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# LTE-A Multi-hop Network with Zero Link Overflow Utilizing OTFWC Scheduling

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**Abstract** Multi-hop Relay networks are proposed to fulfill the demanding coverage and capacity requirements for current applications in a cost efficient way. It can be used in IMT-Advanced technologies such as 3GPP LTE-Advanced. In this paper, Resource Blocks (RBs) proposed scheduling scheme is considered for zero multi-hop links overflow in Uplink LTE-Advanced. Then based on this scheduling scheme and other network assumptions the best Relay Station (RS) placement in the cell was estimated in order to improve LTE-A Uplink performance. The total LTE-A uplink Throughput, average throughput per user, and Mean File Transfer Time (MFTT) in the LTE-A network are considered as performance measures. This is done and measured as a function of different arrival rates of UEs assigned from random positions in the cell. Adaptive Modulation, and Coding (AMC) scheme with high order 2x4MIMO is used to maximize network throughput with low bit error rate (BER). Simulation results show effective improvement in uplink network performance using the proposed scheduling scheme and 2x4MIMO-AMC with RS at 50% of cell radius towards cell edge.

***Keywords:*** *LTE-A, Multi-hop Network, Uplink LTE-A, RS positioning, AMC, MIMO, link overflow*

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## 1. Introduction

LTE-Advanced offers better network performance than LTE Release 8 [1]. The most important key to current and future mobile generations is to propose more techniques that are able to provide higher data rate in which an especial attention is given to the uplink transmission merits such as higher throughput, higher network capacity, and lower Mean File Transfer Time (MFTT). To achieve this scope, a lot of scheduling schemes were proposed for LTE and LTE-A to make efficient use of frequency resources and reduce waste of them [1] and according to this, network performance will be improved.

Cellular networks with Single-Input-Single-Output (SISO) offer limited channel capacity and throughput. Nowadays, interactive services and applications produce high traffic which creates bottlenecks at radio interface. Multi Input Multi Output (MIMO) transmission mode uses multiple number of antennas at transmitter and receiving side. It can be a solution to improve network performance and solve bottleneck problem. High order 2x4MIMO was also used in LTE-A in parallel with adaptive Modulation And Coding (AMC) as candidate solution to improve total system performance [2]. Adaptive Modulation and Coding (AMC) is Link adaptation technique which provides modulation scheme and coding rate adaptation. For data rate improvement Higher order modulation schemes can be used, but there provide more probability of error. To overcome this problem higher SNR can be used with high order Modulation schemes. Also coding rate can be chosen to be proportional to SNR [2].

Another promising LTE-A Performance improvement technique is adding Relay station in the cell, which will help to increase the cell edge users (CEU) throughput which utilize the radio channel usage, it affects directly on cell center users (CCU) performance, total cell throughput, capacity, and maximum arrival rate [3], or alternatively; to extend the cell coverage area. Relays are relatively small nodes with low power consumption, which connect the core network through the eNB with wireless backhaul link, see Figure 1 [4].

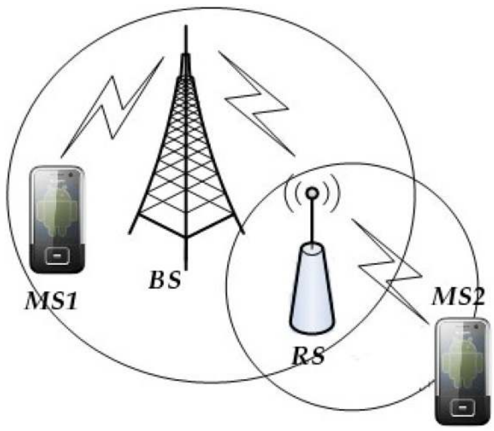


**Figure 1.** Multi-hop Relay Network

Most cellular networks research studies focus on downlink traffic scenarios, as most of wireless communications are a dominant traffic in downlink direction. However, in all 4G and all future networks this situation is changed, since popular file transfer and social network applications are supported as shown in Figure 2 [2]. This requires large uplink traffic to solve the two links bottleneck problem. So this thesis will focus on the LTE-A Uplink performance to overcome this problem.

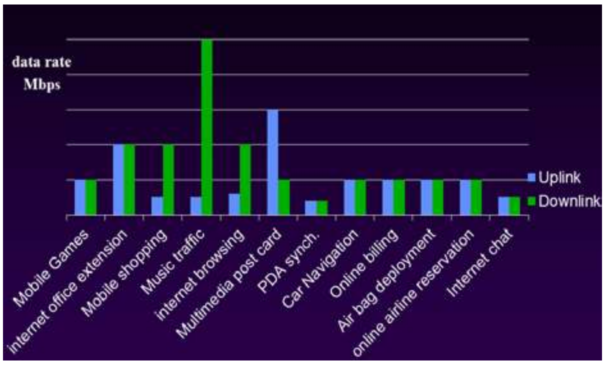


**Figure 2.** Uplink and downlink traffics for popular applications

LTE-A performance using relays have been considered in several studies. In [3], The RS placement and the bandwidth allocation were jointly optimized to maximize the downlink capacity for SISO relay networks. In [4], the optimal RS placement problem for coverage extension in downlinks SISO LTE-A was discussed. In [5] an adaptive MIMO detection algorithm for LTE-A system was proposed. In [6] LTE downlink switching scheme between multiplexing and diversity was discussed. There are few studies considered uplink performance in Multi-hop LTE-networks. In [7] the authors considered SISO LTE uplink relay positioning to enhance cell throughput using RS neglecting the effect of RS-eNB link on throughput. In [8] the authors considered LTE-A uplink performance as a function of relay position using Adaptive MIMO switching and AMC techniques.

There are two main objectives for the present work. The first one is, to propose scheduling scheme named Optimum Time Fair Work Conserving (OTFWC) for zero Asymmetric Multi-hop links overflow and Uplink performance improvement. The second objective is to study the effect of Relay station (RS) and its position on the uplink LTE-A performance, and to estimate the best position of RS in the cell based on this proposed scheduling scheme, and compare results with the standard FWC scheduling scheme.

The paper is organized as follows. Section 2 presents the LTE-A system features. Section 3 defines the LTE-A channel capacity model, and link adaptation. In section 4 the performance study was defined including the cell modeling, RS distance and uplink data rate estimation, the proposed scheduling scheme, and estimating the best location of RS in the cell. In section 5 Computer Simulations using Matlab are conducted. In section 6 results are presented. Finally, section 7 presents conclusions and future work.

# 2. LTE-A System Features

In this section, brief description of LTE time frequency structure, Physical RBs, UL Scheduling, Relaying in LTE networks, FWC with RS, MIMO, and HARQ are presented.

## 2.1. LTE Time Frequency Structure

In LTE and LTE-A; Resources are shared between Uplink and Downlink using either Frequency Division Duplex (FDD), or Time Division Duplex (TDD). Both of DL and UL has the same Frame structure in FDD mode as shown in Figure 3 [2].

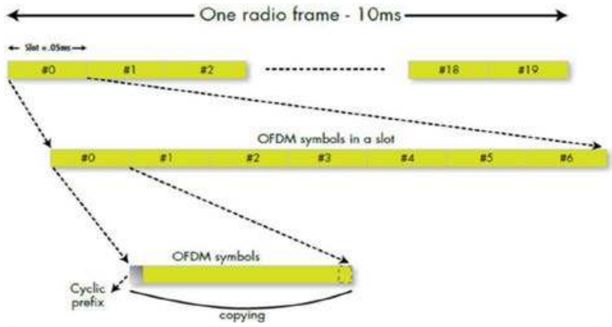


**Figure 3.** FDD-LTE Frame Structure

The LTE Radio Frame length is 1msec. This frame is divided into 10 sub-frames of length 1 msec each which also divided into two 0.5msec. But the minimum scheduling unit is the sub-frame of 1 msec. LTE transmission is performed using OFDM in DL, and SC-FDMA in UL. The advantage of SC-FDMA over OFDM is lower Peak-to-Average-Power ratios (PAPR), because only one bit is transmitted at a time, see Figure 4.

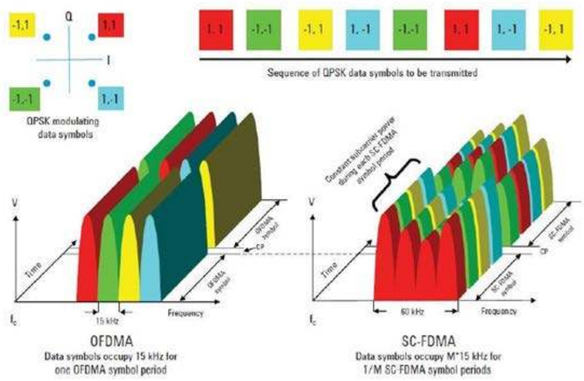


**Figure 4.** OFDMA and SC-FDMA in LTE

## 2.2. Physical Resource Blocks

In the SC-FDMA Uplink LTE and LTE-A, the physical resources take the form of a time-frequency grid as shown in Figure 5. The sub-carrier spacing for LTE is constant and equals 15kHz. The minimum defined resource unit called resource element (RE). It consists of one symbol in time domain and one sub-carrier in frequency domain. The number of symbols per sub-carrier during a slot of 0.5 msec is 7 using normal cyclic prefix or 6 using extended cyclic prefix. In the frequency domain 12 sub-carriers form a chunk carrier with sub-carrier spacing is 15 kHz as shown in Figure 2. The intersection between one slot in time domain (7 symbols) and one chunk carrier in frequency domain give block named Resource Block (RB). Since the minimum Transmission Time Interval (TTI) is one sub-frame, which consists of 2 slots, the minimum scheduling block comprises two RBs and named Scheduling Resource Block (SRB) or Physical Resource Block (PRB) [9].

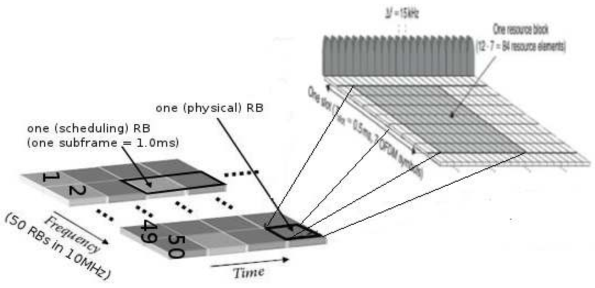


**Figure 5**. Uplink resource block

From the previous definition it can be concluded that in LTE-A, the Resource Block (RB) is defined to consist of the intersection of 12 consecutive SC-FDMA sub-carriers with180 kHz each, each subcarrier has 7 SC-FDMA symbols with total time 0.5ms for 10 MHz bandwidth, 50RBs are provided as shown in Figure 5 [9]. In addition a guard band of 1MHz is required [9].

## 2.3. LTE Uplink Scheduling Algorithms

LTE-A uplink scheduling have to utilize resource blocks (RBs) usage in such a way in order to maximize the total throughput and capacity, and to ensure the required Quality of Service (QoS) for voice calls and real time applications. Many different Uplink-scheduling algorithms are presented by vendors; the simplest Algorithm among all of them is channel-unaware Round Robin such as the Fair Fixed Assignment (FFA), and Fair Work Conserving (FWC). Another algorithm is channel-aware Maximum Added Value (MAV) which gives number of RBs to user according to its channel conditions [10].

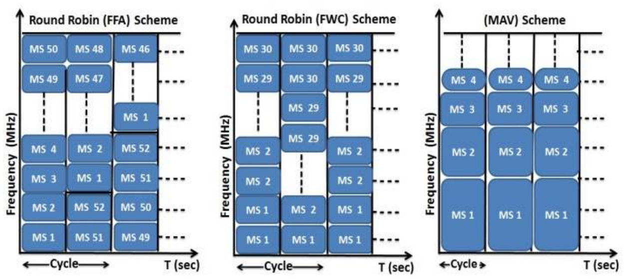


**Figure 6.** RB Scheduling schemes for uplink LTE-A

Figure 6 illustrate these three types of scheduling algorithms, FFA and FWC are resource-fair scheduling algorithms, while (MAV) is considered as resource-unfair scheduling algorithm. FWC provides better performance than FFA and MAV on average, this is due to the fact that it's RB scheduling is fair and channel unaware (less complexity and delay than channel aware). Therefore, the FWC scheduler will be modeled in the performance measurements in this paper.

## 2.4. Relaying in LTE and LTE-A networks

Adding Relay station in the cell is an efficient Performance improvement technique. This technique helps Cell Edge Users (CEUs) to increase their received SINR, and hence to utilize Resource Blocks (RBs) usage. This will directly improve Cell Center Users (CCUs) performance and will improve total cell throughput, and capacity [8]. RS can be used in service improvement, local extension, and coverage extension as shown in Figure 7 [8].

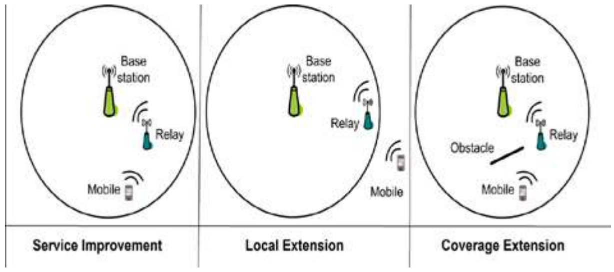


**Figure 7.** RS Applications

### 2.4.1. Relay Station (RS) Modes

Generally two Modes of relay nodes have been defined by LTE-Advanced and IEEE802.16j standards; there are Non-transparent Mode (Type 1 RS), and Transparent Mode (Type 2 RS) [8,9].

Type-1 RS act as BS for the connected UEs by transmitting reference signal and control information. It uses centralized or distributed scheduling mode, as scheduling is done in BS and RSs. It has its own CID, see Figure 8 [8,9].

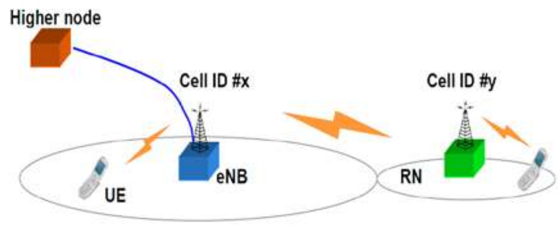


**Figure 8.** Non-transparent Mode RS

Transparent RS increases the CEUs throughput leading to total throughput incensement within the eNB coverage area as shown in Figure 9. This type of RSs has the same CID as the eNB and can't forward frame information or control signal to eNB, so it can't be used for coverage extension. It supports two hop networks, and centralized scheduling only as scheduling is done only in eNB [10].

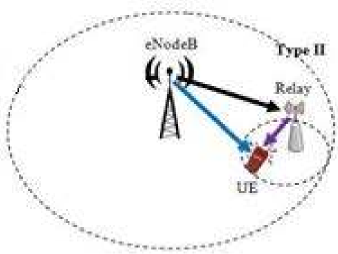


**Figure 9.** Transparent Mode RS

### 2.4.2. Relay Transmission Schemes

RSs are divided into many types according to its strategy, i.e.: Amplify and Forward (AF) RS, Decode and Forward (DF) RS, and Demodulate and Forward (DMF) RS.

AF Relay acts as a layer 1 repeater. It amplifies the received signal from source, and then forwards it to destination as shown in Figure 10 [8,10]. The main advantages of this relay strategy are simplicity and very low delay. But the disadvantage of it that it amplifies the received noise also. The AF relay is named also non-regenerative repeater, as no regeneration process is done in this strategy [10].

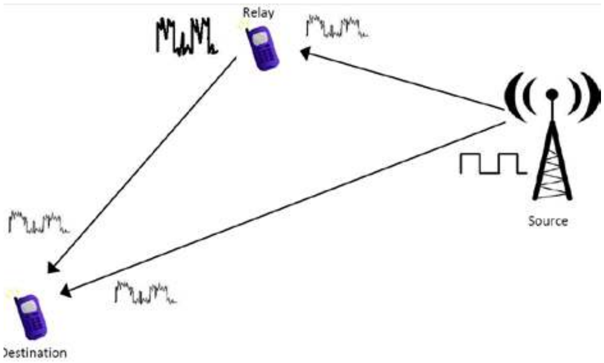


**Figure 10.** Amplify and Forward RS

In DF Relay strategy, the received signal from source will be decoded and amplified, and then re-encoded before sending to destination as shown in Figure 11 According this process, the DF can be called Regenerative relay. The main advantages of this relay strategy are that it removes the noise before resending signal, and it can be used in more than two hops as it considered being layer 2 relay. On the other hand, if the channel is very poor, the relay will decode the received signal in more time, and hence it will cause higher delay time [10].

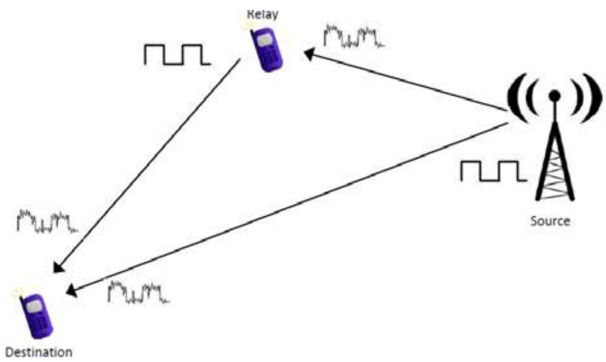


**Figure 11.** Decode and Forward RS

The relay station in DMF strategy demodulate the received signal from the source (eNB, or UE), and then resend it to destination after modulating it. This operation is performed without any decoding or encoding process, and hence the channel errors can't be corrected. This strategy takes less processing time than DF relaying and less complexity, but has more error probability [10].

### 2.4.3. Relay Station scenarios

According to transmission scenario, Relay Stations (RSs) are divided into two types; Stationary RSs, and Mobile RSs.

Stationary Relay Stations may be also called Fixed Relay Nodes (FRNs). FRNs are installed near cell edge to increase the cell coverage and the cell edge users throughput [9]. However, the performance improvement in the system occurred by RS is depending on the location of the RS within cell size as shown in Figure 12.

Moving Relay Node (MRN) has the same characteristics as FRNs, but the difference here is works while moving with the users as shown in Figure 12. MRN is new technology that can serve vehicular users at LTE-A network to increase throughput for passengers in buses or trains over rural area in cases where FRNs are not.

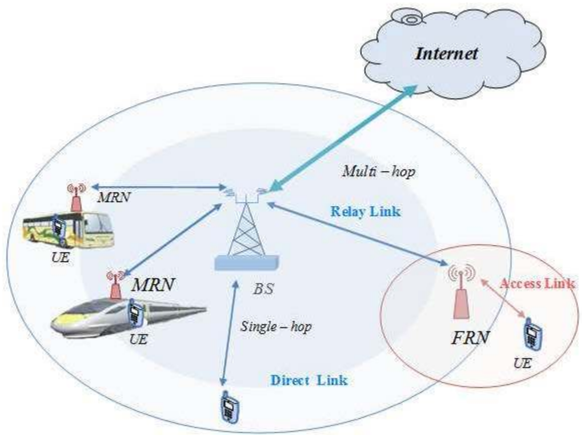


**Figure 12.** Relay Station scenarios

### 2.4.4. RS-eNB Link Types

The RS-eNB link can be Fixed-Line, or Radio Link as shown in Figure 13. The Fixed Line Connection has less errors and more SINR than RF-connection. But in so far RS, the wireless RF-connection will be better and easier.

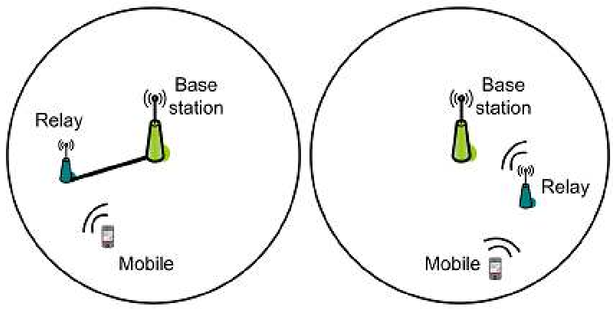


**Figure 13.** RS Link Types

## 2.5. FWC Scheduling using Relay Station

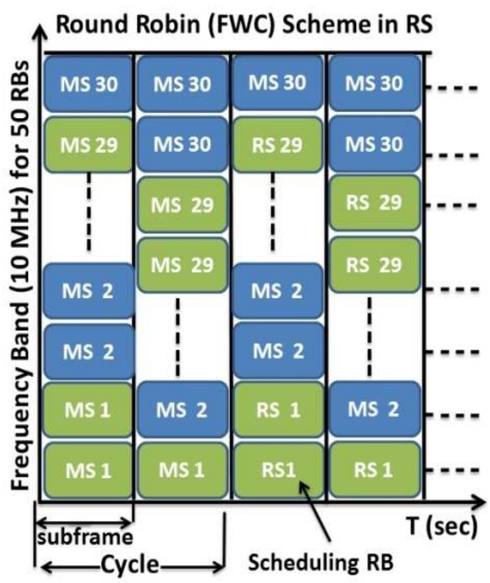


**Figure 14**. FWC Scheduling with RS

FWC Scheduling scheme using RS is similar to FWC without RS but a little more complex than it. To describe how it works, assume that there are 30 active MSs scheduled using FWC as shown in Figure 14. MS1, and 29 are CEUs which transmit data to eNB via RS using two cycles. The cycle is defined as sub-frame or more according to scheduling scheme. In the first cycle MSs 1 and 29 use the scheduled RBs to transmit data to RS, and in the second cycle the RS resend data to eNB.

## 2.6. MIMO Technique

AMC causes performance improvement in LTE system. MIMO can also improve network performance. There are different methods to make MIMO according to transmitting and receiving antennas configuration; as transmit diversity (TD), receive diversity (RD), and spatial multiplexing (SM). In transmit diversity the same information can be sent from multiple antennas using Multiple input single output method (MISO) [14]. In Receive diversity multiple antennas are used in receiving side using Single Input Multiple Output (SIMO) method. TD and RD improve SNR, and this affects the throughput indirectly. In Spatial Multiplexing the throughput can be increased using number of transmitting antennas which transmit independent data to increase transmitted data rate [14].

## 2.7. Hybrid Automatic Repeat Request (HARQ)

It is a technique used in LTE for detecting and correcting errors at receiver side. It consists of combining of two techniques, Forward Error Correction (FEC), and Automatic Repeat Request (ARQ) [11]. In ARQ the detected errors in the received frames can't be corrected, but it send a request to transmitter to repeat sending this frame. The FEC sends some additional correction bits with the original data in order to enable detecting and correcting the errors at the receiver [11].

# 3. System Model

This section presents the considered Channel capacity model, and link adaptation.

## 3.1. LTE-A Uplink Channel Capacity Model

The maximum Throughput that can be sent in one time transmission interval (TTI) can be obtained using Shannon's theory (1) for the maximum capacity of a communication channel [8].

$$C = B \times \log_2(1 + SNR) \qquad (1)$$

Where C is the maximum capacity in bits/second, B is the channel's bandwidth; SNR is the total received signal to noise power. But in [12,13] the authors used different modulation and coding schemes to estimate the LTE-A spectral efficiency, and the results was lower than theoretical spectral efficiency, and from their results LTE-A uplink channel capacity model was:

$$\frac{R_b}{B} = \eta_{BW} \times \log_2\left(1 + \eta_{SNR} \times SNR\right); SNR \le SNR_{\max}$$
$$or: \frac{R_b}{B} = \frac{R_b}{B}_{\max}; SNR \ge SNR_{\max} \qquad (2)$$

Where $\eta_{BW,r}$ and $\eta_{SNR,r}$ are bandwidth and SNR efficiencies respectively with values shown in table 1. as a function of number of transmitting antennas for uplink LTE-Advanced.

**Table 1. SNR and BW efficiencies**

| Number of trans. antennas | $\eta_{BW,r}$ | $\eta_{SNR,r}$ |
|---|---|---|
| 1 | 0.4 | 0.91 |
| 2 | 0.38 | 1.05 |
| 3 | 0.37 | 1.11 |
| 4 | 0.34 | 1.24 |

## 3.2. Link Adaptation

Adaptive Modulation and Coding (AMC) is Link adaptation technique which provides modulation scheme and coding rate adaptation. For data rate improvement higher order modulation schemes can be used providing more probability of error. To overcome this problem higher SNR can be used with high order Modulation schemes. Also coding rate can be chosen to be proportional to SNR. In [12], the authors generated the BER-SNR curves for the 13 different MCSs available in the LTE standard for BER = 1e-3 for Voice, video (live streaming), interactive gaming. In the LTE uplink AMC schemes are used according to CQI from 1 to 11 [13] as shown in Table 2. 2x4 MIMO is used in parallel with AMC switching to maximize the cell throughput and reduce MFTT with improved coverage [8].

**Table 2. AMC-CQI thresholds**

| CQI | Max. SNR | Modulation | Code rate |
|---|---|---|---|
| 1 | -6 dB | QPSK | 1/8 |
| 2 | -4 dB | QPSK | 1/5 |
| 3 | -2.1 dB | QPSK | 1/4 |
| 4 | 0 dB | QPSK | 1/3 |
| 5 | 2.1 dB | QPSK | 1/2 |
| 6 | 3.8 dB | QPSK | 2/3 |
| 7 | 6 dB | QPSK | 4/5 |
| 8 | 7.8 dB | 16QAM | 1/2 |
| 9 | 9.9 dB | 16QAM | 2/3 |
| 10 | 12.6 dB | 16QAM | 4/5 |
| 11 | 15 dB | 64QAM | 2/3 |

# 4. Performance Study

A single LTE-A/E-UTRAN cell in urban area is considered with network parameters as given in table 3. Study is carried out for Uplink. The cell has one RS, whose position is variable and its best position in the cell is evaluated for higher Throughput, and lower MFTT, and results are compared with theoretical estimated optimum placement. Cost-231hata path loss model is used [15], and [16]. Proposed OTFWC scheduling scheme is used in the RS, and results compared with the standard FWC scheduling scheme. New file transfers from random users at random locations in the cell, are initiated with wide range of arrival rates λ [16]. High order 2x4 MIMO technique is used in simulations [17].

**Table 3. LTE-A Network parameters**

| Network Parameter | Value |
|---|---|
| Cell radius | 1000 m |
| UE Maximum Trans. Power | 23dBm |
| Bandwidth of 1 PRB (W) | 180 KHz |
| Total bandwidth | 10MHz |
| Number of RBs in10MHz | 50 RBs |
| Subcarrier spacing | 15KHz |
| noise spectral density (No) | -174dBm/Hz |
| Noise Figure of RSs (NF) | 5 dB |
| Max SNR for uplink | 15dB |
| Carrier Freuency (Fc) | 2.6 GHz |
| Transmission Time Interval | 500 msec |

## 4.1. Cell Modeling

The cell is divided into number of zones (N) and number of sectors (K) as shown in Figure 15. The intersection between each zone and sector named geometrical sector or segment, so the cell is divided into (N.K) segments. Each new UEs will be positioned on geometrical sector with position (i,j) where (i=1,2,….,N) and (j=1,2,….,K). Uniform random distribution for placing the UEs is considered. Calling the radius to zone x $r_x$ so the zone radius can be calculated as follows:

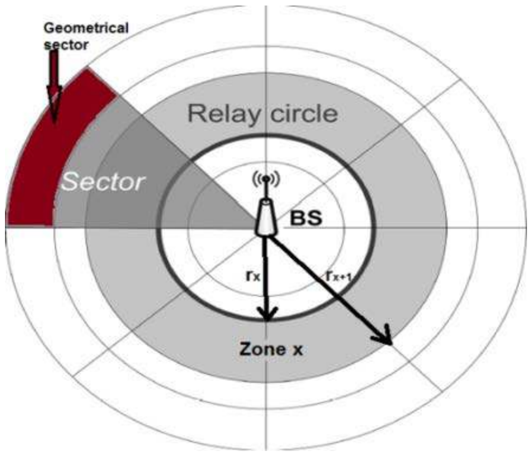


**Figure 15**. Cell with N-zones and K-sectors

$$\int_{r_x}^{r_{x+1}} 2\pi r.dr = c \tag{3}$$

With $r_o = 0$ and C=surface per zone

$$\pi r_{x+1}^2 - \pi r_x^2 = C \tag{4}$$

$$r_{x+1} = \sqrt{\frac{C}{\pi} - r_x^2} \tag{5}$$

Where

$$C = \pi r_{cell}^2 / Z_{total} \tag{6}$$

Where $r_{cell}$ is the cell radius and $Z_{total}$ is the total number of zones per cell.

## 4.2. Estimating Distance from UE to RS

As shown in Figure 16, the distance between UE and RS may be expressed as:

$$d^2 = r_1^2 + r_2^2 - 2 \times r_1 \times r_2 \times \cos\varphi \tag{7}$$

Where: $r_1$ is the distance between UE and eNB, $r_2$ is the distance between RS and eNB, and $\varnothing$ may be obtained as shown in (8),

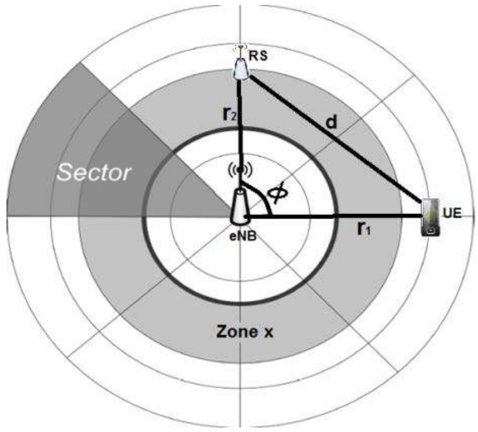


**Figure 16**. Estimating distance to relay

$$\varphi = \frac{2\pi}{K} \times \left| j_{RS} - j_{UE} \right| \tag{8}$$

K is assumed to be total number of sectors per cell which have to be very large to describe the UE and RS position more accuracy, $j_{RS}$ the number of sector where the RS is placed in the cell, and $j_{UE}$ the number of sector where the UE is placed in the cell.

## 4.3. LTE-Advanced Uplink Throughput

The throughput of a UE in a physical segment at distance x from the (BS or RS) given $n_t$ transmitting antennas and $n_r$ receiving antennas is expressed as:

$$C(SNR(x)) = \mu_{\mathrm{BW}} \times \min(n_t, n_r) \times RB \times W \times \log_2\left(1 + \mu_{\mathrm{SNR}} \times \frac{n_r}{\min(n_t, n_r)} \times SNR(x)\right) \tag{9}$$

$$SNR(x) = \frac{P_{T\_\max}}{N_o \times W \times RB \times L(x)}; SNR \le SNR_{\max} \quad or: SNR(x) = SNR(x)_{\max}; SNR \ge SNR_{\max} \tag{10}$$

RB is defined as the number of used resource blocks scheduled to each user according to used FWC scheduling scheme, path loss L(x), W is 180kHz bandwidth, No is the noise power spectral density. All UEs in the cell are assumed to have the same maximum transmit power $P_{T\_ma}$. However, using power control:

$$P_{T\_new} = SNR_{\max} \times N_o \times RB \times L(x) \tag{11}$$

Where

$$P_{T\_new} \prec P_{T\_new} \tag{12}$$

### 4.3.1. Throughput Estimation without Relay

The data rate of a UE in a segment at distance r1 from the BS

$$R = C\left(\mathrm{SNR}\left(\mathrm{r1}\right)\right) \quad (13)$$

Where the SNR can be estimated as:

$$SNR(r_1) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r_1)}; SNR \le SNR_{max} \quad (14)$$
$$or: SNR(r_1) = SNR(r_1)_{max}; SNR \ge SNR_{max}$$

Where $P_{UE\_max}$ is the maximum transmit power of the UE.

### 4.3.2. Throughput Estimation Using Relay for Asymmetric links with FWC

Cell Center users are users who don't need relay station and transmit data to eNB directly with data rate higher than when using RS. The data rate of a CCU in a segment at distance r1 from the BS is estimated in (15),

$$R(CCU) = C(SNR(r_1)) \quad (15)$$

Cell Edge users are users who need RS to transmit data to eNB with higher data rate than when transmit directly. The data rate of CEUs can be defined as the bottleneck of the UE-RS link and RS-eNB link as:

$$R(CEU) = \frac{1}{2}\min\left[C(SNR(d)), C(SNR(r_2) + SNR(r_1))\right] \quad (16)$$

The constant (1/2) is placed in (18) as the RS operates in half duplex technique. The CEU-MS use the scheduled RBs to transmit data to RS for a cycle, and in another cycle the RS resend CEU's data to eNB. According to this the half of total data rate is achieved as shown in Figure 17. The SNR of these two links have to be obtained as (19), (20) respectively.

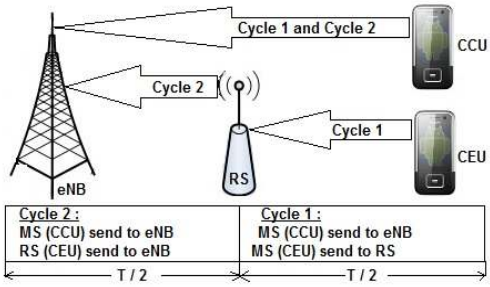


**Figure 17**. LTE-A UL FWC using RS

$$SNR(d) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(d)}; SNR \le SNR_{max} \quad (17)$$
$$or: SNR(d) = SNR(d)_{max}; SNR \ge SNR_{max}$$

$$SNR(r_2) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r_2)}; SNR \le SNR_{max} \quad (18)$$
$$or: SNR(r_2) = SNR(r_2)_{max}; SNR \ge SNR_{max}$$

## 4.4. Proposed OTFWC Scheme for Zero Link Overflow

In order to avoid wasting resource blocks and data overflow in multi-hop links, the amount of data transferred from MS to RS have to be equal the data transferred from RS to eNB. This can be done using modified FWC scheduling named Optimum Time Fair Work Conserving (OTFWC) with MS-RS transmission in (ψ.T) cycles, and RS-eNB transmission in ((1-ψ).T) cycles as shown in Figure 18, and Figure 19, where (ψ.T) is inverse proportional to MS-RS link data rate, and ((1-ψ).T) is inverse proportional to RS-eNB link. Using OTFWC (18) will be modified to be as follows:

$$R(CEU) = \min\begin{bmatrix} \psi C(SNR(d)), (1-\psi) \\ C(SNR(r_2) + SNR(r_1)) \end{bmatrix} \quad (19)$$

With

$$\psi^* C(SNR(d)) = (1-\psi^*) C(SNR(r_2) + SNR(r_1)) \quad (20)$$

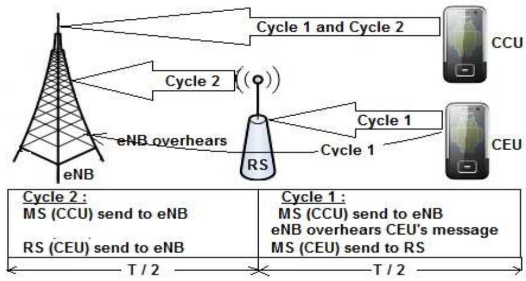


**Figure 18**. OTFWC cycles using RS

And then the optimum Time for the 1'st cycle will be:

$$\psi^* = \frac{C(SNR(r_2) + SNR(r_1))}{C(SNR(d)) + C(SNR(r_2) + SNR(r_1))} \quad (21)$$

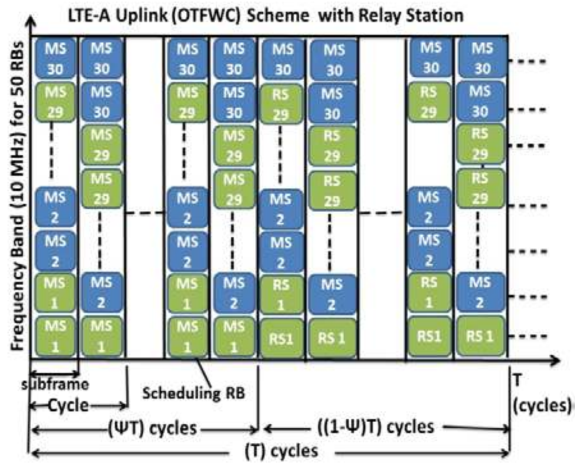


**Figure 19**. OTFWC transmission using RS

And according this the total CEU data rate using optimum time will be as follows:

$$R(CEU) = \left[\frac{C(SNR(d)) \times C(SNR(r_2) + SNR(r_1))}{C(SNR(d)) + C(SNR(r_2) + SNR(r_1))}\right] \quad (22)$$
$$= \left[\frac{C_1 \times C_2}{C_1 + C_2}\right]$$

From Figure 18, and Figure 19 it can be seen that (T), (ψT), and ((1- ψ)T) are number of cycles and have to be integers. So practically; ( 24) will modified to be as follows

$$R^*_{Modified}(CEU) = \max\begin{pmatrix} \min\left(\frac{\lfloor \psi^* \times T \rfloor}{T} \times C_1, \frac{\lceil (1-\psi^*) \times T \rceil}{T} \times C_2\right), \\ \min\left(\frac{\lceil \psi^* \times T \rceil}{T} \times C_1, \frac{\lfloor (1-\psi^*) \times T \rfloor}{T} \times C_2\right) \end{pmatrix} \quad (23)$$

Where

$$T = \frac{File\_size}{R^{*}(CEU)} \text{Cycles} \quad (24)$$

### 4.5. Estimating the Best RS Placement

Using OTFWC scheme, the CEU's data rate will be as follows:

$$R(CEU) = \frac{C_1 \times C_2}{C_1 + C_2} \quad (25)$$

For maximum capacity

$$R(CEU)_{\max} = \frac{C_1^{*}}{2} = \frac{C_2^{*}}{2} \quad (26)$$

So:

$$d = r_2^{*} \quad (27)$$

And from equation 9 the following equation can be estimated:

$$r_2^{*} = \sqrt{r_1^{2} + r_2^{*2} - 2 \times r_1 \times r_2^{*} \times \cos\varphi} \quad (28)$$

$$r_2^{*} = \frac{r_1}{2 \times \cos\varphi} \quad (29)$$

Equation 31 is formulated for 1RS located at distance r2 from eNB and 1UE located at distance r1 from eNB. For n- CEUs uniformly distributed, Using Monte Carlo Integration

$$r_2^{*} = \frac{E[r_1] \pm \sqrt{E[r_1^{2}] - \left(E[r_1]\right)^2}}{2 \times \cos(E[\varphi] \pm \sqrt{E[\varphi^{2}] - \left(E[\varphi]\right)^2})} \quad (30)$$

Where the condition for using RS for CEUs is:

$$\frac{C(r_2^{*})}{2} > C(r_1) \quad (31)$$

Assuming uniform distribution of CEUs in the cell, with cost231hata model, the optimum RS distance from eNB will be

$$r_2^{*} = 0.76 \times \left( \left( \frac{10^{6} - r_{1\min}^{2}}{2 \times (1000 - r_{1\min})} \right) \pm \sqrt{\left( \frac{10^{9} - r_{1\min}^{3}}{3 \times (10^{3} - r_{1\min})} \right) - \left( \frac{10^{6} - r_{1\min}^{2}}{2 \times (10^{3} - r_{1\min})} \right)^{2}} \right) \quad (32)$$

Where

$$r_{1\min} = \log^{-1} \frac{\left( \begin{array}{l} \dfrac{\mu_{SNR} \times P_{RS_{\max}}}{N_o \times W \times \left( \sqrt{\left( \begin{array}{l} 1 + \mu_{SNR} \\ \times \dfrac{P_{UE_{\max}}}{N_o \times W \times L(r_2^{*})} \end{array} \right)} - 1 \right)} \\ -46.3 - 33.9 \times \log(f) \\ +13.82 \times \log(h_b) \\ +3.2(\log(11.75 \times h_m))^2 - 4.97 - 3 \end{array} \right)}{-(44.9 - 6.55\log(h_b))} \quad (33)$$

From (32), and (33); the optimum RS placement can be estimated to be at $r_2^{*} = 482m$ which will be approximately at 50% of cell radius towards cell edge.

## 5. Simulations Environments Setup

First the cell is modeled with N-zones and K-sectors, N and K are chosen to large enough to establish a sharp site for each UE, RS, and the honor eNB. The performance measurements were done for each arrival rate (λ) value from 1 to 18 with steps of λ=0.25. Simulations were done also with different positions of RS in the cell to estimate the best location according to total cell throughput to be compared with theoretical results, and to compare performance with that without relay station.

In second step a loop is entered with one new iteration for each time step among all of simulation time. For each time step a random number of new UEs according to given arrival rate are assigned to random segment and added to queue. All UEs were classified whether there are cell edge users (CEU) or cell center users (CCU). According to given scheduling scheme (FWC, or OTFWC) each UE begins to transmit file directly to eNB if it's CCU or via RS if it's CEU, when the file is completely transmitted; the UE is removed from the queue. At the end of simulation time the total cell throughput is obtained according to total transmitted files size and total required time for transmission, and from these results the maximum capacity and arrival rate will be obtained.

The simulations were done for 2x4MIMO with FWC scheduling, and 2x4MIMO with OTFWC scheduling to compare performance. Finally, the previous simulations were repeated but with less number of zones and sectors, since many UEs need to arrive in a segment to obtain mean file transfer time in the cell. In this step as the simulation time is finished, the total upload time is divided by the total amount of complete files transmitted to obtain the mean file transfer time per segment, and then per cell. This step also was done using 2x4MIMO with FWC scheduling, and 2x4MIMO with OTFWC scheduling, to obtain the impact of different schemes on MFTT.

## 6. Results and Discussions

Figure 20, Figure 21, Figure 22 and Figure 23 illustrate the LTE-Advanced total Uplink throughput for 2x4MIMO with FWC scheduling, 2x4MIMO with OTFWC scheduling, average user throughput for 2x4MIMO with FWC, and 2x4MIMO with OTFWC scheduling; respectively. This is done using Cost-231hata model without RS and with RS located at different positions.

From Figure 20, Figure 21, Figure 22 and Figure 23 it can be seen that the maximum capacity was achieved using RS 50% of cell radius. Therefore, it may be the best position for RS placement in LTE-A cell. However the maximum capacity using RS at best position is increased by less than 10% of the capacity without RS. This may be considered as marginal increase since the total throughput is mainly affected by CCUs, beside the CEUs effect.

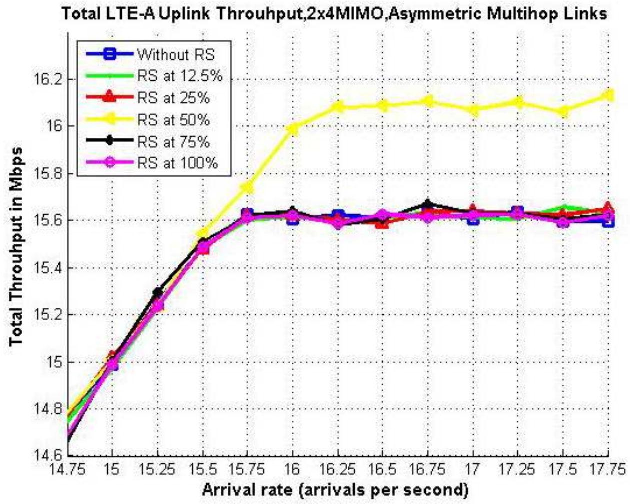


**Figure 20**. UL throughput, 2X4MIMO, FWC

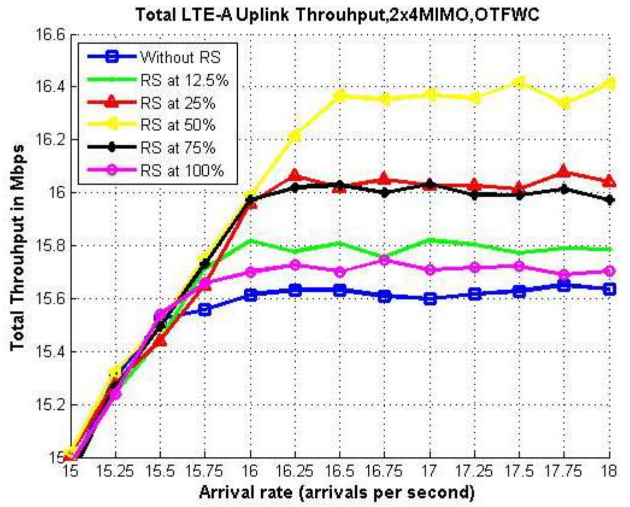


**Figure 21**. UL Throughput, 2X4MIMO, OTFWC

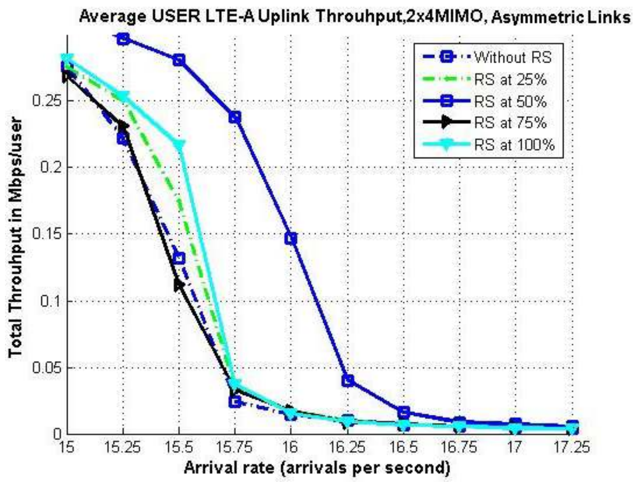


**Figure 22**. Average User Throughput, 2X4MIMO, FWC

Also Figure 23, and Figure 24 show that the user data rate is decreased as the arrival rate increase because in this case each user will be assigned to less number of RBs. And the minimum data rate was achieved by each user as system reaches to maximum capacity, because in this case each user will be assigned to only one RB.

Moreover, from these figures it can be seen that the maximum throughput, Capacity, and arrival rate is achieved using high order 2X4MIMO with proposed OTFWC scheduling schemes.

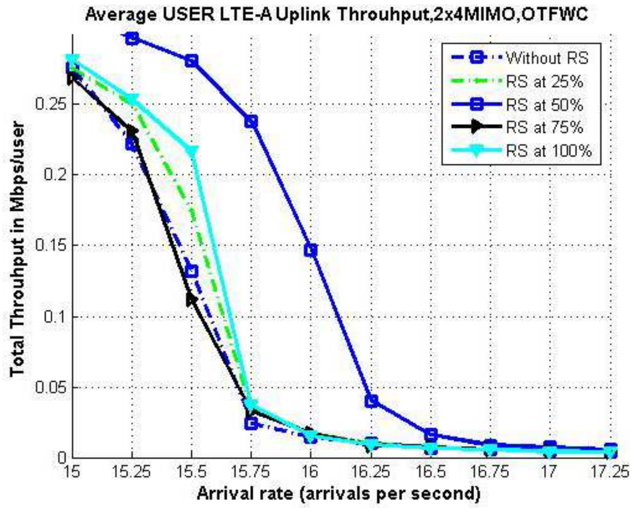


**Figure 23**. Average User Throughput, 2X4MIMO, OTFWC

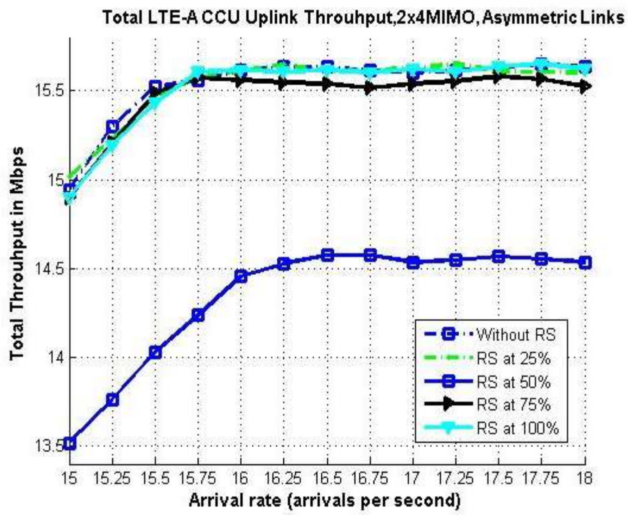


**Figure 24**. Uplink CCU Throughput, 2x4MIMO, FWC

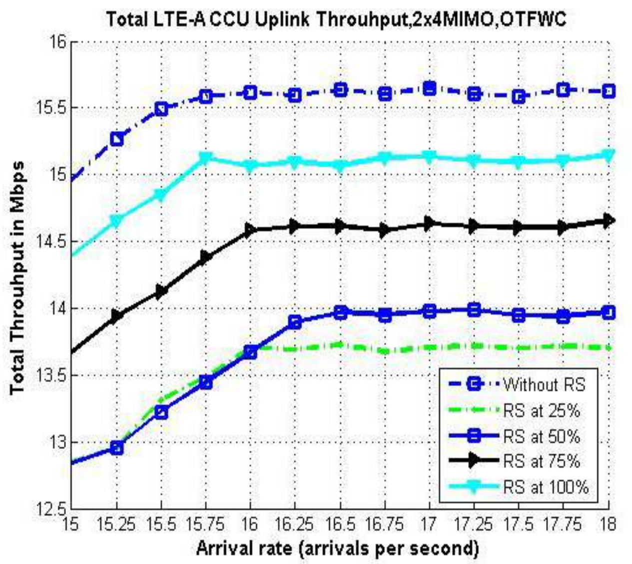


**Figure 25**. Uplink CCU Throughput, 2x4MIMO, OTFWC

Figure 24, Figure 25, Figure 26, and Figure 27 show the RS and its position effect on all UEs in the cell using

FWC, and OTFWC; respectively. These figures show that adding RS in the network and changing its position affects the CEUs more than CCUs. But the throughput gain was very low as the sum of CCUs and CEUs (the total throughput) will basically affected by CCUs. Another observation that CCUs have better performance when no RS is used.

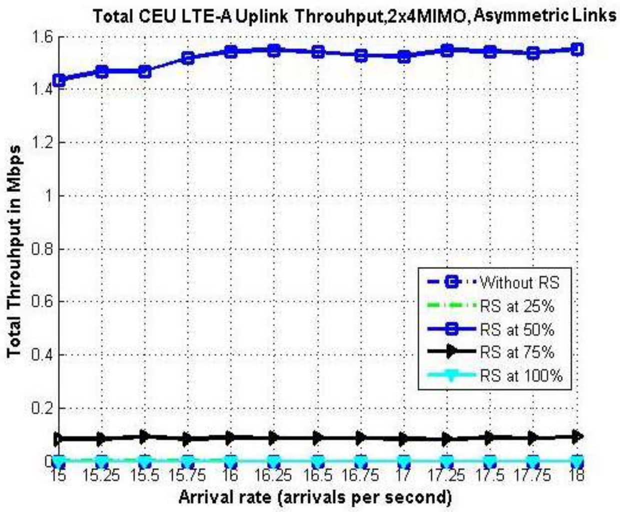


**Figure 26**. Uplink CEU Throughput, 2x4MIMO, FWC

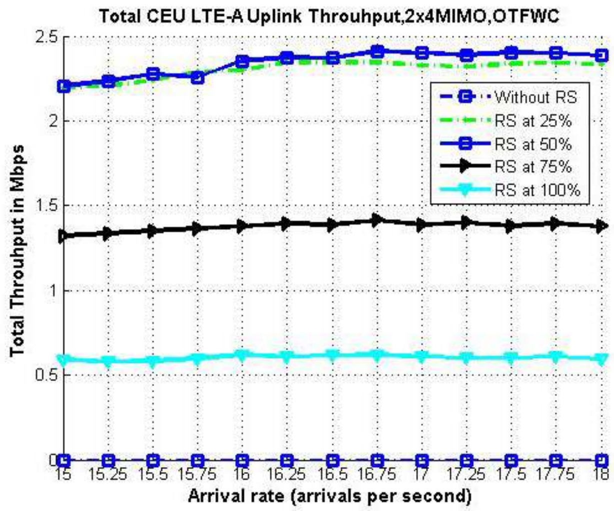


**Figure 27**. Uplink CEU Throughput, 2x4MIMO, OTFWC

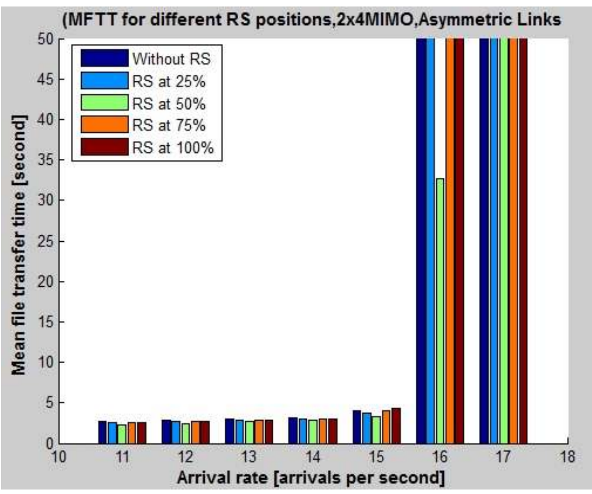


**Figure 28**. MFTT per cell, 2X4MIMO, FWC

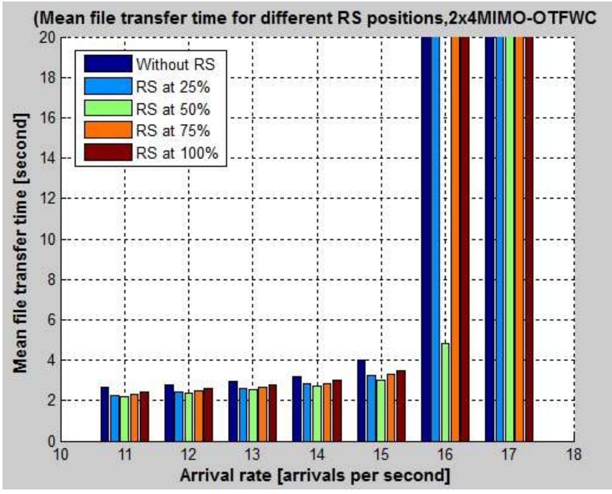


**Figure 29**. MFTT, 2X4MIMO, OTFWC

Figure 28, and Figure 29 show the Mean file transfer time MFTT (sec per 1Mbit) for 2X4MIMO with FWC scheduling, and with OTFWC scheduling; respectively. The two figures show that the MFTT for RS at 50% is always less than all other cases. Moreover, the lowest MFTT was achieved using 2X4MIMO with OTFWC. The mean file transfer time goes infinite for 2X4MIMO with FWC at $\lambda$=16 arrivals per second, for 2X4MIMO with OTFWC at $\lambda$=16 arrivals per second.

However for 2X4MIMO using OTFWC with $\lambda$=16 arrivals per second, RS at 50% don't saturate, whereas the MFTT schemes mentioned above reach saturation. So it can be concluded that 2X4MIMO using OTFWC has the best performance according to MFTT.

# 7. Conclusions and Future Works

This paper has investigated the uplink performance improvements using Multi-hop Relay technology with based on 2X4MIMO in LTE-A networks. This research mainly answers two questions; where a relay station's would be positioned in the LTE-A cell for best performance, and how to improve network performance or eliminating the asymmetric multi-hop links data overflow. For this study, a model has been developed for an urban area single LTE-A cell. The cell is split into equally sized segments. In order to calculate the data rate of the UEs; Adaptive Modulation and Coding (AMC) with (2X4MIMO) is considered. Furthermore, the resource blocks allocation was made regarding the UL scheduling scheme. The channel-unaware Fair Work Conserving (FWC) uplink RB scheduler was used, and OTFWC scheduling scheme was proposed for zero Multi-hop links overflow.

Total and average LTE-A uplink throughput and system capacity was investigated as a function of arrival rates for the three scenarios. It was shown that under empirical path loss model like cost-231hata the RS placed at 50% of the cell radius (counted from the center towards the cell edge) provide the highest total uplink throughput, and also provides the highest system capacity. Also when the mean file transfer time (MFTT), it can be concluded that the best place to locate an RS is at 50% of cell radius. This best place is as the best place calculated by equations. Moreover, it can be concluded that OTFWC can overcome data overflow resulted from asymmetric links, so it can increase CEUs throughput resulting a significant increase in network capacity. Also it can be concluded that by using the 2X4MIMO; CEUs achieve full use of available scheduled RBs. According to this; their throughput will be increased, and MFTT in the cell will be decreased.

Future study should be done to investigate the effect of (1) incorporating multiple RSs into the cell, (2) take interference from other cells into account, (3) using other types of schedulers, (4) formulate optimization problem using the current network assumptions using joint nonlinear optimization, (5) adding some LTE-A features to enhance performance like carrier aggregation, Coordinated Multipoint reception for uplink, and (6) Using moving Relay station (MRS).

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