Uplink LTE-A Performance Improvement Using Synchronous Direct and Multi-hop Transmission

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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, LTE-A Uplink performance will be improved using Synchronous direct and multi-hop transmission (SDMT) between user equipment and Base Station. Also the effect of adding RS to the network and its position will be discussed. 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 LTE-A uplink performance improvement using 2x4MIMO-AMC and SDMT scheme with RS at 50% of cell radius towards cell edge.

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1. Introduction

LTE-Advanced offers better network performance than LTE Release 8 [1]. 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. This requires large uplink traffic to solve the two links bottleneck problem. So this paper will focus on the LTE-A Uplink performance to overcome this problem.

Adding Relay station in the cell is an efficient LTE-A uplink Performance improvement technique. This technique helps Cell Edge Users (CEUs) to utilize Resource Blocks (RBs) usage. This will directly improve Cell Center Users (CCUs) performance and will improve total cell throughput, and capacity [2].

Cellular networks with Single-Input-Single-Output (SISO) have small channel capacity. Channel capacity can be increased using Multi Input Multi Output (MIMO) in which multiple number of antennas are used at transmitter and receiving side [2] creating Spatial Diversity and Multiplexing.

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 three main objectives for the present work. The first one is, to propose transmission scheme named Synchronous Direct and Multi-hop Transmission (SDMT) for LTE-A Network Uplink performance improvement, and to compare results with both standard Multi-hop transmission and transmission without Relay station (RS). The second objective is to study the effect of RS and its position on the uplink LTE-A performance. And the third objective is to study the effect of using high order 2x4MIMO on uplink performance in LTE-A network.

2. LTE-A System Features

In this section, brief description of Physical RBs, UL Scheduling, Relaying, and MIMO are presented.

2.1. Physical Resource Blocks

In LTE-A the radio frequency spectrum is distributed for multiple users using SC-FDMA in uplink. 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 1 [9]. In addition a guard band of 1MHz is required [9].
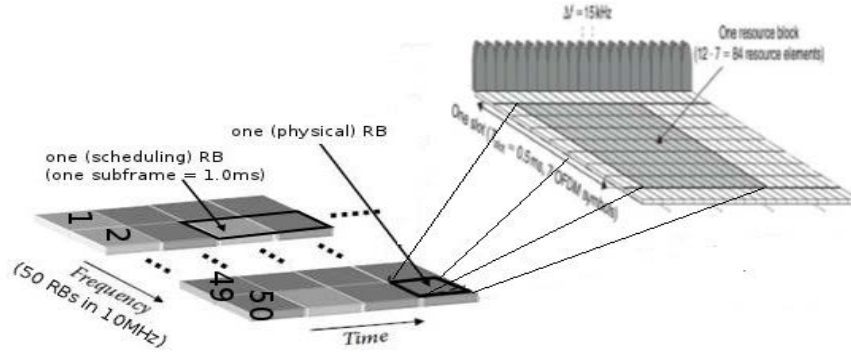

Figure 1. Uplink resource block

2.2. LTE Uplink RB Scheduling Algorithms

LTE-A uplink scheduling have to utilize resource blocks (RBs) usage in such a way in order to maximize the spectral efficiency, total throughput and network capacity. Many different RB-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].
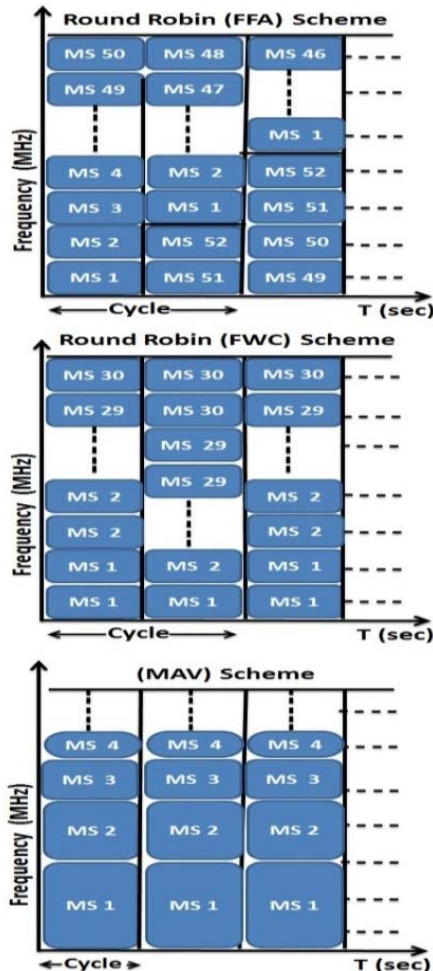

Figure 2. LTE-A UL Scheduling schemes

Figure 2 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.

2.3. LTE-A Relaying

Relaying in LTE-A Networks can be classified into two types; Transparent (Type2), and Non-transparent (Type1). The main difference between the two types is how to manage the resources. Non-transparent RS acts as small eNB sending control messages and cell IDs, It improves CEUs throughput. This type is used to improve overall system capacity [11]. Transparent RS is used to help UE within the coverage of eNB to improve his service.
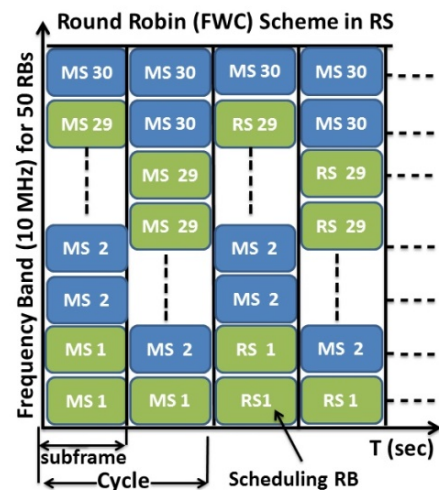
2.4. FWC Scheduling Using Relay Station

Figure 3. 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 3. 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.

2.5. 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]. SM and SD are combined to give higher order 2x4MIMO which can be used in uplink LTE-A future networks.

3. System Model

This section presents the considered Channel capacity model, cost231hata 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:

$$\frac{R_b}{B} = \eta_{BW} \times \log_2\left(1 + \eta_{SNR} \times SNR\right); SNR \le SNR_{max}$$

$$or: \frac{R_b}{B} = \frac{R_b}{B}_{max} \quad ; SNR \ge SNR_{max} \qquad (2)$$

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. Cost-231hata Propagation Model

COST-231hata model was proposed for use in the frequency range of 500MHz to 2GHz, although most research studies use this path loss model for frequency range from 500 MHz to 3GHz use this model to estimate channel path loss because of its simplicity and the availability of correction factors. It is restricted to macro-cells. The pass loss is expressed as [15,16]:

$$P_L = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b)$$
$$-ah_m - (44.9 - 6.55\log_{10}(h_b))\log_{10} d + C_m \qquad (3)$$

Where the parameters Cm and ah_m are used to specify the environmental characteristics for urban area: Cm=3dB and

$$ah_m = 3.20(\log_{10}(11.75h_m))^2 - 4.97 \qquad (4)$$

3.3. 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 SDMT scheme is used in the RS, and results compared with the standard transmission 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 4. 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:
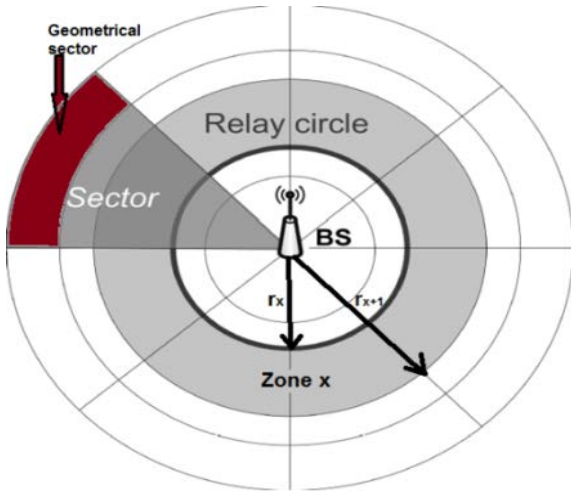
Figure 4. Cell with N-zones and K-sectors

$$\int_{r_x}^{r_{x+1}} 2\pi r.dr = c \tag{5}$$

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

$$\pi r_{x+1}^2 - \pi r_x^2 = C \tag{6}$$

$$r_{x+1} = \sqrt{\frac{C}{\pi} - r_x^2} \tag{7}$$

Where

$$C = \pi r_{cell}^2 / Z_{total} \tag{8}$$

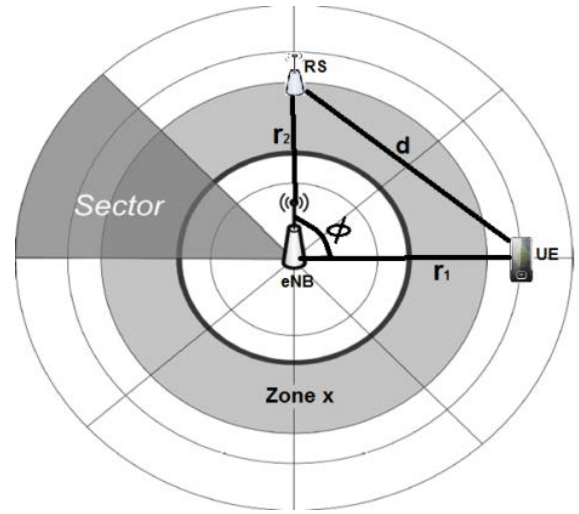Where r_{cell} is the cell radius and Z_{total} is the total number of zones per cell.

4.2. Estimating Distance from UE to RS

As shown in Figure 5, the distance between UE and RS may be expressed as:

$$d^2 = r_1^2 + r_2^2 - 2 \times r_1 \times r_2 \times \cos\phi \tag{9}$$

Where: r_1 is the distance between UE and eNB, r_2 is the distance between RS and eNB, and ϕ may be obtained as shown in (10),

Figure 5. Estimating distance to relay.

$$\phi = \frac{2\pi}{K} \times \left| j_{RS} - j_{UE} \right| \tag{10}$$

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 nt transmitting antennas and nr receiving antennas is expressed as:

$$C(SNR(x)) = \mu_{BW} \times \min(n_t, n_r) \times RB \times W \times$$
$$\log_2\left(1 + \mu_{SNR} \times \frac{n_r}{\min(n_t, n_r)} \times SNR(x)\right) \tag{11}$$

$$SNR(x) = \frac{P_{T\_max}}{N_o \times W \times RB \times L(x)}; SNR \le SNR_{max} \tag{12}$$

$$or : SNR(x) = SNR(x)_{max}; SNR \ge SNR_{max}$$

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_max}. However, using power control:

$$P_{T\_new} = SNR_{max} \times N_o \times RB \times L(x) \qquad (13)$$

Where

$$P_{T\_new} \prec P_{T\_new} \qquad (14)$$

4.3.1. Throughput Estimation without Relay

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

$$R = C\big(SNR(r1)\big) \qquad (15)$$

Where the SNR can be estimated as:

$$SNR(r_1) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r_1)} ; SNR \leq SNR_{max} \qquad (16)$$

$$or : SNR(r_1) = SNR(r_1)_{max} ; SNR \geq SNR_{max}$$

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 (17),

$$R(CCU) = C(SNR(r_1)) \qquad (17)$$

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:

$$R(CEU) = \frac{1}{2}\min\big[C(SNR(d)), C(SNR(r_2))\big] \qquad (18)$$

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 6. The SNR of these two links have to be obtained as (19), (20) respectively.
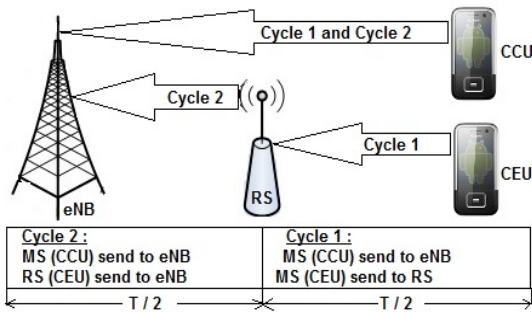

Figure 6. LTE-A UL FWC using RS

$$SNR(d) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(d)} ; SNR \leq SNR_{max} \qquad (19)$$

$$or : SNR(d) = SNR(d)_{max} ; SNR \geq SNR_{max}$$

$$SNR(r_2) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r_2)} ; SNR \leq SNR_{max} \qquad (20)$$

$$or : SNR(r_2) = SNR(r_2)_{max} ; SNR \geq SNR_{max}$$

4.4. Proposed SDMT Transmission Scheme for Uplink LTE-A Performance Improvement

CEUs have to improve their performance in order to make the best use of available scheduled RBs, and then CCUs and total network performance will be improved. This can be done by increasing their data rate, and this incensement can be achieved by increasing SNR. The proposed transmission scheme named Synchronous Direct and Multi-hop Transmission (SDMT) shown in Figure 7 can do this. The transmission of CEU's data from UE to eNB via RS can be done over two cycles. In the 1st cycle CEU send data and RS receive it, while eNB overhears it. In the 2nd cycle RS resend CEU's data to eNB after re-encoding it, and the received SNR at eNB will be the sum of received SNR from RS and from UE. CCUs send their data over the 2 cycles.
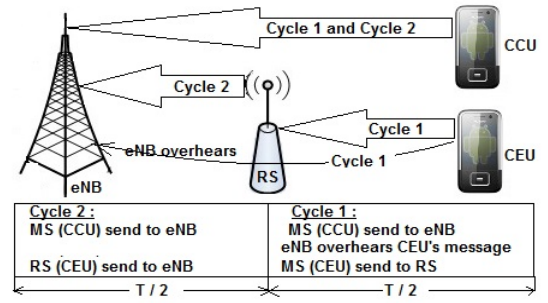

Figure 7. SDMT cycles using RS

According to this; (18) will be modified simply to be as follows:

$$R(CEU) = \frac{1}{2}\min\big[C(SNR(d)), C(SNR(r_2) + SNR(r_1))\big] \qquad (21)$$

Where;

$$SNR(d) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(d)} ; SNR \leq SNR_{max} \qquad (22)$$

$$or : SNR(d) = SNR(d)_{max} ; SNR \geq SNR_{max}$$

$$SNR(r_2) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r_2)} ; SNR \leq SNR_{max} \qquad (23)$$

$$or : SNR(r_2) = SNR(r_2)_{max} ; SNR \geq SNR_{max}$$

$$SNR(r_1) = \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r_1)} ; SNR \leq SNR_{max} \qquad (24)$$

$$or : SNR(r_1) = SNR(r_1)_{max} ; SNR \geq SNR_{max}$$

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 see the impact of RS position on network performance.

Second; 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) 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 using SISO, SIMO, MISO, 2x2MIMO, and 2x4MIMO to compare performance. Also simulations repeated using standard multi-hop transmission and proposed SDMT 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 standard Multi-hop transmission mode, and 2x4MIMO with proposed SDMT transmission mode, to obtain the impact of different modes on MFTT.
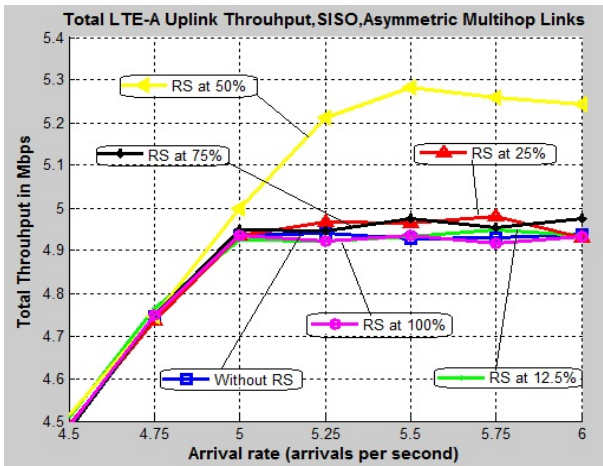
6. Results

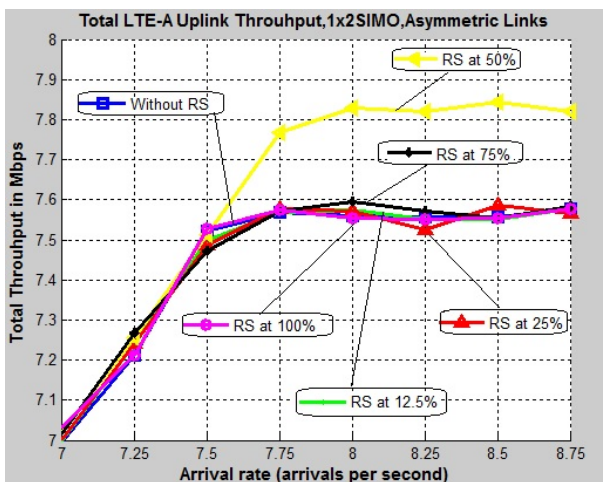**Figure 8**. UL throughput, SISO, standard Multi-hop transmission

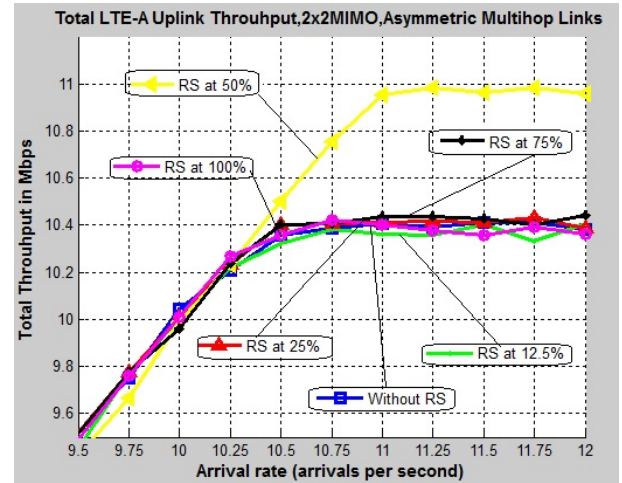**Figure 9**. UL throughput, SIMO, standard Multi-hop transmission

Figure 10. UL throughput, 2x2MIMO, standard Multi-hop transmission

Figure 8, Figure 9, Figure 10, and Figure 11 illustrate the LTE-Advanced total Uplink throughput for uplink LTE-A network using SISO, SIMO, 2x2MIMO, and 2x4MIMO with FWC scheduling; respectively.

This is done using Cost-231hata model without RS and with RS located at different positions. From these figures it can be seen that the 2x4MIMO LTE-A system achieve the maximum throughput and capacity compared to other systems. Also these figures show that the maximum capacity was achieved using RS 50% of cell radius. Therefore, it may be the best position for RS placement.
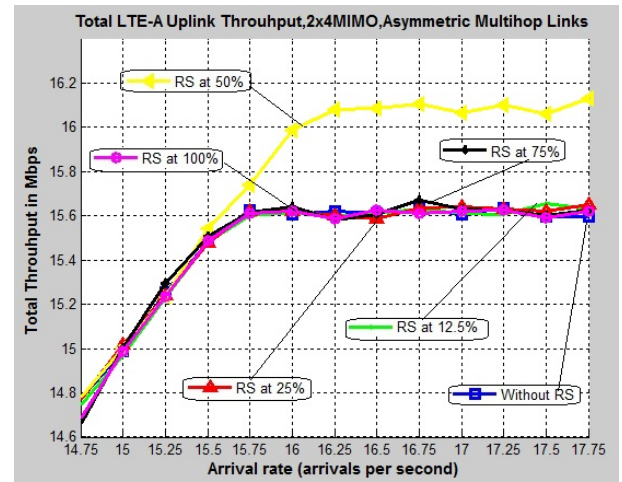
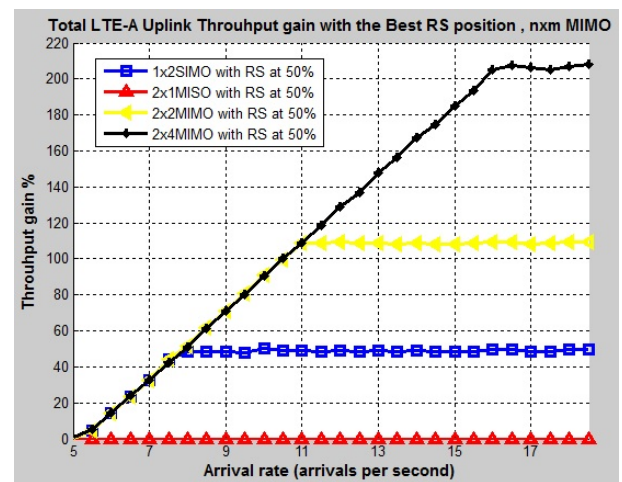**Figure 11**. UL throughput, 2x4MIMO, standard Multi-hop transmission

Figure 12. UL throughput gain, standard Multi-hop transmission

Figure 12 illustrates the LTE-Advanced total Uplink throughput gain for uplink LTE-A network using SIMO, 2x2MIMO, and 2x4MIMO; respectively over SISO system. This Figure compares throughput gain using RS at 50% of cell radius. The maximum throughput gain was 220% of SISO throughput, and was achieved using higher order 2x4MIMO.

Figure 13, and Figure 14 illustrate the LTE-Advanced total Uplink throughput for 2x4MIMO using standard Multi-hop transmission mode, 2x4MIMO with SDMT mode; respectively.
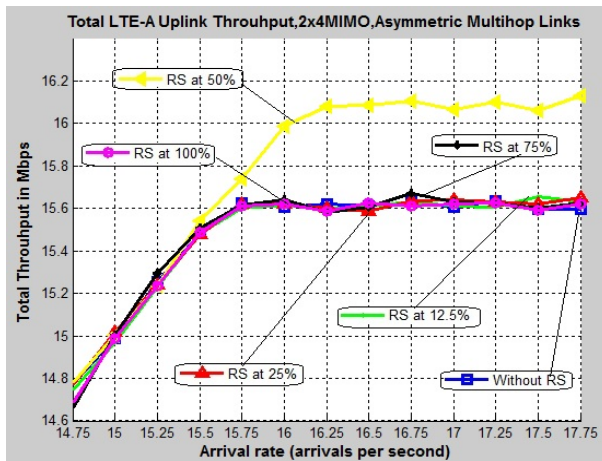

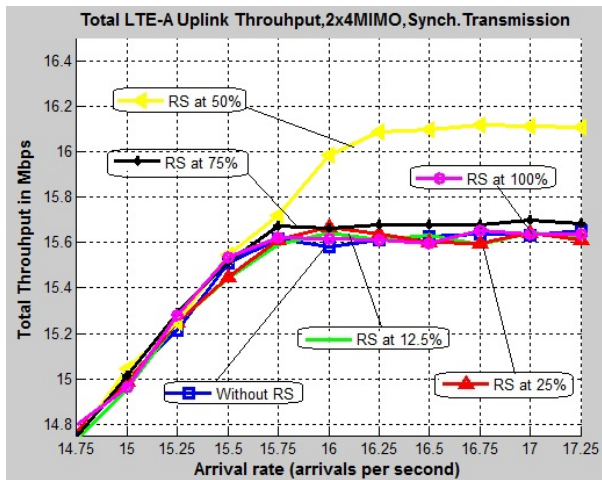**Figure 13**. UL throughput, 2X4MIMO, standard Multi-hop transmission

Figure 14. UL Throughput, 2X4MIMO, SDMT mode

This is done using Cost-231hata model without RS and with RS located at different positions. These figures show that 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 15, and Figure 16 illustrate the LTE-Advanced average user throughput for 2x4MIMO standard Multi-hop transmission mode, and 2x4MIMO with SDMT mode; respectively. This is done without RS and with RS located at different positions.

Figure 15 and Figure 16 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.
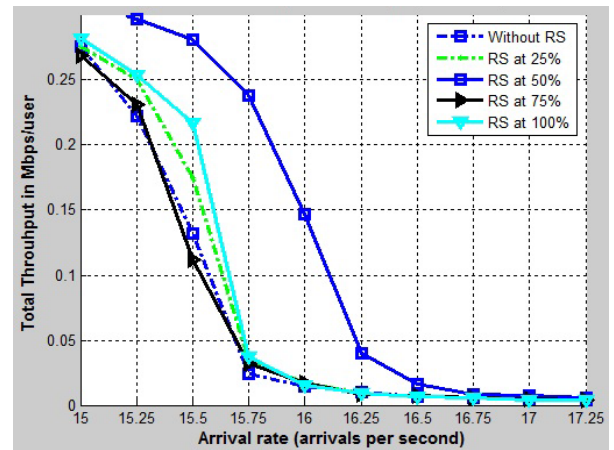

Figure 15. User Throughput, 2X4MIMO, standard Multihop transmission
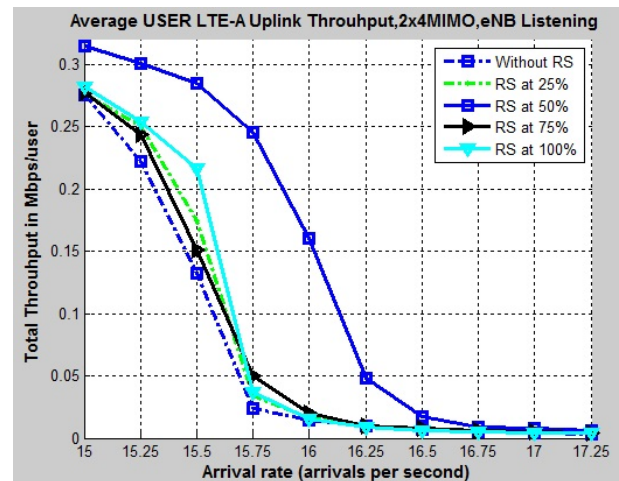

Figure 16. Average User Throughput, 2X4MIMO, SDMT mode

Figure 17, and Figure 18 show the RS and its position effect on all CEUs in the cell using standard Multi-hop transmission and SDMT mode; respectively. These figures show that adding RS in the network and changing its position affects the CEUs. But the throughput gain was very low as the sum of CCUs and CEUs (the total throughput) will basically affected by CCUs.
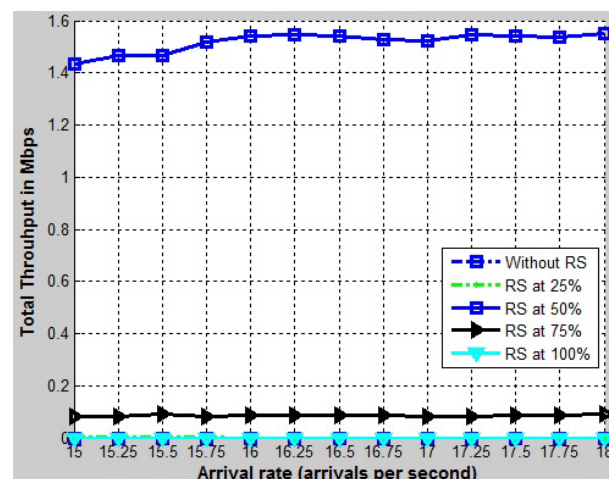

Figure 17. Uplink CEU Throughput, 2x4MIMO, standard Multi-hop transmission
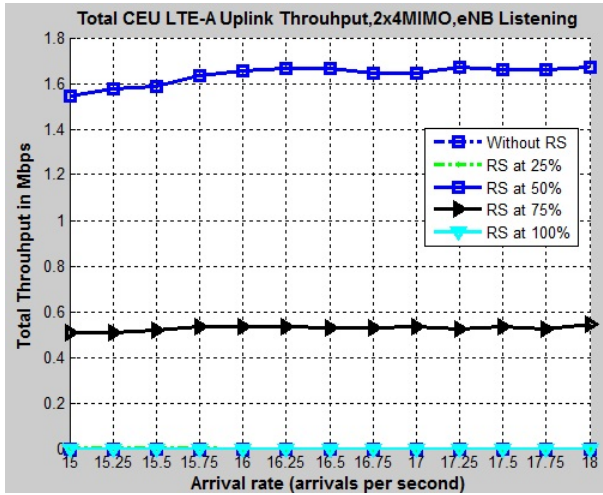
Figure 18. Uplink CEU Throughput, 2x4MIMO, SDMT mode

From Figure 13 to Figure 18 it can be concluded that proposed SDMT improve CEUs throughput more than using standard transmission mode. But total throughput gain is too low to be seen in figures since the total throughput is mainly affected by CCUs, beside the CEUs effect.
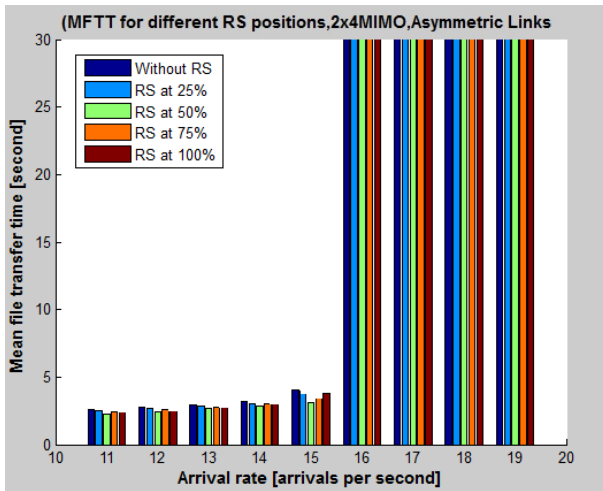

Figure 19. MFTT per cell, 2X4MIMO, standard Multi-hop transmission
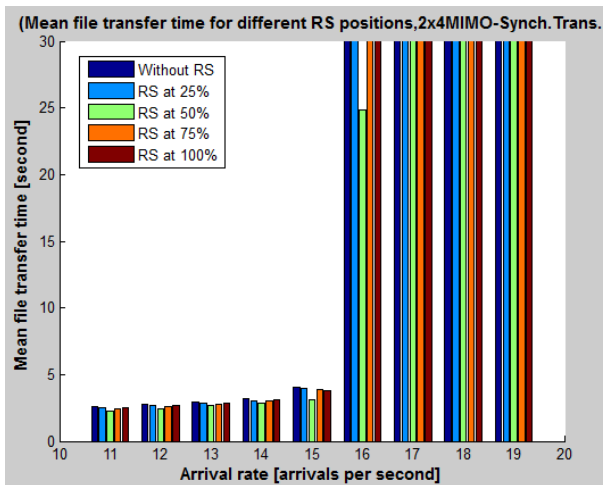

Figure 20. MFTT, 2X4MIMO, SDMT mode

Figure 19, and Figure 20 show the Mean file transfer time MFTT (sec per 1Mbit) for 2X4MIMO with standard transmission mode, and SDMT mode; 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 SDMT mode. The mean file transfer time goes infinite for 2X4MIMO with standard Multi-hop transmission at Λ=16 arrivals per second, for 2X4MIMO with SDMT mode at Λ=16 arrivals per second.

However for 2X4MIMO using SDMT mode with Λ=16 arrivals per second, RS at 50% don't saturate, whereas the MFTT using standard Multi-hop transmission mode mentioned above reach saturation. So it can be concluded that 2X4MIMO using SDMT mode has the best performance according to MFTT.

7. Conclusions

This paper has investigated the uplink performance improvements using Multi-hop Relay technology with based on 2X4MIMO compared with other antenna configurations in LTE-A networks. This research mainly discusses two points; the impact of RS position on LTE-A uplink performance, and how to improve network performance. 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. Transmission is done using two transmission modes; standard Multi-hop transmission mode, and proposed Synchronous Direct and Multi-hop transmission mode.

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. Moreover, it can be concluded that SDMT mode can increase CEUs throughput with a marginal increase in network capacity. Also it can be concluded that by using the 2X4MIMO with SDMT; CEUs achieve full use of available scheduled RBs. According to this; their throughput will be increased, and MFTT in the cell will be decreased.

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