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Spatial Diversity and Multiplexing Effects on Uplink Multi-hop LTE-Advanced

تأثير التعدد المكاني والخلط المتعدد علي كفاءة الارسال في القناة الصاعدة متعددة المراحل لمنظومة التطور البعيد المدى المتقدم

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الملخص

تستخدم الشبكة متعددة المراحل باستخدام محطات التقوية لتوسيع التغطية وتعزيز كفاءة الطيف الترددي لتلبي احتياجات التطبيقات الحالية بطريقة عملية وغير مكلفة، كما يمكن استخدام تلك التقنية في مشروع شراكة الجيل الثالث لمنظومة التطور البعيد المدى المتقدم . تم اعتماد تقنيات التعدد المكاني و الخلط المتعدد في الارسال بمنظومة التطور البعيد المدي المتقدم الخلوية لتحسين نسبة قوة الاشارة الي الشوشرة و كفاءة الطيف الترددي المتاح. الهدف من هذا البحث هو تقييم تقنيات التعدد المكاني و الخلط المتعدد في الارسال باستخدام تقنية التعديل المتهايئ مع التشفير حسب الوسط المتاح للبث في القناة الصاعدة متعددة المراحل لمنظومة التطور البعيد المدى المتقدم من حيث متوسط الإنتاجية، وتحقيق مكاسب في الإنتاجية ومتوسط وقت نقل الملفات. كما تمت دراسة تأثير محطة التقوية و موقعها الامثل في الخلية علي اداء المنظومة. تم الاخذ في الاعتبار تأثير عدم التماثل بين مراحل الاتصال، معدلات وصول متغيرة للبيانات من مواقع عشوائية للمستخدمين، وخوارزميات الجدولة. وتوضح تجارب المحاكاة أنه يمكن تحقيق تحسن كبير في متوسط الإنتاجية وزمن ارسال الملفات بالجمع بين التعدد المكاني و الخلط المتعدد للارسال بواسطة اثنين من الهوائيات و الاستقبال بواسطة اربعة هوائيات مع استخدام محطة التقوية عند منتصف الخلية.

Abstract

Multi-hop Relay networks are proposed to fulfill the demanding coverage and capacity requirements in both uplink and downlink for current applications in a cost efficient way. It can be used in IMT-Advanced technologies such as 3GPP LTE-Advanced. Spatial Diversity (SD) and Multiplexing (SM) have been adopted to improve the Signal to interference Noise Ratio (SINR) and spectrum efficiency in wireless networks. The objective of this paper is to evaluate the performance of Spatial Diversity and Multiplexing based on Adaptive modulation and coding (AMC) schemes in Uplink LTE-A. The average throughput, Throughput gain, and Mean File Transfer Time (MFTT) are considered as performance measures. The best Relay Station (RS) location in the cell was also estimated in order to improve LTE-A Uplink performance. The study takes into consideration the impact of Asymmetry between multi-hop links, the effect of different arrival rates from random positions of UEs in the cell. Resource blocks scheduling algorithm is used for more efficient use of resource blocks (RBs). Simulation results show effective improvement in uplink network performance by Combining Spatial Diversity and Multiplexing in 2x4MIMO system with RS at 50% of cell radius towards cell edge.

Keywords:

LTE-A, Multi-hop, RS Positioning, AMC, Spatial Diversity, Spatial Multiplexing.

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 the two links bottleneck 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

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throughput, capacity, and maximum arrival rate [2]. Relay stations are considered to be small station with low power consumption, which connect the core network through eNB.

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, but the impact of Asymmetry between multi-hop links is neglected.

There are two main objectives for the present work. The first one is to study the impact of Spatial Diversity (SD) and Spatial Multiplexing (SM) schemes and their combinations on the uplink LTE-A performance. The second objective is to study the effect of adding RS on the uplink LTE-A throughput and mean file transfer time. And also, the best location for the RS in the cell was estimated.

2. LTE System Features

In this section, brief description of Physical Resource Blocks, Uplink Scheduling, Relaying, adaptive modulation and coding schemes, multiple antenna configurations (MIMO) are presented.

2.1. 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. In addition a guard band of 1MHz is required. The 1RB time period is denoted as a slot. Each two slots named sub-frame or scheduling RB [9].

2.2. LTE Uplink Resource 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]. Fig. 1 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.

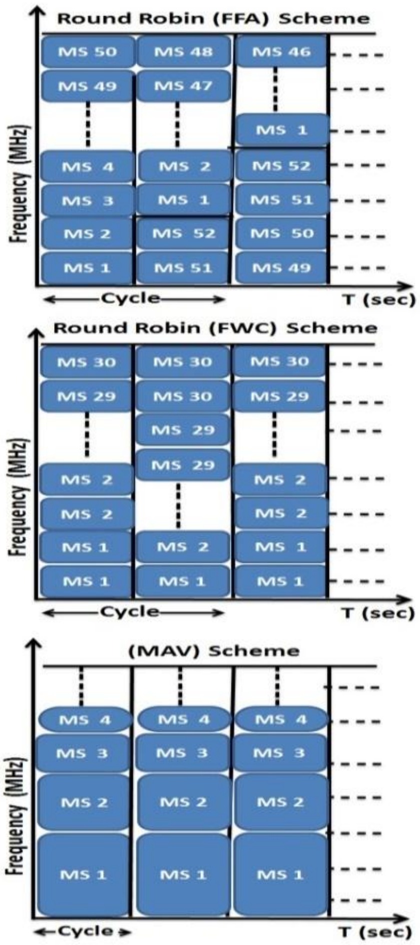

Figure 1. LTE-A UL Scheduling schemes

2.3. LTE-A Relaying:

There are two types of Relay Stations (RSs) defined in 3GPP standards. There are Type-I and Type-II. The main difference between the two types is how to manage the resources. Type-I RS acts as small eNB with its own control messages and cell IDs, it helps the remote UE which located far from the eNB to access it. This type is used to improve overall system capacity [11]. Type-II RS (transparent) is used to help UE within the coverage of eNB.

2.4. Link Adaptation

Link adaptation is proposed to maximize user data rate according to given channel conditions to make full usage of given radio channel with high QoS. 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.

Table 1. CQI-AMC Schemes for low BER

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
12	16.2 dB	64QAM	3/4
13	18.1 dB	64QAM	4/5

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 for max SNR 15dB [13] as shown in table 1.

2.5. Memo 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]. SD and SM are combined to get 2x4MIMO.

3. System Model

This section presents the considered Channel capacity model, and Propagation model used in the conducted Simulations.

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].

$$C = B.\log_2(1 + SNR) \quad \textbf{(1)}$$

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:

$$\frac{R_b}{B} = \begin{cases} \eta_{BW}.\log_2\left(1+ \eta_{SNR}.\frac{S}{N}\right) & ;\text{for } \frac{S}{N} \le \frac{S}{N_{max}} \\ \frac{R_b}{B}_{max} & ;\text{for } \frac{S}{N} > \frac{S}{N_{max}} \end{cases} \quad \textbf{(2)}$$

Where $\eta_{BW,r}$ and $\eta_{SNR,r}$ are bandwidth and SNR efficiencies respectively with values shown in table.2 as a function of number of transmitting antennas for uplink LTE-Advanced.

Table 2. 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 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]:

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

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

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

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. Cost-231hata path loss model is used. FWC scheduling scheme is used in the RS. New file transfers from random users at random locations in the cell, are initiated with rate λ according to a Poisson process [16]. AMC with different antenna are used in simulations [16].

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)	-174 dBm/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 MODELLING

The cell is divided into number of zones (N) and number of sectors (K) as shown in Fig. 2. 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

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

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

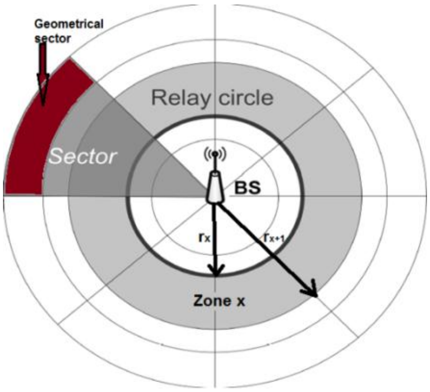

Figure 2. Cell model with N-zones and K-sectors.

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

This gives the following formula

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

Where $C = \pi r_{cell}^2 / Z_{total}$ **(8)**

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

4.2. Estimating Distance To Relay Station

As shown in Fig. 3, the distance between UE and RS may be expressed as:

$$d^2 = r_1^2 + r_2^2 - 2 \times r_1 \times r_2 \times \cos\phi \quad (9)$$

Where: r_1 is the distance between UE and eNB, r_2 is the distance between RS and eNB, and $\emptyset$ may be obtained as equation 10

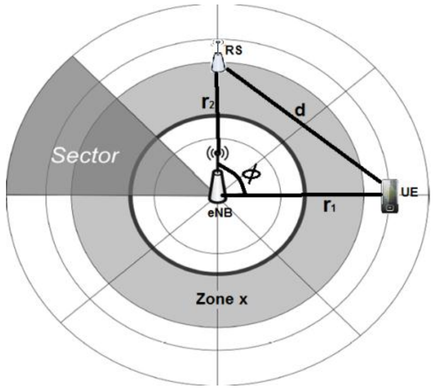

Figure 3. Estimating distance to relay.

$$\emptyset = \frac{2\pi}{K} \times |j_{RS} - j_{UE}| \quad (10)$$

Where K is the total number of sectors per cell, j_{RS} the sector number where the relay station is placed, and j_{UE} the sector number where the UE is placed.

4.3. LTE-Advanced Uplink Throughput Estimation

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:

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

$$SNR(x) = \begin{cases} \frac{P_{T\_max}}{N_o \times W \times RB \times L(x)} & ; SNR < SNR_{max} \\ SNR_{max} & ; SNR \geq SNR_{max} \end{cases} \quad (12)$$

Where, RB is the number of used resource blocks per user according to used FWC 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, depending on UE location and the max acceptable SNR, maximum transmit power or a lower power will be used, The actually applied transmit power is chosen such that a UE maximizes its utilization of the RBs, so max transmitted power can be used in simulations and if SNR>SNRmax new transmitted power has to be estimated for SNR=SNRmax as shown in equation 19.

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

Where : $P_{T\_new} \le P_{T\_max}$

(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(SNR(r1)) **(15)**

Where the SNR can be estimated as:

$$SNR(r1) = \begin{cases} \frac{P_{UE\_max}}{N_o \times W \times RB \times L(r1)}; SNR < SNR_{max} \\ SNR_{max} \quad ; SNR \ge SNR_{max} \end{cases} \quad (16)$$

Where P_{UE_max} is the maximum transmit power of the UE.

4.3.2. Throughput Estimation using relay

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 equation 17.

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

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 shown:

$$R(CEU) = \frac{1}{2}\min\left[C(SNR(d)), C(SNR(R_2))\right] \quad (18)$$

Where the SNR of these two links have to be obtained as equations 19,20 respectively.

$$SNR(d) = \begin{cases} \frac{P_{UE\_max}}{N_o \times W \times RB \times L(d)}; SNR < SNR_{max} \\ SNR_{max} \quad ; SNR \ge SNR_{max} \end{cases} \quad (19)$$

$$SNR\left(R_2\right) = \begin{cases} \frac{P_{RS\_max}}{N_o \times W \times RB \times L(r2)}; SNR < SNR_{max} \\ SNR_{max} \quad ; SNR \ge SNR_{max} \end{cases} \quad (20)$$

Where P_{RS_max} is the maximum transmit power of the RS

4.4. When to Use Relay

If R(CEU) <= R(CCU) so it will be cell center user and connect to eNB directly, so the total throughput for UL-LTE-A will be:

R=max(R(CEU),R(CCU)) **(21)**

5. Simulation Setup

First the cell is modeled with N-zones and K-sectors, N and K are chosen to be 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 type 1 RS in the cell to estimate the best location according to total cell throughput, and to compare the performance with that without relay station.

In the 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) 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 repeated for SISO, 2x1 MISO, 1x2 SIMO, 2x2 MIMO, and 2x4 MIMO 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 for each segment. 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

SISO, SIMO, 2x2, and 2x4MIMO to obtain the impact of different schemes on MFTT.

6. Results

Figs. 4, 5, 6, and 7 illustrate the LTE-Advanced total Uplink throughput for SISO, SIMO, 2x2 MIMO, 2x4 MIMO; respectively. This is done using Cost-231hata model without RS and with RS located at different positions in the cell. From these figures it can be observed that the maximum capacity was achieved with RS at 50% of cell radius. Therefore, it may be considered the best position for RS placement. However the throughput using RS at 50% of cell radius is increased by less than 10% of the throughput without using RS. This may be considered as marginal increase since the total throughput is mainly affected by CCUs, beside the CEUs effect.

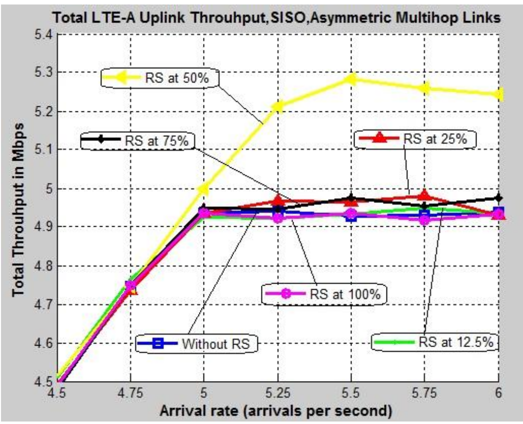

Figure 4. UL throughput, SISO, 2x1 MISO

Moreover, it was observed that the total throughput is independent of the RS before reaching maximum capacity. This due to the fact that the total throughput equals the average arrival rate multiplied by average file size independently of RS. In addition, it can be seen that the maximum capacity, and arrival rate is achieved using 2x4 MIMO.

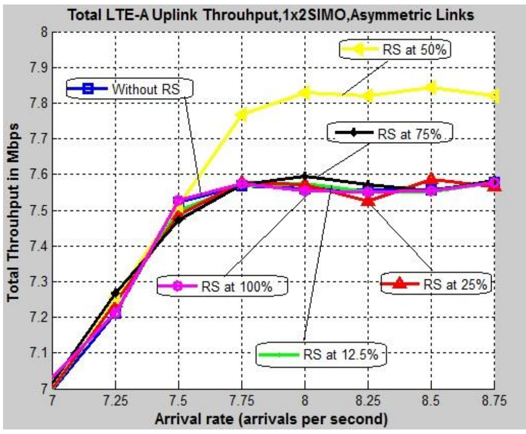

Figure 5. UL throughput, 1x2 SIMO

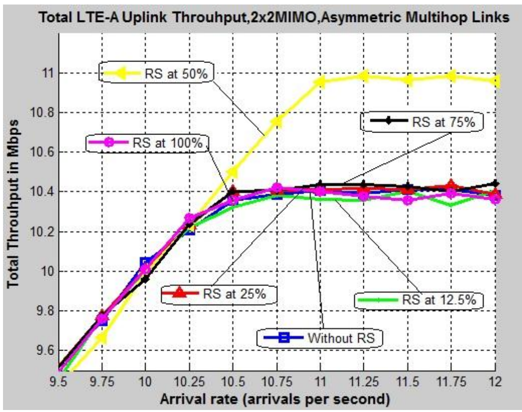

Figure 6. UL throughput, 2x2 MIMO

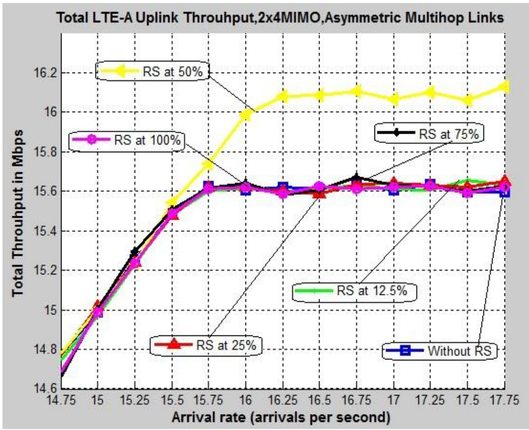

Figure 7. UL throughput, 2x4 MIMO

Figs. 8, 9, 10, and 11 show the Mean file transfer time MFTT (sec per 1Mbit) for the entire cell using SISO, SIMO, 2x2 MIMO, 2x4 MIMO; respectively.

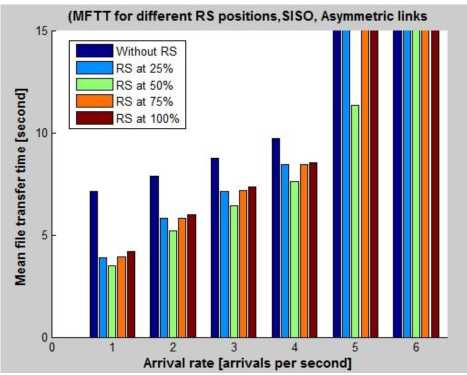

Figure 8. MFTT per cell, SISO, 2x1 MISO

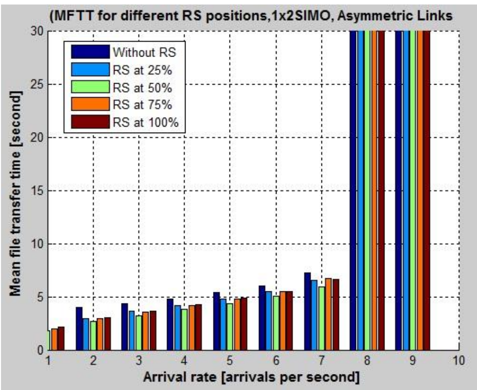

Figure 9. MFTT per cell, 1x2 SIMO

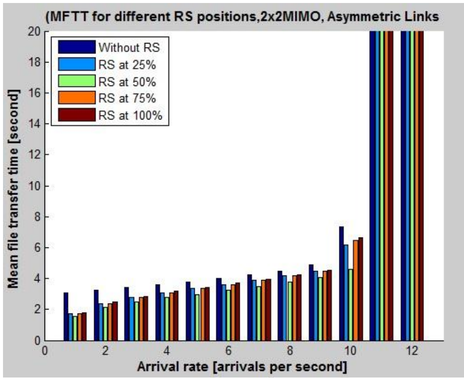

Figure 10. MFTT per cell, 2x2 MIMO.

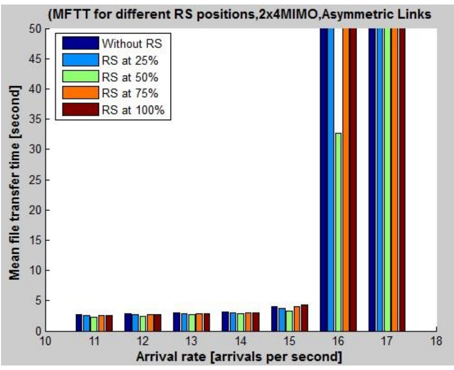

Figure 11. MFTT per cell, 2x4 MIMO.

It can be seen from these figures that the MFTT for RS at 50% is always less than all other cases. Moreover, the file transfer time goes infinite for SISO at arrival rate (ʎ) of 6 arrivals per second, for SIMO at ʎ=8 arrivals per second, for 2x2 MIMO at ʎ=11 arrivals per second, for 2x4 MIMO at ʎ=17. However for2x4 MIMO with ʎ=16 arrivals per second, RS at 50% don't saturate. Whereas the MFTT schemes mentioned above reach saturation. So it can be concluded that 2x4 MIMO has the best performance according to MFTT.

Table 4 summarizes the above mentioned results. From which it can be concluded that the best performance from the point of view of throughput, capacity, maximum arrival rate, and MFTT was provided by 2x4 MIMO with RS at 50% of cell radius.

Table 4. Spatial Diversity and multiplexing Performance for best LTE-A RS location

Transmission mode	Max. Capacity Mbps	Arrival rate
SISO	5.3	5.5
MISO	5.3	5.5
SIMO	7.8	8
2x2MIMO	10.88	11
2x4MIMO	16.1	16.25

7. CONCLUSIONS

This paper has investigated the uplink performance improvements using Multi-hop Relay technology with spatial diversity and multiplexing based on AMC in LTE-A networks. This research mainly answers two questions; where a relay station's would be in the best location in the LTE-A cell, and which antenna configuration scheme has better performance on average. 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; SISO, 1x2 SIMO, 2x2 MIMO and 2x4 MIMO schemes were 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.

The total LTE-A uplink throughput and system capacity was investigated as a function of arrival rates for the four used schemes of antenna configurations. 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) for the cell for different arrival rates and RS positions was investigated based on different antenna configuration schemes, it can be concluded that the best place to locate an RS is at 50% of cell radius. Moreover, it can be concluded that 1x2 SIMO improves SNR, but the throughput improvement is not effective, whereas 2x2 MIMO system effectively improves throughput. But when SD and SM are combined to get 2x4 MIMO the SNR, throughput and MFTT were effectively improved.

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