department of Electronics & Communication Engineering, National Institute of Technology, Rourkela, India, 2014.

[7] A. Yahya, LTE-A Cellular Networks: springer nature, 2016.

[8] M. S. H. ElBamby, "Resource allocation and interference management for LTE-advanced systems with carrier aggregation," Faculty of Engineering at Cairo University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electronics and Electrical Communications Engineering Faculty of Engineering, Cairo University Giza, Egypt 2013, 2013.

[9] D. Duggal, J. Malhotra, and K. Arora, "Performance evaluation of Downlink Non Contiguous Carrier Aggregation in LTE-A," work, vol. 8, 2015.

[10] A. Tanner, "LTE-A 3CC Carrier Aggregation," Bachelor, Information Technology, Helsinki Metropolia University of Applied Sciences, 2016.

[11] R. Zhang, "Radio Resource Management in LTE-Advanced Systems With Carrier Aggregation," Doctor of Philosophy, Electrical and Computer Engineering, Waterloo, Ontario, Canada, 2016.

[12] M. Á. Lema Rosas, "Contribution to the optimization of 4G mobile communications by means of advanced carrier aggregation strategies," 2015.

[13] L. Miller, "Carrier Aggregation Fundamentals for Dummies," ed: New Jersey: John Wiley & Sons, Inc, 2016.

[14] B. Hasiandra, "Planning and performance analysis of downlink inter-band carrier aggregation for LTE-Advanced 3GPP Released 13," in Telecommunication Systems Services and Applications (TSSA), 2016 10th International Conference on, 2016, pp. 1-6.

[15] K. Suresh, N. Kumaratharan, and V. Rajaram, "Study on LTE-Advanced Carrier Aggregation Optimization," an international journal of advanced computer technology, p. 3, 2016.

[16] M. Njiraine and S. Musyoki, "Carrier Aggregation in the Scheduling Schemes for LTE Advanced Systems," in Proceedings of Sustainable Research and Innovation Conference, 2016, pp. 119-125.

[17] H. R. Chayon, K. Dimyati, H. Ramiah, and A. W. Reza, "An Improved Radio Resource Management with Carrier Aggregation in LTE Advanced," Applied Sciences, vol. 7, p. 394, 2017.

[18] H. S. B. Abdelmula, M. M. Warip, O. B. Lynn, and N. Yaakob, "TECHNICAL REVIEW OF RRM FOR CARRIER AGGREGATION

IN LTE-ADVANCED," Journal of Theoretical and Applied Information Technology, vol. 91, p. 397, 2016.

[19] D. Robalo, F. J. Velez, R. R. Paulo, and G. Piro, "Extending the lte-sim simulator with multi-band scheduling algorithms for carrier aggregation in lte-advanced scenarios," in Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st, 2015, pp. 1-6.

[20] S. Gao, H. Tian, J. Zhu, L. Chen, and X. She, "A throughput-optimized component carrier selection algorithm for LTE-advanced systems," Proceedings ojICCTA2011, 2011.

[21] H. Tian, S. Gao, J. Zhu, and L. Chen, "Improved component carrier selection method for non-continuous carrier aggregation in LTE-advanced systems," in Vehicular Technology Conference (VTC Fall), 2011 IEEE, 2011, pp. 1-5.

[22] C. Li, B. Wang, W. Wang, Y. Zhang, and X. Chang, "Component carrier selection for LTE-A systems in diverse coverage carrier aggregation scenario," in Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on, 2012, pp. 1004-1008.

[23] J. Parikh and A. Basu, "Scheduling schemes for carrier aggregation in LTE-Advanced systems," International journal of research in engineering and technology, vol. 8, 2014.

[24] A. Shahid, S. Aslam, H. S. Kim, and K.-G. Lee, "Component carrier selection method for LTE-Advanced using metaheuristic approach," in ICT Convergence (ICTC), 2013 International Conference on, 2013, pp. 561-564.

[25] H.-S. Liao, P.-Y. Chen, and W.-T. Chen, "An efficient downlink radio resource allocation with carrier aggregation in LTE-advanced networks," IEEE Transactions on Mobile Computing, vol. 13, pp. 2229-2239, 2014.

[26] H. A. M. Ramli, F. N. M. Isa, and A. L. Asnawi, "An Improved Component Carrier Selection Algorithm for Downlink Long Term Evolution-Advanced," in Computer and Communication Engineering (ICCCE), 2014 International Conference on, 2014, pp. 201-204.

[27] I. B. Chaabane, S. Hamouda, and S. Tabbane, "Enhanced component carrier selection strategy for LTE-A under carrier aggregation mode," in Wireless Communications and Mobile Computing Conference (IWCMC), 2015 International, 2015, pp. 238-243.

[28] H. S. Narman and M. Atiquzzaman, "Selective periodic component carrier assignment technique in LTE and LTE-A systems," in Global Communications Conference (GLOBECOM), 2015 IEEE, 2015, pp. 1-6.

[29] M. Z. Al Katsha and H. A. M. Ramli, "Development of a novel component carrier selection algorithm in Long Term Evolution-Advanced (LTE-A) with Carrier Aggregation," in Research and Development (SCOReD), 2016 IEEE Student Conference on, 2016, pp. 1-5.

[30] S. Sun, S. Shen, Y. Fu, and Y. Zhao, "A Dual Priority Component Carrier Selection Algorithm in LTE-Advanced Systems," in Wireless Communications and Networking Conference (WCNC), 2017 IEEE, 2017, pp. 1-5.

[31] B. Kreidl, "Carrier Aggregation with the LTE System Level Downlink Simulator," tuwienMarch 2016.

[32] S. S. a. M. T. Markus Rupp. (2016, 13-5). Vienna LTE-A Downlink System Level Simulator. Available: https://www.nt.tuwien.ac.at/research/mobile-communications/vccs/vienna-lte-a-simulators/lte-a-downlink-system-level-simulator/.

[33] R. R. Amitabha Ghosh, Essentials of LTE and LTE-A, 2011.

[34] G. Basilashvili, "Study of Spectral Efficiency for LTE Network," American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS), vol. 29, pp. 21-32, 2017.

[35] M. T. Markus Rupp, The Vienna LTE-Advanced Simulators Up and Downlink, Link and System Level Simulation: SpringerNature, 2016.
[36] D. Martín-Sacristán, J. Monserrat, V. Osa, and J. Cabrejas, "LTE-advanced system level simulation platform for IMT-advanced evaluation," in Waves, 2011.
[37] S. Rostami, K. Arshad, and P. Rapajic, "Optimum Radio Resource Management in Carrier Aggregation based LTE-Advanced Systems," IEEE Transactions on Vehicular Technology, 2017.
[38] L. Kiwoli, A. Sam, and E. Manasseh, "Performance analysis of carrier aggregation for various mobile network implementations scenario based on spectrum allocated," arXiv preprint arXiv:1711.02287, 2017.

APPENDIX A

Code of Cyclic Component Carrier Selector

```
classdef cyclic_CC_selector < CC_selectors.CC_selector
  properties
  end
  methods
    % Class constructor.
   function obj = cyclic_CC_selector(attached_eNodeB)
    obj=obj@CC_selectors.CC_selector(attached_eNodeB);
      obj.name = 'cyclic CC selector';
    end

    function select_CC(obj)
      UEs_to_assign = obj.attached_eNodeB.attached_UEs_vector;
      n_UEs = length(UEs_to_assign);
      n_CC = length(obj.attached_eNodeB.CC);
      CC_UE_count = zeros(1,n_CC);

      for u_ = 1:n_UEs
        UE_assigned = false;
        for i_ = 1:n_CC
     if UEs_to_assign(u_).CC(i_).active && obj.attached_eNodeB.CC(i_).active && ~UE_assigned
            CC_UE_count(i_) = CC_UE_count(i_) + 1;
            UE_assigned = true;
          elseif UEs_to_assign(u_).CC(i_).active && ~obj.attached_eNodeB.CC(i_).active
            error('UE CC is active but eNodeB CC is not')
          elseif UEs_to_assign(u_).CC(i_).active && UE_assigned
            error('multiple CC activated')
          end
        end
      end

      for i_ = 1:n_CC
        if ~obj.attached_eNodeB.CC(i_).active
          CC_UE_count(i_) = NaN;
        end
      end
```

```
            for u_ = 1:n_UEs
                UE_assigned = false;
                for i_ = 1:n_CC
                    if UEs_to_assign(u_).CC(i_).active
                        UE_assigned = true;
                    end
                end

                if ~UE_assigned
                    [~, cc] = min(CC_UE_count);
                    UEs_to_assign(u_).CC(cc).active = true;
                    UEs_to_assign(u_).primary_CC = cc;
                    obj.attached_eNodeB.CC(cc).scheduler.add_UE(UEs_to_assign(u_).id)
                end
            end
        end
    end

end
```

Code of All Component Carrier Selector

```
classdef all_CC_selector < CC_selectors.CC_selector

    properties
    end

    methods

        % Class constructor.
        function obj = all_CC_selector(attached_eNodeB)
            obj      = obj@CC_selectors.CC_selector(attached_eNodeB);
            obj.name = 'all CC selector';
        end

        function select_CC(obj)
            UEs_to_assign = obj.attached_eNodeB.attached_UEs_vector;
            n_UEs = length(UEs_to_assign);
            n_CC = length(obj.attached_eNodeB.CC);

            for u_ = 1:n_UEs
                if UEs_to_assign(u_).CA_supported
```

```
            for i_ = 1:n_CC
                if obj.attached_eNodeB.CC(i_).active
                    if UEs_to_assign(u_).CC(i_).active;
                        %UE already assigned
                    else
                        UEs_to_assign(u_).CC(i_).active = true;
                        obj.attached_eNodeB.CC(i_).scheduler.add_UE(UEs_to_assign(u_).id)
                    end
                else
                    if ~UEs_to_assign(u_).CC(i_).active;
                        %do nothing
                    else
                        error('UE CC is active but eNodeB CC is not')
                    end
                end
            end
        else
            for i_ = 1:n_CC
                if UEs_to_assign(u_).primary_CC == i_ && obj.attached_eNodeB.CC(i_).active
                    if UEs_to_assign(u_).CC(i_).active
                        %UE already assigned
                    else
                        UEs_to_assign(u_).CC(i_).active = true;
                        obj.attached_eNodeB.CC(i_).scheduler.add_UE(UEs_to_assign(u_).id)
                    end
                elseif UEs_to_assign(u_).primary_CC == i_ && ~obj.attached_eNodeB.CC(i_).active
                    error('UE primary CC is not active for eNodeB')
                else
                    if ~UEs_to_assign(u_).CC(i_).active;
                        %do nothing
                    else
                        error('UE CC is active but eNodeB CC is not')
                    end
                end
            end
        end
    end
end
end
end
```

APPENDIX B

In this appendix results of UE throughput, cell throughput, spectral efficiency and fairness with various number of users for all and cyclic CC selectors concluded in tables.

Bw=20MHz 3CC (800, 2400, 2600) MHz 5 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	18.08 /10.02 / 4.58 Mbit/s	73.13 / 29.84 / 5.07 Mbit/s
Spectral Efficiency	13.24 bit/cu	36.56 bit/cu
Fairness	0.863836	0.516571
Average Cell Throughput	50 Mbit/s	149.18 Mbit/s

Bw=20MHz 3CC (800, 2400, 2600) MHz 10 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	9.28 / 4.71 / 2.06 Mbit/s	44.55 / 14.58 /2.11 Mbit/s
Spectral Efficiency	7.85 bit/cu	20.8 bit/cu
Fairness	0.81359	0.525562
Average Cell Throughput	47.1 Mbit/s	145.76 Mbit/s

Bw=20MHz 3CC (800, 2400, 2600) MHz 15 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	5.48 / 2.76 /1.08 Mbit/s	26.11 / 9.22 /1.4 Mbit/s
Spectral Efficiency	5.67 bit/cu	15.28 bit/cu
Fairness	0.807699	0.540535
Average Cell Throughput	41.35 Mbit/s	138.25 Mbit/s

Bw=20MHz 3CC (800, 2400, 2600) MHz 20 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	3.79 /1.97 /0.8 Mbit/s	18.75/ 6.67 / 0.89 Mbit/s
Spectral Efficiency	4.95 bit/cu	12.9 bit/cu
Fairness	0.802679	0.556982
Average Cell Throughput	39.49 Mbit/s	133.4 Mbit/s

Bw=20MHz 3CC (800, 2400, 2600) MHz 25 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	3.25/ 1.56 /0.59 Mbit/s	14.28 /5.26 / 0.67 Mbit/s
Spectral Efficiency	4.4	11.26
Fairness	0.742628 bit/cu	0.548667 bit/cu
Average Cell Throughput	38.96 Mbit/s	131.39 Mbit/s

Bw=20MHz 3CC (800, 2400, 2600) MHz 30 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	2.65 / 1.28 / 0.41 Mbit/s	12.72/ 4.32/ 0.55 Mbit/s
Spectral Efficiency	4.25 bit/cu	10.38 bit/cu
Fairness	0.739651	0.516395
Average Cell Throughput	38.34 Mbit/s	129.54 Mbit/s

Bw=20MHz 3CC (800, 2400, 2600) MHz 35 users/eNodeB

statistics	Cyclic	All
Peak /Avg/edge UE Throughput	2.37/ 1.12/ 0.39 Mbit/s	10.5/ 3.73/ 0.44 Mbit/s
Spectral Efficiency	4.12 bit/cu	9.85 bit/cu
Fairness	0.729255	0.534133
Average Cell Throughput	39.25 Mbit/s	130.04 Mbit/s