Performance Evaluation of Frequency Reuse Schemes in LTE Based Network

Mustafa M. M. El-Tantawy, Mohamed Aboul Dahab, Hesham El-Badawy

***Abstract* — Inter-Cell Interference Cancellation (ICIC) is the talk of the town, when considering a system aiming to use the full Bandwidth in all its cells like in the case of LTE in Frequency Reuse-1 mode. We will attempt to analyze the different frequency allocation schemes reuse-1 and reuse-3 and impact of interference from surrounding cells, using an analytical model, to support in the dimensioning of a Long Term Evolution Frequency Division Duplexing (LTE-FDD) system.**

***Keywords* — reuse 1; reuse 3; FFR; dimensioning; LTE; cell coverage.**

I. Introduction

In this paper we focus our studies on LTE, which is a development under 3G technologies Release-8 of the 3GPP Project plan and is considered a baseline and step towards the LTE-Advanced.

In this context and where a frequency reuse of 1 is proposed, i.e. all cells/sectors of the network operate on the same frequency. Whilst as the classical frequency distribution scheme of Reuse-3 operates on one third of the band.

These different frequency allocation techniques have been analyzed by simulations in [1][2] and an analytical model for the interference was devised in [3] to mathematically evaluate these schemes, yet there remains the evaluation of these schemes under various parameters for an exact dimensioning of the system of these frequency allocation schemes and their best use in a cellular network.

In this paper, we present a framework, to analyze analytically and compare 2 different frequency allocation schemes: reuse 1 and reuse 3 in the downlink mode of an LTE FDD system. We then propose these schemes under different system dimensioning parameters, and evaluate the scenarios in terms of the impact on throughput.

The remainder of this paper is organized as follows. In section II, we briefly present two of the different frequency allocation schemes proposed in the 3G LTE system. In Section III, we present workflow of the analytical model under evaluation, namely for the Re-use 1 and Re-use 3 frequency allocation schemes, taking into consideration Adaptive Modulation and Coding (AMC) and various inter-cell interference patters, to eventually cross compare numerically with the proposed model by [3]. In section IV, unique to this paper, we shall explore the various dimensioning limitations for the system and present our numerical results under different power and cell Radius. Section V we finally conclude the paper and present the usage recommendations.

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II. Frequency Allocation Schemes

In the downlink the modulated OFDM symbols are transmitted in the unit of *chunks*. One chunk is defined as a block of physical layer resources that spans over one TTI (Transmission Time Interval) in time and a fixed number of adjacent OFDM subcarriers in the frequency domain [4].

A. Frequency Re-use 1

One of the main objectives of LTE is to achieve a high spectral efficiency [5], meaning the use of the whole of the system's bandwidth in all cells, this approach is called Frequency Re-use 1, and it is considered the simplest scheme, it can be said that, all chunks of the available bandwidth are to be allocated to each cell.

B. Frequency Re-use 3

In Re-use 3, the system bandwidth is divided into 3 equal sub-bands, each of these sub-bands are allocated to cells in a manner that no other surrounding cell is using the same sub-band, this can be illustrated in Fig. 1.

III. Analytical Model

Now we will present the proposed analytical model by [3], along with the assumptions we used to apply it using a program created on MATLAB for dimensioning of the system. Limiting our presentation to frequency re-use schemes 1 and 3 in the Downlink mode.

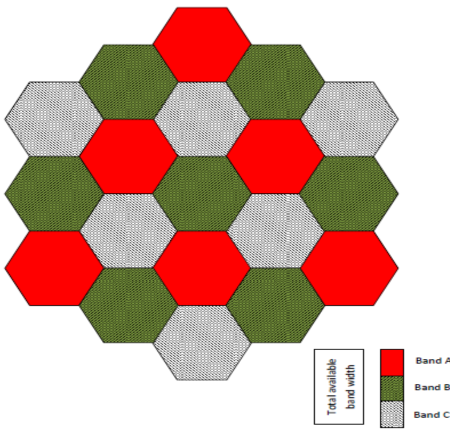

Fig. 1. Frequency Re-use 3 cell layout

We will begin by presenting the workflow for analysis of the model and finally display a couple of confirmation graphs, which is to be considered as evidence that the analytical model proposed matches our implementation and assumptions. It should be noted that during the evaluation of this system, we will consider a Homogenous network i.e. Load in all cells are equal, service calls are of elastic type (file transfer), there are n=12 interfering cells and that the power per chunk is fixed and no adaptive power loading is employed. Nevertheless, transmission rate adaptation is still performed by altering the Modulation and Coding Scheme (MCS) on the chunks.

A. Reuse 1 Downlink Throughput

The overall program cycle for calculating the cell throughput for a specific cell radius "R" and Chunk power "P" of the frequency Re-use 1 scheme in the downlink case, can be presented in the following steps:

1) Input system dimensioning parameters under evaluation like: BW (chunk bandwidth)*, P* (chunk power)*, R* (Radius in Km)*, Z* (File Size)*, C*(# of chunks) *and λ* (calls arrival rate).

2) *Assume an initial value of π(U), so that:* $\pi(U)=1/(C+1)$ *; which leads to a 50% loaded cell; (x)=0.5.* Where π(U) is the Probability of existing "U" active users in a cell taking the following possible values: $0 \le \pi(U) \le 1$.

3) Calculate cell loading (x): calculated by:

$$x=(1/C)\sum_{U=0}^{C} U\times \pi(U) \qquad (1)$$

4) Calculate the mean throughput "$\overline{D}$" for a defined load "x":

It should be noted that "$\overline{D}$" is effected by the amount of interference from cells of ring 1 and 2 with respect to the user's position in his cell, as illustrated in Fig. 2, where the interference pattern X=[0 0 0 1 0 1 0 0 0 1 0 0], here interference is received at a UE from cells 4, 6 and 10. Thus, the throughput must be averaged over all possible interference patterns (X), and for each of these interference patterns of X we need to calculate the mean over all possible user positions. We use the following set of equations by [3] to calculate an instantaneous throughput D for a given interference pattern X and with respect to their position r_i & r_0.

$$D\left(\tfrac{C}{I}(X)\right)= BW \times B\left(\tfrac{C}{I}(X)\right) \qquad (2)$$

Where:

$$B\left(\tfrac{C}{I}(X)\right)= e\left(\tfrac{C}{I}(X)\right)\times \left(1-BLER\left(\tfrac{C}{I}(X)\right)\right) \qquad (3)$$

And:

$$\frac{C}{I}(X)=\frac{P/q_0}{\sum_{i=1}^{n}\left(\frac{X_i\times P}{q_i}+N_0\right)} \qquad (4)$$

$C/_I(X)$ is the SINR received at UE at a given pattern X, $e(C/_I(X))$ and $BLER(C/_I(X))$ are the efficiency and Block Error Rate respectively of the MCS used at a specific $C/_I(X)$, N_0 is Noise power per chunk,

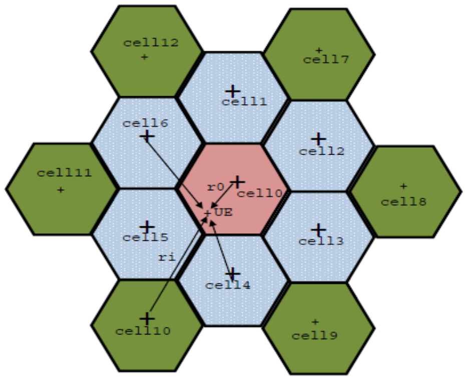

Fig. 2. Example of a Downlink Interference Pattern

q_i & q_0 are the path loss of transmission from eNodeB of cell ***i*** and ***0*** respectively to the target UE under analysis in cell (0). For simplicity we have neglected the effect of Shadowing and fading, thus $(q_i = r_i^{\alpha})$ & $(q_0 = r_0^{\alpha})$ and Path loss Coefficient $\alpha \in [2,4]$. To calculate D, we first calculate C/I from (4), and find the efficiency at the state **X** for the relevant MCS using the lookup Table 1 proposed by [3], and substitute the value of (3) into (2).

Remark 1: Table 1 presents the AMC lookup table used by [3] for analysis, and will be used throughout this paper. AMC is used by the eNodeB and UEs to align together the most robust MCS to be used for a given SINR range where BLER∈0~0.1. AMC is the method proposed by the 3GPP standards [10] for MCS selection.

we work to calculate the harmonic mean of D(X) over the target cell area for a given interference pattern X using the following:

$$D(X)=BW\times E_{r0}\left[\frac{1}{B\left(\tfrac{C}{I}(X)\right)}\right]^{-1} \qquad (5)$$

Remark 2: For simplicity in our simulation due to the complexity of the possible interference patterns, we assumed that all cell's inference effect are equal and used their average value, eventually re-presenting the required number of X possible combinations to be only 49 possible patterns instead of 2^{12} probabilities, after this simplification, the physical position of an interfering cell in its ring with respect to our UE has no impact. Thus we proceed in our analysis by calculating all combinations of number of interfering cells in each ring, where combined # of interfering cells (k_1) in 1st ring are 0,1,2...6 & # of interfering cells (k_2) in 2nd ring are 0,1,2...6 independent of their angular position.

TABLE 1: PROPOSED AMC LOOKUP TABLE SHOWING ALLOWABLE SINR RANGE FOR EACH MCS.

(Modulation, Coding)	MCS Performance		
	e(C/E)	*$SINR_{MIN}$*	*$SINR_{MAX}$*
(QPSK,1/2)	1		8dB
(8PSK,1/2)	1.5	8dB	11 dB
(16QAM,1/2)	2	11 dB	14 dB
(16QAM,2/3)	8/3	14 dB	18.5 dB
(16QAM,3/4)	3	18.5 dB	

Remark 3: For averaging over cell area we use UE distance values to be r_0 =0.1R to 0.8R and find the average value of $\frac{1}{B\left(\frac{C}{I}(X)\right)}$ over these values.

Finally, we calculate the mean throughput "$\overline{D}$" using the harmonic mean for D(X) and its probability function Pr(X) for all possible X patterns using (6) [3]:

$$\overline{D} = \left[\sum_X \frac{\Pr(X)}{D(X)}\right]^{-1} \tag{6}$$

Remark 4: Pr(X) is now the probability of k_1 of 1's in the first 6 elements of the vector **X** and k_2 of 1's in the remaining 6 elements of vector **X**, which can be calculated by binomial law, and is represented as follows:

$$\Pr(X) = \Pr(k_1, k_2) = \binom{6}{k_1} x^{k1}(1-x)^{6-k1} \binom{6}{k_2} x^{k2}(1-x)^{6-k2} \tag{7}$$

$$0 \le k_1 \le 6 \quad \& \quad 0 \le k_2 \le 6$$

5) Calculate the Average service time "$\overline{T}$":

The average time $\overline{T}$ used for transferring the File **Z** is:

$$\overline{T} = Z / \overline{D} \tag{8}$$

6) Calculate system steady state convergence:

Here we calculate the new value of π(U) by (9), and then we compare the values of $\pi_{new}(U)$ with the initial values of π(U) which were set at step 1 of the system simulation and repeat steps 3 to 6 until values converge. The final "$\overline{D}$" value at this stage is the average overall throughput of the system at the steady state.

$$\pi(U) = \frac{1}{G}\frac{(\lambda\overline{T})^U}{U!} \quad ; \quad G = \sum_{U=0}^{C} \frac{(\lambda\overline{T})^U}{U!} \tag{9}$$

Where G is the normalizing constant.

B. Reuse 3 Downlink Throughput

We calculate the reuse 3 throughput with the exact manner, as was done in reuse 1, except here we divide the BW into 3 equal sub-bands as previously explained in Section II of this paper. Taking the "C" value to be one third of the previously used "C" parameter of reuse 1. Also we consider interference to be received from only the cells of the 2nd ring, meaning k_1=0 and k_2 takes values from 0-6 from (7) to be as follows:

$$\Pr(X) = \Pr(k_2) = \binom{6}{k_2} x^{k2}(1-x)^{6-k2} \quad ; \; 0 \le k_2 \le 6 \tag{10}$$

IV. Numerical Results

A. Results verification

Now that we have presented the used model and how we redesigned it with our own assumptions and data, we will move on by verifying our results with the work presented by [3]. Fig. 3 presents the overall throughput of reuse 1 & 3 in contrast with the results presented in [3].

It can be clearly seen that our model and assumptions unique to our paper, have achieved almost 95% in the case of reuse 1, however in reuse 3, due to the different used assumptions and parameters, the curve has showed a

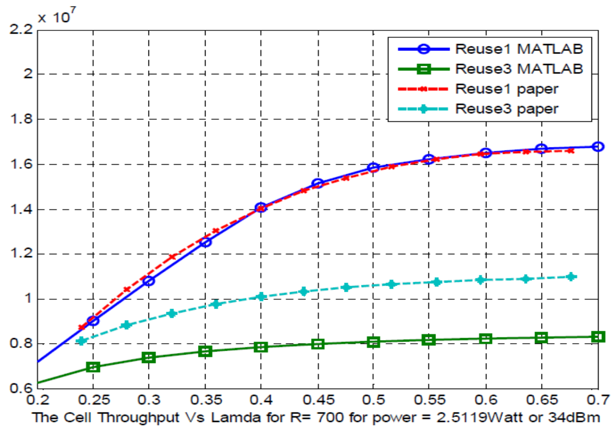

Fig. 3. Downlink overall throughput comparison for reuse 1 and 3 against the results of paper [3]

minor difference in the peak throughput results against [3], yet the curves have the exact same texture. Thus this concludes the verification of our proposed approach and its MATLAB implementation against the proposal by [3].

B. System Performance Evaluation and Comparison

To evaluate the performance of the system and compare the different reuse schemes under different conditions, we first consider an LTE FDD cellular network, transmitting a radio frame of 30 chunks, each chunk has a bandwidth 0.3 MHz; eNodeBs are transmitting at a constant power P. Users are downloading FTP-like files with a mean size of 4.5 MByte and arrive in the system with a Poisson rate (λ), such that users stay in the system until they download the file within 60 seconds if allocated one chunk with a 16QAM 1/2 MCS.

Using link level simulation curves, we can choose, for each C/I value, the corresponding MCS and the resulting BLER, knowing that the maximum allowed BLER is 10%.

In Fig. 4 & 5, we present the reuse 1 and reuse 3 overall cell throughput respectively, after setting the arrival rate to 0.7 and exploring the different power levels of the system against the increase of the cell radius.

The results show that reuse 1 achieve about double peak throughputs when compared to reuse 3, this is because in reuse 3 we used only one third of the available system bandwidth. However, reuse 3 shows almost three times cell area coverage capability when compared to reuse 1.

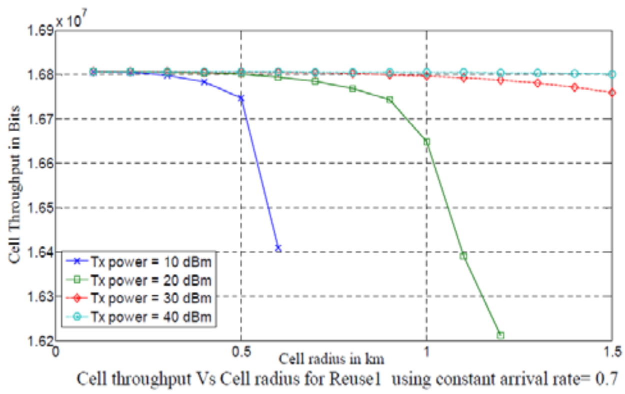

Fig. 4. Cell throughput for Reuse 1 with const. λ at different power levels

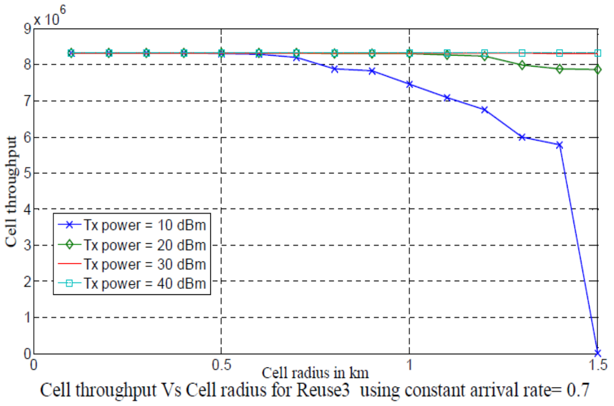

Fig. 5. Cell throughput for Reuse 3 with const. λ at different power levels.

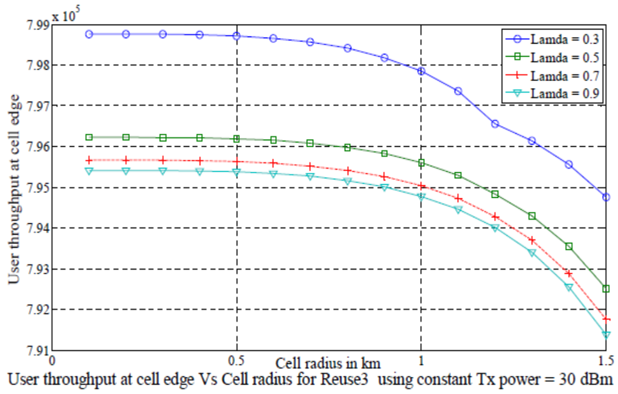

Fig. 7. User Cell Edge throughput for Reuse 3 with const. P at different λ

This is due to the fact, that as cell radius increases, the amount of interference coming from the second ring, in the case of reuse 3, tends to become negligible, yet the curves converge because the pathloss from our target user become greater, and leaves more users unserved.

In Fig. 6 & 7, we present the reuse 1 and reuse 3 cell edge user throughputs respectively, after setting the power level transmitted by eNodeBs to 30 dBm and plotting the curves for different arrival rates against the cell radius increase. The results show that in reuse 3, a user is able to achieve almost three times the peak throughput at the cell edge, than a user located at the cell edge of a reuse 1 cell. Also with respect to λ, the ratio of throughput decrease in reuse 3 is considerably smaller when compared to reuse 1. These results suggest that as the loading of the system increases, a reuse 1 tends be more vulnerable at the cell edge. It should be noted that as the radius increased, there was just a minor decrease in user throughput for both reuse schemes; this is because of the high power of the system, the system can accommodate a larger cell area coverage than the 1.5 km radius set in the above evaluation curves.

V. Conclusions

In this paper, we studied two different frequency planning schemes in the forthcoming OFDMA-based cellular system LTE in FDD mode. These schemes where reuse 1 and reuse 3 frequency allocation schemes. We began by calculating the expected number of collisions for an arbitrary number of users in a target cell. We then

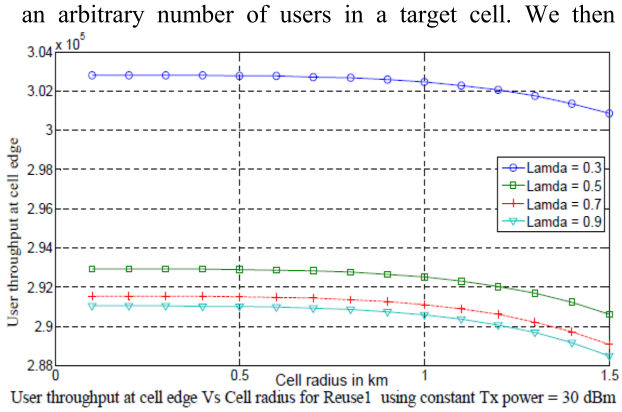

Fig. 6. User Cell Edge throughput for Reuse 1 with const. P at different λ

considered a cellular system with elastic traffic and calculated the performance measures using a Markovian approach and taking into account the physical layer (propagation conditions, AMC, inter-cell interference), we finally simulated our model and explored the limitations and performance of the system under different system dimensioning parameters.

Our numerical results have shown that a reuse 3 scheme increases substantially user cell-edge performance, and is more immune to the increase of system loading when compared to a reuse 1 scheme, due to the fact that interference is very limited in the reuse 3 than in reuse 1, because in reuse 1 the highest expected region for interference are on the cell edges.

Also a reuse 1 scheme shows to be very promising in terms of overall cell peak throughputs when compared to a reuse 3 scheme; this is due to the capacity limitation set by using only one third of the system bandwidth. However, reuse 3 has shown to be capable to achieve much greater cell area coverage, with a low power being able to cover a 1km cell radius.

To conclude, if an operator is willing to achieve high peak throughput and area coverage, while keeping eNodeBs implementation costs to a minimum, it would be suggested to use a cellular system consisting of both reuse 1 and reuse 3 schemes simultaneously. That is to say, reuse 3 frequency allocations to be used in a rural, less dense area and highways. Whilst as a reuse 1 allocation scheme can be implemented in dense urban areas.

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