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PERFORMANCE ANALYSIS OF MULTI-CARRIER AGGREGATION WITH ADAPTIVE MODULATION AND CODING SCHEME IN LTE-ADVANCED SYSTEM

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ABSTRACT

Although LTE-Advanced system is targeted at enhancing the users' throughput and increasing connection reliability, however user's mobility tends to degrade the efficiency of the services and applications in terms of throughput degradation and outage probability reduction. Particularly this is during the handover from the source to the target eNBs. Therefore, the Carrier Aggregation (CA) technique is based on different numbers of Components Carrier (CCs) utilizing AMC scheme is implemented in this paper in order to further enhance the system performance. A simple mathematical formulation for user's throughput and outage probability evaluation are derived and then used in the simulation for random mobility. It has shown that, the integration of CA and AMC (CA-AMC) on the downlink significantly outperforms systems either by employing CA with common Modulation and Coding Schemes (MCSs) or that by implementing Non-CA technique with MCSs or AMC scheme in terms of throughput and outage probability. The total throughput gains achieved by CA-AMC integration are 50 to 80% over non-CA employed AMC when between 2 to 5 CCs are used respectively with AMC integration. Similarly, the total user's outage probability is improved when the number of CCs is increased with AMC integration.

Keywords: *Carrier Aggregation, AMC, Throughput, Outage Probability, LTE-Advanced.*

1. INTRODUCTION

Accessing multimedia services and Internet broadband applications through the user's mobility with seamless connectivity in Long Term Evolution (LTE) network require high throughput and service continuity, especially during handover from the serving to the target Evolved Nodes B (eNBs). Furthermore, users' mobility within the cells leads to a constant change in the channel condition, which in turn leads to throughput degradation and service disconnection, especially if a fixed common MCS is considered. These insufficiencies will affect the quality and efficiency of multimedia services and Internet broadband applications. However, CA technology and Adaptive Modulation and Coding (AMC) scheme have been proposed to enhance system throughput and support service continuity in wireless communication systems, especially through the users' mobility. CA is a new technology has been proposed in International Mobile Telecommunications-Advanced (IMT-Advanced) system in order to enhance system throughput [1], [2]. CA can provide higher transmission data rate over a wider bandwidth to the Users Equipments (UEs) within the cell area. AMC scheme can adaptively change the MCS based on the channel condition change. AMC scheme has been proposed to enhance system throughput and support service continuity [3], [10]. Therefore, CA technology and AMC scheme can enhance user's throughput and reduce its outage probability.

Most of the wireless cellular systems consider one of the common MCSs as a modulation and coding scheme, which may lead to throughput degradation and disconnecting service, especially when the channel condition is being relatively harsh. Therefore, implementing CA technique employing any common MCSs increases throughput degradation and outage probability [11-13] through the users' mobility. Therefore, study the performance of LTE-Advanced system when CA technology is implemented employing AMC scheme needs to be investigated. In addition, the

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enhancement gains that can be achieved by CA technology and AMC scheme should be comparable with single carrier and common MCS respectively in terms of throughput and outage probability.

In wireless communication systems, throughput and outage probability [13-24] are an important performance metrics which should be highlighted and studied in LTE-Advanced system. These two metrics need to be studied when multi carriers are considered, whereas the most of the literature studies have been achieved when only a single CC is considered. Throughput is the rate of successful bits that can be received correctly at the terminal UE over a communication channel in a certain amount of time. This data is usually measured in bits per second (bit/s or bps). The outage probability of the cell can be defined as the percentage of area within the cell that does not meet its minimum power requirement [13-24]. In other word, it is the probability that, the instantaneous Signal-to-Interference-Noise-Ratio (SINR) falls below a given threshold level, where the threshold level represents the target minimum SINR level below which performance becomes unacceptable. However, outage probability is considered as an important key performance metric in cellular networks under the effect of path loss, shadowing, multipath fast fading and Co-Channel Interference (CCI). In the literature, there are several studies explain outage probability in detail as illustrated in [13-24], and many of the references have been cited there. Most of these literature researches have been done on the computation of outage probabilities when only one single CC is implemented. Moreover, since CA is a new technology has been introduced in IMT-Advanced system which is still under development until now the throughput and outage probability are required to be studied when multiple CCs employing different MCSs are considered in the system. In addition, formulating simple mathematical formula for estimating user's throughput and outage probability when CA technique is implemented employing AMC scheme is a new issue need to be studied in the current researches.

In this paper, CA technique based on N CCs employing AMC scheme will be investigated in LTE-Advanced environment. This integration of CA technique and AMC scheme targets to overcome the degradation of throughput and reducing users' outage probability. Furthermore, mathematical expressions for estimating user's throughput and its outage probability will be simplified when CA technology employing AMC scheme is applied in LTE-Advanced system.

The rest of this paper is organized as follows: section 2 describes Background followed by System Assumptions and Simulation Environment in section 3. Section 4 presents Performance evaluation analysis. Results and discussions are illustrated in section 5, and then the conclusion in section 6.

2. BACKGROUND

2.1 Adaptive Modulation and Coding Scheme

The AMC scheme is considered as one of the significant schemes that can enhance system performance in terms of data throughput and outage probability, when compared with the common MCSs approach. It is introduced by combining different modulations with different coding techniques in order to achieve higher throughputs and better spectral efficiencies subjected to the channel condition as well as to reduce the user's outage probability. The main goal of the AMC scheme is to ensure that the transmission path always utilize the best efficient model over variable channel conditions [6], [8]. LTE-Advanced system operates higher modulation levels and higher channel coding rates when the channel condition is favourable. However, when the channel condition is relatively harsh it uses lower modulation levels and lower channel coding rates. It is therefore obvious that, an implementation of AMC scheme gives the system more options to choose from when compared to using common MCS.

2.2 Carrier Aggregation

CA technique is defined by aggregated several smaller contiguous or non-contiguous component carriers to achieve higher transmission data rate over a wider system bandwidth to the residential and higher mobility speed users. Therefore, CA technology allows the LTE-Advanced networks to support high peak data rates up to 1.5 *Gbps* in the Downlink (DL) and 700 *Mbps* in the Uplink (UL) over a wider spectrum bandwidth in Rel.11, up to 100 MHz by aggregated five CCs with 20 MHz bandwidth for each CC [1-3], [25 -26]. Furthermore, the whole system bandwidth can be signed to a single UE unit in the DL or UL, while preserving backward compatibility with legacy systems [27].

CA is an attractive technique as it has the ability to improve the LTE-Advanced system performance in terms of throughput and outage probability with the possibility to schedule a UE on multiple CCs

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simultaneously. Furthermore, the CA technique transmits the data on multiple sub-bands, located on multiple CCs by using a single Radio Frequency (RF) transmitter and one Base Band (BB) processing a single large Fast Fourier Transform (FFT).

3. SYSTEM ASSUMPTIONS AND SIMULATION ENVIRONMENT

3.1. CA Employing AMC Scheme.

In this paper, CA technique based on *N* CCs utilizing AMC scheme is implemented in LTE-Advanced system to further enhance system performance. Furthermore, mathematical formulas for estimating user's throughput and its outage probability will be simplified when CA technology employing AMC scheme is applied in LTE-Advanced system. However, Figure 1 illustrates the concept of implementing CA with employing AMC scheme. The serving eNBs is allowed to transmit data over multiple CCs utilizing different combinations of constellation sizes and code rates, which is adaptively selected based on the channel condition for each subcarrier at the UE. Thus, the serving eNB adaptively selects the suitable MCS that yield a higher throughput based on the SINR level requirement for each subcarrier over any CCs.

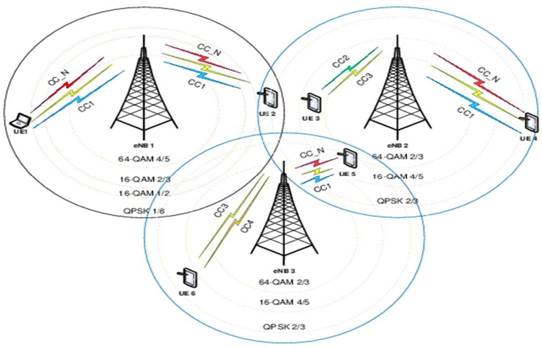

Figure 1: Concept of Carrier Aggregation Employing AMC Scheme.

Multiple component carriers (CC1, CC2, CC3, CC4 and CC5) in Non-contiguous bands are configured for each eNB and UE. Each CC with 20MHz bandwidth is aggregated with other CCs to configure total system bandwidth up to 100*MHz*. Each CC consists of 100 Physical Resource Blocks (PRBs). One PRB consist of 12 subcarriers in the frequency domain and one time slot in time domain [3], [28]. The operating carrier frequencies (*fc*) are assumed to be 1.8 *GHz*, 2.0 *GHz*, 2.1 *GHz*, 2.6 *GHz* and 3.0GHz for CC1, CC2, CC3, CC4 and CC5, respectively. All transmitted power over all CCs are assumed to be same with identical antenna gains. The shadow and fast fading effects are taken into account for each CC.

AMC scheme offers the capability for the eNB to select the suitable MCS based on the channel condition. It is implemented based on the sets of modulation schemes that are introduced in [1], [4], [10], [28], which are QPSK, 16-QAM and 64-QAM. These sets of MCSs are used to modulate signal based on Orthogonal Frequency Division Multiplexing (OFDM) scheme. 64-QAM is considered the Maximum DL modulation that can be used in LTE / LTE-Advanced system [11], while, QPSK modulation scheme is used for all the control channels [12], [29]. Each modulation scheme is implemented with several Code Rate (CR) [3] [29], which are illustrated in Table 1. Furthermore, each MCS has a specific SINR threshold level as listed in Table 1, under which are selected the suitable MCS.

Table 1: MCS In LTE-Advanced System [3] [29].

Modulation Schemes	Coding Rate	Threshold level [dB]
QPSK	1/8	- 6.5
	1/5	- 4.2
	1/4	- 3.5
	1/3	- 1.5
	1/2	0.5
	2/3	2.0
	4/5	4.5
	1/2	6.1
16-QAM	2/3	8.1
	4/5	10.9
	2/3	12.5
64-QAM	3/4	13.5
	4/5	16.0

3.2. System Model.

On the DL of LTE-Advanced system which is based on 3GPP specifications that have been introduced in [26], [28], [29] the considered system is modelled as shown in Figure 2. It is consists of 61 hexagonal cells with inter-site distance of 0.5km. Each cell has one eNB located at its centre, each cell has 3 sectors, which are configured with different numbers of CCs. In the centre hexagonal cell there are 50 UEs are generated randomly, while in the others cells a random numbers of users are generated and removed randomly in every simulation time step. That aims to consider a random generation of traffic through all the simulation time. All UEs are generated at random positions in the cells. Their direction movement is selected randomly with a fixed speed throughout the simulation. The mobile speed scenario is

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considered to be 120 km/hr. The mobility movements of all users are considered to be inside the first 37 cells only. That is aimed to consider six interferences signals from six eNBs received at the served UE during all the simulation time at any position *x*. Furthermore, the Frequency Reuse Factor (FRF) is assumed to be 1.

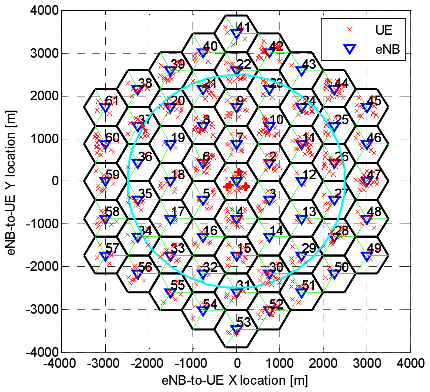

Figure 2: System Layout Including Cell Layout eNBs And UEs Distributions.

Five different Carrier Aggregation Deployment Scenarios (CADSs) are considered as illustrated in Figure 3. Each CC is directed to different direction. In CADS1 one CC is considered only as shown in Figure 3 (a). The operating carrier frequency of CC1 is assumed to be 1.8 GHz. In CADS2 two CCs are considered as shown in Figure 3 (b). The operating carrier frequencies of CC1 and CC2 are assumed to be 1.8 GHz and 2GHz, respectively. In CADS3 three CCs are considered as shown in Figure 3 (c). The operating carrier frequencies of CC1, CC2 and CC3 are assumed to be 1.8 GHz, 2GHz and 2.1GHz, respectively. In CADS4 four CCs are considered as shown in Figure 3 (d). The operating carrier frequencies of CC1, CC2, CC3 and CC4 are assumed to be 1.8 GHz, 2GHz, 2.1GHz and 2.6GHz, respectively. In CADS5 five CCs are considered as shown in Figure 3 (e). The operating carrier frequencies of CC1, CC2, CC3, CC4 and CC5 are assumed to be 1.8 GHz, 2GHz, 2.1GHz, 2.6GHz and 3GHz, respectively. These five scenarios will be investigated and compared in terms of throughput and outage probability.

The performance of these five CADSs is investigated and compared in three steps, which are illustrated in Table 2. In the first step, LTE-Advanced system is implemented based on a single CC with employing AMC scheme and compared with the systems that are considering a single CC with employing different common MCSs. In the second step, the system is implemented based on five Aggregated Component Carriers (ACCs) with employing AMC scheme and compared with systems that are implemented based on five ACCs employing different common MCSs. In the third step, LTE-Advanced system is implemented based on different ACCs with employing AMC scheme and compared with system that is implemented based on a single CC employing AMC scheme.

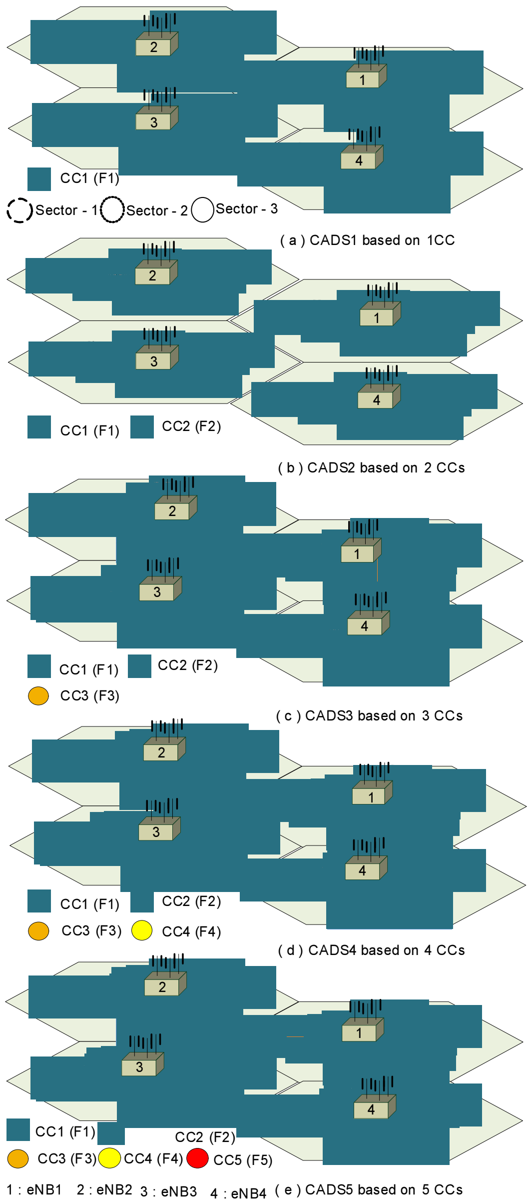

Figure 3: Five CA Deployment Scenarios

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TABLE 2. *Comparison steps Scenarios*

Step No	Comparison System	
Step 1	1CC employing AMC	1CC employ common MCSs
Step 2	Five ACCs employing AMC.	Five ACCs employing common MCSs.
Step 3	CA based on N CCs employ AMC	Non-CA (single CC) employs AMC

The performance of LTE-Advanced system based on all these different comparisons steps are investigated in terms of throughput and outage probability. Furthermore, the essential parameters that are used in this research are listed in Table 3 based on the LTE-Advanced system profile that has been defined by 3GPP's specifications in [26], [28], [29].

TABLE 3: Simulation Parameters Assumptions.

Parameter	Assumption (LTE-A)
Environment	61 Macro hexagonal cells, 3 Sectors in each cell
Minimum Distance between UE and eNB	35 m
Log-Normal Fade Shadow	10 dB
eNBs Noise Figure	5 dB
White Noise Power Density	-174 dBm/Hz
eNBs max TX Power	46 dBm.
eNBs Antenna Gain	15 dBi.
eNBs Antenna Height	15 m.
eNBs Noise Figure	5.
UE Height	1.5 m.
UE total Gain	0 dBi.
UE Noise Figure	9 dB.
Total System Bandwidth	100 MHz (5CCs x 20 MHz)
Physical Resource Block (PRB) size	180kHz.
Subcarrier (SC) size	15kHz.
Subcarriers number per RB	12 Subcarriers per RB.
Number of OFDM symbols per Subframe	7.
Handover Margin (HOM)	3 dB
Time-To-Trigger (TTT)	320 ms
Q_rxlevmin	-101.5 dBm
Measurement Interval	50ms for PCC and SCC
Each eNB Process Delay	10 ms
Each X2-interface delay	10 ms

3.3. Simulation Scenario

The Reference Signal Received Power (RSRP) is measured periodically across all neighboring eNBs for the PCCs and SCCs simultaneously. This measurement is performed every measurement interval to evaluate the triggering Measurement Reports (MR) as performed in the real UE. The best eNB is selected as a target eNB candidate, and then the serving eNB makes a handover decision based on the MR. The serving eNB makes the handover decision based on the quality of the serving RSRPs over the PCC and the quality of the selected target CC. Once the target RSRP becomes greater than the serving RSRP by the handover margin level during the TTT period of time, the serving eNB makes a handover decision and sends the handover request message to the target eNB. The handover decision considered in this paper can be expressed by the following algorithm:

```
Algorithm: Handover Decision Algorithm
1:  If  Target_RSRP > Serving_RSRP + HOM then
2:      If Trigger_timer >= TTT then
3:          Handover Decission ←True
4:      else
5:          Handover_Decission ←false
6:          Run Trigger Timer
7:      end
8:  else
9:      Handover_Decission ←false
10:     Reset Trigger Timer
11: end

HOM : Handover Margin Value.
```

If the handover decision is true, the serving eNB will prepare for handover by sending a HANDOVER REQUEST message to the target eNB. Thus, the UE will enter the handover procedure to establish connection with the target eNB. The handover procedure is performed based on the handover procedure of the LTE-Advanced system as illustrated in the details of [12]. Moreover, the Radio Link Failure (RLF) detection, Radio Resource Control (RRC) re-establishment and Non-Access Stratum (NAS) recovery procedures are considered.

4. PERFORMANCE EVALUATION ANALYSIS

4.1. Downlink SINR Evaluation.

In this paper, the modulated signals are transmitted based on OFDM scheme, while, a macro cell path loss model is applicable with considering the shadowing and Rayleigh Fast Fading effects. Consequently, the model can be formulated as [5], [14], [15], and [30]:

$$PL = K \left(\frac{d}{d0}\right)^{-\mu} \psi\,\vartheta \qquad (1)$$

where K represents the Free Space Path Loss (FSPL). μ represents the path loss exponent which sets to be 3.7 in this research. d represents the distance between user at position x and eNB j and ψ is a random variable that represents shadowing which is given by $\psi = 10^{\xi/10}$, where ξ represents zero mean and standard deviation (σ), which is assumed to be 10 dB. As for ϑ, it represents

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Rayleigh fast fading effect. For simplicity, the path loss model can be given in dB by:

$$PL(dB) = 10\,log_{10}(K) - 10\,\mu\,log_{10}\left(\frac{d}{d0}\right) - \psi_{dB} - \vartheta_{dB} \quad (2)$$

The transmitted signals in the DL transmission in LTE-Advanced network based on CA technique and OFDM scheme is considered, thereby every single eNB can serve each user by N_{sc}^{UE} subcarriers over N_{CC}^{UE} CCs assigned to each user. That means, each UE has the ability to receive data from multiple subcarriers N_{sc}^{UE} over several CCs. Furthermore, the definition of the PRB that was introduced in [3] is also considered in this paper. Moreover, the total transmission power of the eNB over each CC is equally distributed over the whole subcarriers. So, if the total numbers of subcarriers in a single CC is represented by N_{sc}^{CC} and the total transmission power is represented by P_t, the total transmission power on each subcarrier P_{tsc} is expressed by the following [33]:

$$P_{tsc} = P_t / N_{sc}^{CC} \quad (3)$$

The transmitted power over any subcarrier is assumed to be the same. So, the useful received signal power $P_{rsc_{j,k,n,x}}$ at UE j on subcarrier k over CC n at position x in the DL transmission can be expressed as [29]:

$$P_{rsc_{j,n,k,x}} = P_{tsc}\; g_t\; g_r\; K\; \left(\frac{d}{d0}\right)^{-\mu} \psi\,\vartheta \quad (4)$$

where, g_t and g_r represent transmitter and receiver antenna gains respectively.

The received interference signals by user j are considered from the six neighbours eNBs that are located in the first tier around the serving eNB, while, the interference signals that are received from the eNBs those are located in the second tier will be neglected, due to their weakness compared to the received interference signals from the eNBs that are located in the first tier. Thus, the Interference received signals by user $j$on subcarrier k over CC n at position x from H neighbours eNBs located at the first tier around the serving eNB is expressed by:

$$I_{j,k,n,x} = \sum_{i=1}^{H} P_{tsc_i}.Gt_i.Gr_i.K_i\left(\frac{d_i}{d0}\right)^{-\mu}\psi_i\,\vartheta_i \quad (5)$$

For simplicity P_{int_j,k,n,x_i} can be set to represent the interference received signal power by user j on subcarrier k over CC n at position x from neighbours eNB i, which can be expressed as:

$$P_{int\_j,k,n,x\_i} = P_{tsc_i}.Gt_i.Gr_i.K_i\left(\frac{d_i}{d0}\right)^{-\mu}\psi_i\,\vartheta_i \quad (6)$$

From (5) and (6) the total Interference received signals by user j on subcarrier k over CC n at position x from H neighbours eNBs can be simplified and expressed as:

$$I_{j,n,k,x} = \sum_{i=1}^{H} P_{int\_j,k,n,x\_i} \quad (7)$$

Consequently, the Signal-to-Interference-Noise-Ratio (SINR) for user j on subcarrier k over CC n at position x is formulated by:

$$SINR_{j,n,k,x} = \frac{P_{tsc}.Gt.Gr.K\left(\frac{d}{d0}\right)^{-\mu}\varphi\,\vartheta}{\sum_{i=1}^{H} P_{int\_j,k,n,x\_i} + Pno_{j,n,k,x}} \quad (8)$$

where, $Pno_{j,n,k,x}$, represents the Noise Power for user j on subcarrier k over CC n at position x.

4.2. Throughput Evaluation Performance

The transmission throughput over a radio link can be defined by the number of data bits that can be successfully transmitted per modulation symbol. The coding scheme adds a few redundant bits to the data bits which can correct errors in the received bits at the receivers' terminals. The degree of coding rate is determined by its rate. The proportion of data bits to coded bits is typically varies from 1/8th to 4/5ths [29].

Based on the 3GPP specifications that have been explained in detail in [2], [12], [29] and [32], one radio frame consists of 10 sub-frame (i.e. one radio frame = 10 *ms*), each sub-frame consists of two time-slots, one time-slot consists of 0.5 *ms* (i.e. 1 sub-frame = 1 *ms*), one time-slot consists of 7 modulation symbols (when normal Cyclic Prefix (CP) length is used), where, the number of OFDM symbols in each slot depends on CP length and the configured subcarrier spacing. Each modulation symbol consists of 2, 4 or 6 bits if QPSK, 16-QAM or 64-QAM is used as modulation schemes respectively.

The transmitted signal in each time slot is configured by one or several resource grids. Each resource grid consists of several DL PRBs N_{RB}^{DL}, each PRB consists of N_{sc}^{RB} subcarriers and each subcarrier includes N_{symb}^{DL} OFDM symbols. The quantity of N_{RB}^{DL} depends on the whole DL transmission bandwidth that is configured in the cell. Each PRB consists of $N_{symb}^{DL}\;x\;N_{sc}^{RB}$ resource elements which are corresponding to one slot in the time domain and *180 kHz* in the frequency domain.

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Therefore, the number of bits in one time-slot consists of N_{symb}^{sc} modulation symbols can be given by the following formula:

$$B_{bit}^{slot} = N_{symb}^{sc} \; x \; m_{bit}^{symb} \quad (9)$$

Each PRB has N_{sc}^{RB} subcarrier, each subcarrier has N_{symb}^{sc} symbols in time domain. So, each PRB has $N_{sc}^{RB} \; x \; N_{symb}^{sc}$ symbols in time domain. In each PRB there are four resource elements configured as reference symbols which allow the UE to estimate the channel condition. Figure 4 illustrates one PRB consists of four reference symbols which are represented by R. Therefore, the number of useful bits in one PRB can be given by:

$$B_{bit}^{RB} = (N_{sc}^{RB} \; x \; N_{symb}^{sc} - 4) \; x \; m_{bit}^{symb} \quad (10)$$

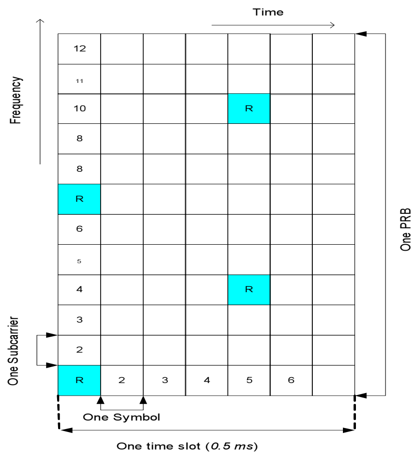

Figure 4: One PRB With Four Refrence Symbols As Reference Signals (Extended CP ($\Delta f = 15kHz$)) [3]

The total number of PRB that can be assigned to each active UE (N_{RB}^{UE}) depends on the number of active users in the cell and the total available PRB over the whole system bandwidth. However, the proposed algorithm in [32] is considered to determine the number of PRBs that can be assigned to one user. In case of the very limited numbers of available PRBs, some users may be dropped. Thus, the number of PRBs that can be assigned to each UE ($N_{RB}^{UE\_CCn}$) from CC n, can be expressed by the following formula [32]:

$$N_{RB}^{UE\_CCn} = \frac{N_{RB}^{DL\_CCn}}{N_{Act\;UEs}^{sys}} \quad (11)$$

where, $N_{Act\;UEs}^{sys}$ represents the total number of active UEs in the system, while, $N_{RB}^{DL\_CCn}$ represents the total available DL PRB over one CC ($CC\; n$) only. Consequently, the total number of bits that can be transmitted to each user B_{bit}^{UE} over one CC can be expressed by the following formula:

$$B_{bit}^{UE} = N_{RB}^{UE\_CCn} \; x \; (N_{sc}^{RB} \; x \; N_{symb}^{sc} - 4) \; x \; m_{bit}^{symb} \quad (12)$$

Since every user in LTE-Advanced system can be paired to multiple CCs simultaneously, thus the total number of bits that can be transmitted to each user B_{bit}^{TUE} over all the aggregated CCs can be expressed by:

$$B_{bit}^{TUE} = \sum_{n=1}^{N_{CC}^{UE}} N_{RB}^{UE\_CCn} \; x \; \left(N_{sc}^{RB} \; x \; N_{symb}^{sc} - 4\right) x \; m_{bit}^{symb} \quad (13)$$

where, N_{CC}^{UE} represents the number of CCs that can be assigned to one UE.

The transmitted bits from the serving eNB to the end user are including the code rate bits, so, the effect of CR is considered in the evaluation. Moreover, the received bits at the terminal UE is evaluated in every subframe interval of time T_j. Consequently, the total user's throughput that can be correctly received from multi-CCs over the whole system bandwidth in a period of time $T_j$can be formulated by the following expression:

$$R_{bit}^{UE} = \sum_{n=1}^{N_{CC}^{UE}} \frac{N_{RB}^{UE\_CCn} x \left(N_{sc}^{RB} \; x \; N_{symb}^{sc} - 4\right) x \; m_{bit}^{symb}}{T_j} \; CR \quad (14)$$

This mathematical formula can be applied when CA technique is implemented employing any common MCSs. Also, this mathematical formula can be applied when CA technique is implemented employing AMC scheme, where the total user throughput is adaptively changed from time to time when AMC scheme is used, where AMC scheme provides higher user's throughput by selecting the best MCS that can provide higher throughput to the users. The selection of MCS depends on the channel condition variation. Thus, integrating CA technique with AMC scheme increases user's throughput by receiving data over multiple CCs through selecting the best MCSs in the system based on the channel condition variation.

4.3. Outage Probability Analysis

This section will simplify mathematical expressions for estimating user's outage probability when single and multi carriers are considered in LTE-Advanced system. Through the derivation of outage probability formula, the path loss, shadowing, fast fading effects and CCI are taken into account. Since frequency reuse factor assumed to be one, inter-cell interference is neglected and focuses on intera-cell interference only. The

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expression of user's outage probability is driven based on the SINR and it is represented as a function of distance, shadowing and fast fading. However, in the following two sections user's outage probability will be simplified when a single CC and CA technique employing AMC scheme are implemented, respectively.

4.2.1. Outage Probability Analysis with Single CC.

In wireless communication systems, outage probability can be defined mathematically as a probability of instantaneous received $SINR$ (γ) to be lower than a threshold level γ_{Thr} [13-24], which is normally represented by:

$$P_{out} = P[\gamma < \gamma_{Thr}]$$
$$= 1 - P[\gamma > \gamma_{Thr}] \quad (15)$$

Thus, substituting (8) into (15) will result the outage probability as a function of distance, shadowing and fading, which can be expressed as in the following formula:

$$P_{out} = 1 - P\left[\frac{P_{tsc}.Gt.Gr.K\left(\frac{d}{d0}\right)^{-\mu}\varphi\,\vartheta}{\sum_{i=1}^{H} P_{int\_j,k,n,x\_i} + Pno_{j,n,k,x}} > \gamma_{Thr}\right] \quad (16)$$

For simplicity, the numerator and denominator in the outage probability expression in (16) can be simplified and expressed in dB as:

$$P_r = \left(P_{tsc\_dBm} + G_{tdB} + G_{rdB} + 10\ log_{10} K - 10\,\mu_{1cc}\ log_{10}\left(\frac{d}{d0}\right) + \vartheta_{dB}\right) \quad (17)$$

$$I_{int} = 10\ log_{10}\left(\sum_{i=1}^{H} P_{int\_j,k,n,x\_i}\right) \quad (18)$$

and

$$P_n = 10\,.log_{10}(Pno_{j,n,k,x}) \quad (19)$$

Also, for more simplicity outage probability can be represented by a Q-function by (20) [14], [16], [24]:

$$P_{out} = 1 - P[\gamma > \gamma_{Thr}]$$
$$= 1 - Q\left(\frac{\gamma_{Thr} - \bar{\gamma}}{\sigma}\right) \quad (20)$$

Therefore, from (16) to (20), user's outage probability based on one single CC (i.e. CCn) can be expressed in dB by:

$$P_{out} = 1 - Q\left(\frac{\gamma_{Thr\_dB} - P_r - I_{int} - P_n}{\sigma_{dB}}\right) \quad (21)$$

Thus, the data from all subcarriers over CC n will be correctly received by the user as long as the instantaneous received SINR for subcarrier k is greater than or equal to the threshold (γ_{Thr}) level. Each MCS has a different threshold (γ_{ThrdB}) level. Since AMC scheme is considered, the data will be correctly received at the user as long as the instantaneous received SINR is greater than or equal to the minimum threshold $(\gamma_{min-Thr})$ level. Thus, utilizing AMC scheme decreases the required minimum threshold $(\gamma_{min-Thr})$ level, which is determined based on the minimum MCS that is employed in the system. Therefore, from (15) and (21) the user's outage probability when only one single CC is implemented and integrated with AMC scheme can be represented by the following formula:

$$P_{out} = P[\gamma < \gamma_{min-Thr}] \quad (22)$$

Thus

$$P_{out} = 1 - Q\left(\frac{\gamma_{min\_Thr\_dB} - P_r - I_{int} - P_n}{\sigma_{dB}}\right) \quad (23)$$

4.2.2. Outage Probability Analysis with CA.

Implementing CA technique based on N CCs supports for high data rate and high connection reliability to the served user. Whereas, multiple CCs can be paired to one UE simultaneously. One CC is configured as a PCC and the other CCs are configured as SCCs. The control data is sent over the PCC only. That means the PCC should be always active, unlike the SCCs, which can be deactivated. The PCC can be changed by performing a handover procedure between the available CCs based on the signal level and resources availability. So, the user can receive data correctly as long as at least the instantaneous received SINR from only one CC is greater than or equal to the threshold (γ_{Thr}) level. Therefore, the user's outage probability will be decreased as long as the number of CCs that can be assigned to the user N_{CCs}^{UE} is increased. Thus, the user's outage probability is inversely proportional to the number of CCs that can be paired to the user, which can be represented by:

$$Outage\ Probability \propto \frac{1}{N_{CCs}^{UE}} \quad (24)$$

Consequently, when CA technique is considered, outage probability can be defined as the probability that the instantaneous received SINR from all CCs falls below a given threshold γ_{Thr} level simultaneously. Therefore, once the instantaneous

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received SINR (γ_{CC_n}) from all N CCs fall below a given threshold level γ_{Thr} outage probability is recorded. Thus, outage probability can be represented by:

$$P_{out_j} = P[(\gamma_{CC\_1}, \gamma_{CC\_2}, \dots, \gamma_{CC\_N}) < \gamma_{Thr}]$$
$$= 1 - P[(\gamma_{CC\_1}, \gamma_{CC\_2}, \dots, \gamma_{CC\_N}) > \gamma_{Thr}] \quad (25)$$

Since each CC has one independent Hybrid Automatic Repeat Request (HARQ) entity and each CC has its own physical characteristics (i.e. MCSs, PRB, OFDM symbols, multiplexing, independently of propagation channel effects, etc.) [10], so that, the user's outage probability can be calculated for each CC separately. Thus, from (25), user's outage probability for each CC paired to UE can be represented separately and expression as:

$$P_{out_{CA}} = \left(1 - P\left[\gamma_{CC_1} > \gamma_{Thr_{CC_1}}\right]\right) \cdot \left(1 - P\left[\gamma_{CC_2} > \gamma_{Thr_{CC_2}}\right]\right) \cdot \dots \cdot \left(1 - P[\gamma_{CC\_N} > \gamma_{Thr\_CC\_N}]\right) \quad (26)$$

From (21) and (26) the total user's outage probability when CA technique is considered can be formulated by:

$$P_{out_{CA}} = \left(1 - Q\left(\frac{\gamma_{ThrdB} - P_{r_{CC1}} - I_{int_{CC1}} - P_{no_{CC1}}}{\sigma_{dBCC1}}\right)\right) \cdot \left(1 - Q\left(\frac{\gamma_{ThrdB} - P_{r_{CC2}} - I_{int_{CC2}} - P_{no_{CC2}}}{\sigma_{dB_{CC2}}}\right)\right) \cdot \dots \dots \cdot \left(1 - Q\left(\frac{\gamma_{ThrdB} - P_{r_{CCN}} - I_{int_{CCN}} - P_{no_{CCN}}}{\sigma_{dB_{CCN}}}\right)\right) \quad (27)$$

Therefore, from (27), the total user's outage probability when N CCs are assigned to one user can be formulated by:

$$P_{out\_CA} = \prod_{n=1}^{N}\left(1 - Q\left(\frac{\gamma_{Thr\_dB} - P_{r\_n} - I_{int\_n} - P_{no\_n}}{\sigma_{dB\_n}}\right)\right) \quad (28)$$

Employing AMC scheme allows the serving eNB to adaptively select the suitable MCS in the system. That leads to decrease the required threshold level to being at the minimum threshold (γ_{mThr}) level. The minimum threshold level is determined based on the minimum MCS that are used in the system. Therefore, the total user's outage probability when CA technology is implemented employing AMC scheme is defined as a probability that the instantaneous received SINR (γ_{CC_n}) from all N CCs fall below the minimum threshold level (γ_{mThr}). Thus, the user's outage probability can be expressed by:

$$P_{out_j} = P[(\gamma_{CC1}, \gamma_{CC2}, \dots, \gamma_{CCN}) < \gamma_{mThr}]$$
$$= P[(\gamma_{CC1}, \gamma_{CC2}, \dots, \gamma_{CCN}) < \gamma_{mThr}]$$
$$= 1 - P[(\gamma_{CC1}, \gamma_{CC2}, \dots, \gamma_{CCN}) < \gamma_{mThr}] \quad (29)$$

Based on (28) and (29), the user's outage probability when CA technology is implemented employing AMC scheme can be represented by:

$$P_{CA\_AMC} = \prod_{n=1}^{N}\left(1 - Q\left(\frac{\gamma_{mThr} - P_{r\_n} - I_{int\_n} - P_{no\_n}}{\sigma_{dB\_n}}\right)\right) \quad (30)$$

This mathematical formula can be applied when CA technique is implemented and employing AMC scheme for any set of co-channel interference signals by taking into account the effect of path loss, shadow fading and fast fading channel.

5. RESULTS AND DISCUSSIONS

In this section, system performance is presented in three different steps. All the presented results are evaluated based on the mathematical expressions those are analysed in section 4. However, in the first step, system performance is presented to show the improvements that are achieved by AMC over common MCSs when single CC is implemented. In the second step, system performance is presented to show the improvements that are achieved by AMC over common MCSs when CA technique based on five CCs is implemented. In the third step, system performance is presented to show the improvements that are achieved by CA based on different numbers of aggregated CCs over single CC when AMC scheme is employed. All the presented results are presented in terms of throughput and outage probability.

5.1. AMC scheme with Single CC

Figures 5 and 6 show the performance of LTE-Advanced system when it is implemented based on a single CC employing different modulation and coding schemes such as AMC and different common MCSs. Figure 5 shows that, the AMC scheme achieves a noticeable enhancement of user's throughput compared to all common MCSs. This achievable enhancement is attributed to the multiple options of MCSs that are provided by AMC scheme, whereby allows the user to communicate with serving eNB utilizing the best MCS that can provide higher data rate. Whereas, the suitable MCS is selected automatically based on the channel condition.

Figure 6 shows that, employing AMC scheme in LTE-Advanced system achieves a noticeable

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reduction of user's outage probability compared to all common MCSs. This reduction is due to the automatic switching between different MCSs, whereby allows the UE to utilize the best MCS that can provide good signal quality greater than the threshold level. That leads to prevent the disconnection probability between UE and serving network.

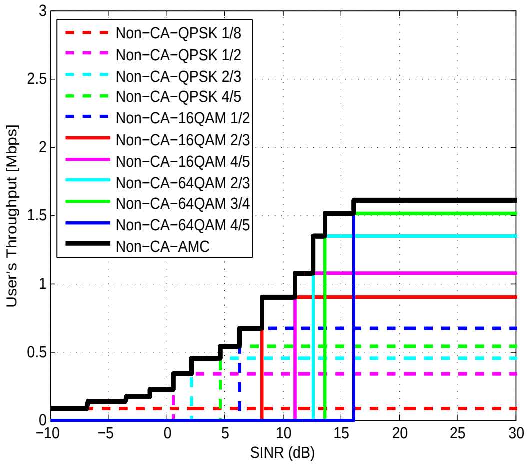

Figure 5: Throughput Versus SINR Based On A Single CC Employing Common And AMC Schemes.

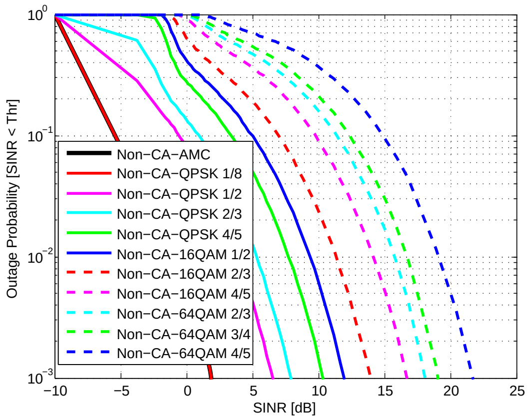

Figure 6: Outage Probability Based On A Single CC Employing Common MCSs And AMC Schemes.

5.2. AMC scheme with Five Aggregated CCs

In this subsection, the performance of LTE-Advanced system based on 5 aggregated CCs is presented when AMC and different common MCSs are used. Figure 7 shows that, AMC scheme enhances user's throughput much better than all common MCSs when 5 aggregated CCs are considered. Figure 8 shows a noticeable reduction of outage probability when AMC scheme is used compare to all the common MCSs. As mentioned in subsection 5.1, these improvements in the throughput and outage probability are attributed to the adaptive selection of multiple modulations and coding schemes that are provided by AMC scheme, whereby provide higher data rate and reducing outage probability. Furthermore, CA technology contributes for reducing outage probability by allowing the users to communicate with the serving eNB over multiple CCs. Thus, the integration between these two techniques improves system performance by enhancing the user's throughput and decreasing its outage probability, which lead to enhanced users' connection reliability.

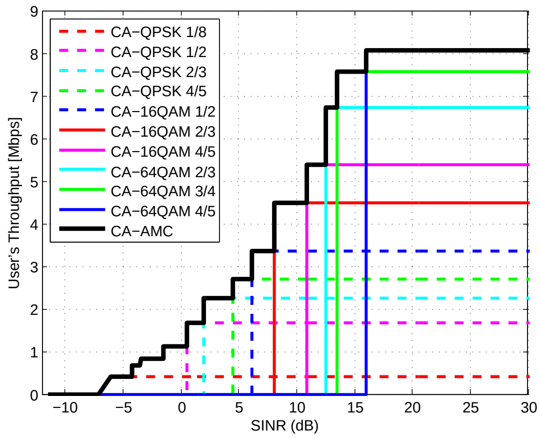

Figure 7: Throughput Versus SINR With CA Technique Employs Common And AMC Schemes.

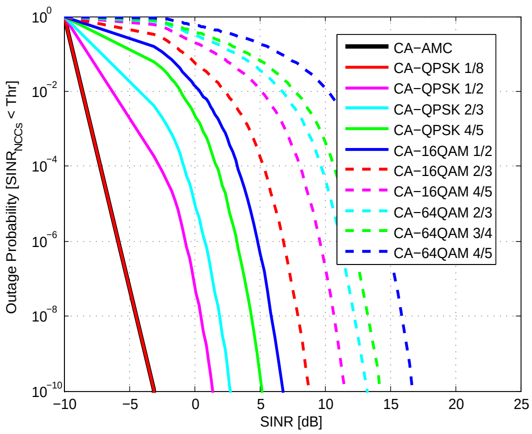

Figure 8: Outage Probability With CA Based On 5CCs Employing Common MCSs And AMC Scheme

5.3. CA based on different CCs

In this subsection, the performance of LTE-Advanced system based on 1CC, 2CCs, 3CCs, 4CCs and 5CCs are presented when AMC scheme is employed. Figure 9 shows the user's throughput enhancements that are achieved by CA technology based on different CCs over a single CC. The average user's throughput gains that are achieved by CA technique employing AMC scheme based on

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5CCs, 3CCs, 4CCs and 2CCs are 80%, 75%, 67% and 50% over a single CC employing AMC scheme, respectively. The presented results indicate that the incremental of aggregated CCs leads to increase the number of CCs that can be assigned to one user, whereby leads to enhance user's throughput.

Figure 10 shows the user's outage probability versus SINR that are resulted when LTE-Advanced system is implemented based on different numbers of CCs employing AMC scheme. It is seen that, there is a tangible reduction when the number of CCs is increased even if only two CCs are implemented in LTE-Advanced system. Therefore, when the number of CCs is going from $N = 1$ to $N = 2$ the total gain that can be achieved is approximately around 92%. Similarly, when the number of CCs is increased from $N = 1$ to $N = 3$, $N = 4$ and $N = 5$ the total gains that can be achieved are approximately around 93%, 96% and 98%, respectively in required SINR. That means, increasing the number of CCs results in an additional reduction in user's outage probability.

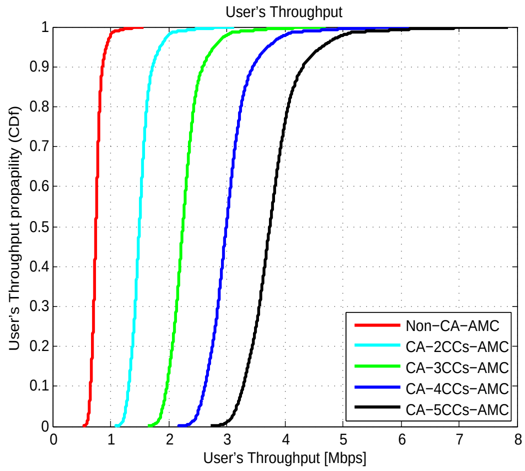

Figure 9: Throughput Versus SINR With CA And Non-CA Employs AMC Scheme.

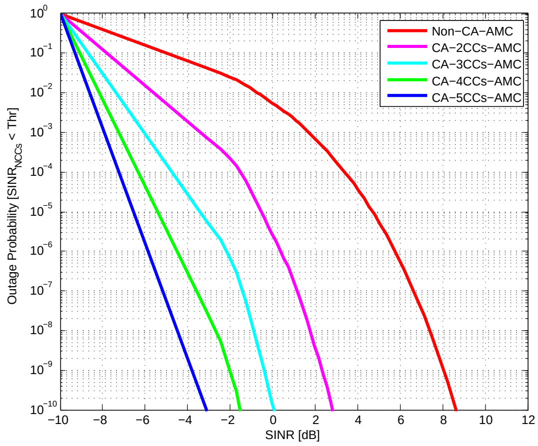

Figure 10: Outage Probability With Different CCs Employing AMC Scheme.

The presented results indicate that, both CA technique and AMC scheme based on the formulated mathematical expression enhance user's throughput and reducing its outage probability. CA technique enhances user's throughput by allowing the UE to communicate over multiple CCs simultaneously. That also leads to reducing disconnection probability since the UE has more available of CCs that can be used. Moreover, the increments of aggregated CCs lead to increase user's throughput and decreasing its outage probability, linearly. Similarly, considering AMC scheme contributes to enhancing the user's throughput and decreasing its outage probability by selecting the suitable MCSs which lead to provide higher data rate and avoiding the disconnection probability.

6. CONCLUSIONS

CA technology based on different numbers of CCs employing common MCSs and AMC schemes are implemented in LTE-Advanced system environment. Mathematical formulas for estimating user's throughput and outage probability have been simplified when CA technology employing AMC scheme is considered. The simulation results have shown that, the integration of CA technique with AMC scheme based on the formulated mathematical expression achieves a significant enhancement gains in terms of throughput enhancement and outage probability reduction as compared to other implemented scenarios. Thus, implementing CA technique employing AMC scheme increases connection reliability better than implementing single CCs either, employing common MCSs or AMC scheme.

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