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Fixed Frequency Reuse for LTE-Advanced Systems in Local Area Scenarios

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Abstract: -
LTE-Advanced systems, which aim to provide high data rate wireless services, have received world-wide researching interests nowadays. In this paper, the performance of fixed frequency reuse with different reuse factors is studied in LTE-Advanced systems. Performance is measured in terms of both average cell throughput and cell edge user throughput. It is found that a properly chosen reuse factor with respect to cell size (which leads to different level of inter-cell interference), can offer up to *30%* gain in average cell throughput and much higher gain for cell-edge user throughput in Local Area (LA). This high gain from frequency reuse makes it attractive for future LTE-Advanced systems.

Keywords: - Frequency Reuse, Local Area, LTE-Advanced.

I. INTRODUCTION

Long Term Evolution (LTE)-Advanced system, which is generally recognized as the evolved LTE system, aims to provide high capacity for improving user experience [1]. The requirements for LTE-Advanced are presented in [2], where the support for indoor Local Area (LA) networks is also highlighted. LA networks in e.g., home or office scenarios, which provide services to users in a limited geographical area [3], were raised by many companies as an important research area in the latest IMT-Advanced workshop [4]; hence, it is very important to study the performance of frequency reuse in LA networks.

In a multi-cell scenario, inter-cell interference is the major limiting factor for the system's performance [5]. This interference becomes critical for users near the cell-edge, where the interference from neighboring cells is usually very high. In order to avoid the high inter-cell interference, one possible solution is to orthogonalize the time/frequency resource unit, leading to spectrum/time sharing among neighboring cells.

Frequency reuse, as a simple way of spectrum sharing among cells, has been object of extensive studies for the existing systems. In [6], frequency reuse for circuit switched services in second generation systems is studied. The performance in packet switch systems, e.g. Evolved Universal Terrestrial Radio Access (E-UTRA) is investigated in [7], which favors reuse factor of 1. Frequency reuse in rural environments and urban areas are analyzed in [8] and [9], respectively.

Frequency reuse assigns the same frequency band in different cells, usually far from each other, thus avoiding the high interference among neighboring cells. By not using the same band for neighboring cells, the Signal to Noise and Interference Ratio (SINR) can be significantly improved, because interference can be reduced to a large extent. However, this benefit of SINR improvement comes together with a reduction of the available spectrum per cell. The capacity can be estimated using Shannon's formula as [10]:

$$TP_k = \frac{BW}{k} * \log_2(1 + SINR_k) \quad (1)$$

Where k is the reuse factor, which means only $1/k^{th}$ of the spectrum can be used by one cell; BW is the total system bandwidth in Hz; $SINR_k$ is the achieved SINR with reuse k.

As shown in Eq. (1), in order for frequency reuse to be beneficial, the increase in SINR must be able to overcome the loss in spectrum. Since the effect of SINR is scaled by the logarithm function, such a benefit can only be obtained when the SINR is not too high. If k is already very high, by further increasing k, available bandwidth will reduce while spectral efficiency remains nearly the same; degradation in system performance is expected. A suitable trade-off between bandwidth and SINR is required to utilize the spectrum in an efficient way. This can be achieved by setting the frequency reuse factor to a proper value.

This paper aims to find out the optimal frequency reuse factor in different LA scenarios, which can provide the best performance. The rest of this paper is organized as follows: Section II describes the targeted scenarios; Section III introduces the simulation methodology and assumptions; Section IV shows the simulation results for different reuse factors; Section V concludes and summarizes the paper.

II. SCENARIOS DESCRIPTION

The performance for frequency reuse in Wide Area (WA) networks, i.e., Macro cells, has been extensively studied. In this paper, we thus devote our effort into LA networks, which are quite new and require some detailed study. Three different scenarios are selected to represent the most common deployment environments for LA networks: *indoor office*, *indoor home* and *outdoor Manhattan scenario*.

A. Indoor Office Scenario [11]

In office scenario, the location of enhanced-NodeB (eNBs) can be pre-planned so that each will cover a certain area. Fig. 1 shows an example of an office scenario with 16 cells. The eNBs are placed at the center point of each cell, with users randomly distributed within the whole area. We consider two cases for simulation purpose, one with 16 cells, another with a smaller area and only 4 cells (shown inside the red rectangle). In this figure and the later one for home scenario, gray dots are used to represent eNBs; a small block represents one room (surrounded by walls) and several neighboring blocks with the same color form one cell, which is served by the eNB geographically located within it. White part is corridor / road.

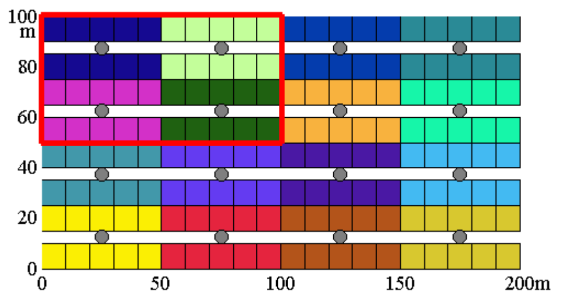


Fig. 1. Indoor Office Scenario with 16 Cells, eNBs Located at Center of Each Cell.

B. Indoor Home Scenario [11]

The difference between home scenario and office scenario is that, in home scenario, the house owner has full freedom to place the eNBs wherever possible, thereby the location of eNBs is modeled as randomized. This freedom of deployment is not available in office scenario. It is reasonable to assume a user is served by its own eNB, thereby receives service from its own eNB even if the signal strength from a neighboring eNB is higher. An example of home scenario with 16 cells is shown in Fig. 2.

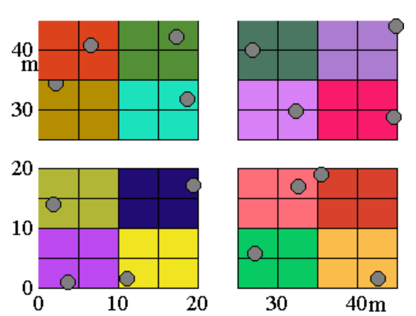


Fig. 2. Indoor Home Scenario with 16 Cells, eNBs Located Randomly Within Each Cell.

C. Manhattan Scenario [11]

Following [11], the eNBs in Manhattan scenario are placed in such a way that Line of Sight (LOS) connection between neighboring eNBs is avoided; users are connected to the eNB with the highest path gain. This secnario is shown in Fig. 3. eNBs and roads are represented in the same manner as with indoor scenarios, while a block means one building.

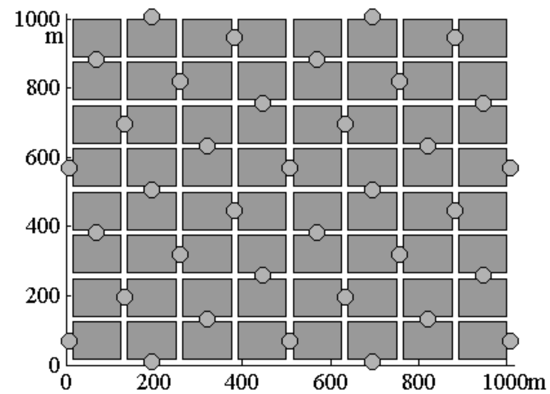


Fig.3. Outdoor Manhattan Scenario with 36 Cells, Coordinated eNB Location.

III. SIMULATION METHODOLOGY AND ASSUMPTIONS

In order to investigate the performance, the snap-shot based simulation method is used:

1. Within each snap-shot, the cell layout is generated according to the scenario;
2. Users are generated with uniformly distributed locations inside that particular scenario;
3. The SINR is calculated according to the received signal power and interference power level;
4. Throughput is obtained by mapping the calculated SINR according to the ideal link-adaptation based LTE link-level capacity.
5. A few thousands of snap-shots are simulated to get the averaged performance.

In Step 4, the capacity in a Single Input Single Output (SISO) system can be estimated by [12]:

$$S = \begin{cases} 0 & SINR < SINR_{\min} \\ BW_{eff} * \log_2(1 + \dfrac{SINR}{SINR_{eff}}) & SINR_{\min} \le SINR \le SINR_{\max} \\ 5.4 & SINR > SINR_{\max} \end{cases} \quad (2)$$

where S is the estimated spectral efficiency in bps/Hz, which is upper limited according to the hard spectral efficiency given by 64QAM with coding rate 4/5; BW_{eff} adjusts for the system bandwidth efficiency of LTE and $SINR_{eff}$ adjusts for the SINR implementation efficiency of LTE. The values for the parameters in Eq. (2) are obtained by extensive link level simulations in macro and micro cell scenarios with 10MHz bandwidth, Turbo coding, 6-tap Typical Urban channel model and LTE frame structure. User velocity is taken as *10*km/h. Table 1 shows the values for a SISO system.

Table 1. Shannon Curve Fit Parameters for LTE Downlink Link Level Capacity (SISO) [12].

BW_{eff}	$SINR_{eff}$	$SINR_{min}$	$SINR_{max}$
0.56	*2.0*	*-10*dB	*32*dB

The following metrics are used for the evaluation of the system performance:

1. *Average cell throughput*: This is the cell throughput averaged among all the simulated cells.
2. *Cell edge user throughput*: This is the *5%* user outage throughput; obtained as the *5%* percentile of the Cumulative Distribution Function (CDF) of user throughput.

To simplify the problem and focus mainly on frequency reuse, we use no power control and simple Round Robin (RR) frequency domain scheduling within each cell. By using RR, each user gets an equal share of the available resources of its own cell. Full buffer mode is assumed for the traffic model so that all possible resources would be used. Also, we do not include the effect of fast fading since the impact is expected to average out over a certain time period. Radio Frequency (RF) imperfections such as Error Vector Magnitude (EVM) etc. are not included in the modeling. This is the reason for the extremely high peak SINR values that we will see in later sections. When calculating system capacity, the SINR values are upper-bounded by $SINR_{max}$, which is 32dB, thereby they will not give a biased peak data rate.

For any frequency reuse factor, an in-advance frequency plan is assumed so that the inter-cell interference is minimized. The following figure shows the frequency plan for 16 rectangular cells, which tries to maximize the spectrum usage while minimizing the inter-cell interference for reuse factors 4 and 8. The number in the matrix is the assigned frequency part for each cell. For Manhattan scenario, because the location of eNBs is coordinated and there is no LOS between neighboring eNBs, assigning frequency band in a sequential manner starting from the bottom left eNB until the top right one should provide good enough performance for frequency reuse. This is how we assign the frequency band in Manhattan scenario simulations.

The assumptions for the simulations in general, including the settings for the link level performance implied by Table 1, is according to the LTE specifications [11,13,14]. Table 2 gives a short summary.

4	3	2	1
1	2	3	4
4	3	2	1
1	2	3	4

8	7	6	5
4	3	2	1
5	6	7	8
1	2	3	4

Fig. 4. Frequency plan for reuse factor of 4 and 8.

Table 2. Parameters and Assumptions for System Level Evaluation [11, 13, 14].

PARAMETER	**SETTING/DESCRIPTION**
Spectrum allocation	100 MHz at 3.5 GHz
Access scheme	OFDMA
Duplexing scheme	TDD
Users per cell	Office: 5 ~ 10 users Home: 2 ~ 4 users Manhattan: 10 users
eNB characteristics	
Total transmit power	Home/office scenario: 24 dBm Manhattan scenario: 30 dBm
Antenna system	"Omni-directional", 3 dBi gain
Minimum Coupling Loss	45 dB
User characteristics	
Antenna system	"Omni-directional", 0 dBi gain
Receiver noise figure	9 dB
Traffic mode	Full buffer
Propagation model	
Indoor modeling	
Room size	Office scenario: 10x10 m Home scenario: 5x5 m
Corridor width	5 m
Internal walls	Office: light attenuation, 5dB Home: inside home: light attenuation, 5dB; between homes: medium attenuation, 10dB.
Path loss model	LOS: $18.7 \log_{10} (d[m]) + 46.8 + 20\log_{10} (f[GHz]/5.0)$ Non Line of Sight (NLOS): $20 \log10 (d[m]) + 46.4 + n_w \cdot L_w + 20\log10 (f [GHz]/5.0)$ where d = direct-line distance [m], f = carrier frequency [GHz], n_w = number of walls between transmitter and receiver, L_w = wall attenuation [dB]
Standard deviation of Shadow fading	LOS: 3dB NLOS: Light wall: 6dB Heavy wall: 8dB
Outdoor modeling	
Model type	Manhattan-grid building [11]. Building size:110x110 m; Street width: 15 m
Path loss model	Location & distance dependent path loss model [11].

IV. SIMULATIONS RESULT

The performance evaluation for fixed frequency reuse in the Downlink (DL) under the assumed scenarios with different frequency reuse factors is presented. For all the cases, the throughput is normalized with respect to the case of reuse 1. Because the LTE link-level capacity is used, similar behavior is also expected for current LTE system, though the bandwidth is much narrower than the LTE-Advanced system.

A. Small Office Scenario

Fig. 5-a shows the average cell throughput with 4 cells, in office scenario; Fig. 5-b shows the cell edge user throughput. From these two figures it can be seen that frequency reuse with factor 2 achieves both the maximum cell throughput and cell edge user throughput, with *19%* and *246%* gain with respect to universal frequency reuse, i.e., reuse factor 1.

As expected, increasing the frequency reuse factor will not always benefit the system performance, because of the reduced transmission bandwidth. Fig. 6 shows how SINR is affected by frequency reuse factors. It can be seen that, when reuse factor increases from 2 to 4, the gain in SINR improvement is not very significant as compared to from 1 to 2. The performance for reuse factor 4 is therefore worse than factor 2, because the gain in SINR cannot compensate for the reduction in bandwidth, which is *50%.*

B. Extended Office Scenario

Fig. 7 shows the performance in extended office scenario. Comparing Fig. 5 and Fig. 7, the following observations can be made: In the small office scenario, the best outage user throughput is achieved with reuse factor 2. However, with high inter-cell interference in the extended scenario, reuse 3 beats the performance of the other reuse factors. Also, it can be seen in average cell throughput, reuse 3 achieves the same performance as reuse 1, while its performance are much worse than reuse 1 in small office scenario.

C. Home Scenario

Fig. 8 shows the performance in home scenario. Because of the randomized eNB location, the frequency plan shown in Fig. 4 is not necessary the optimal solution, this leads to lower cell throughput gain (*6%*) than with fixed eNB location, which is *25%.* However, in terms of cell edge user throughput, high reuse factor still offers much better performance than reuse 1. This is because with frequency reuse 1, a user may suffer from extremely high interference from its neighbors, while the signal strength is very low. Such an unlucky situation is avoided by high reuse factors.

D. Manhattan Scenario

Fig. 9 shows the performance in Manhattan scenario. In this case, the cell size is much larger than in indoor office/home scenarios. This causes high path attenuation and in turn, very low inter-cell interference. According to the discussion before, high inter-cell interference favors high reuse factor, and vice-versa. Indeed, the average cell throughput shows that any reuse factor that is larger than 1 gives worse performance than universal frequency reuse. However, when looking at the cell-edge users' performance, high reuse factor again becomes beneficial. The reason is that cell-edge UEs receive much higher interference than the average level, which can be significantly reduced by frequency reuse. If the target is to maximize the average cell throughput, reuse factor 1 can be used; if protecting cell-edge users' Quality of Service (QoS) is required, a high reuse factor of 4 becomes advantageous.

Comparing the performance between indoor office/home scenarios with Manhattan scenario, the gain from using a high frequency reuse factor is reduced, because of the reduced inter-cell interference. For larger cells, e.g. Macro cell case, the effect of inter-cell interference is even smaller, thus frequency reuse 1 is expected to provide higher cell throughput than any other reuse factor.

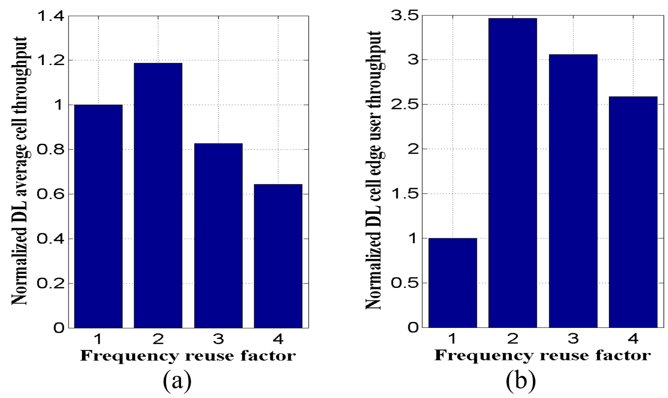


Fig. 5. Frequency reuse in office scenario with 4 cells.
a) Average cell throughput; b) Cell-edge user throughput.

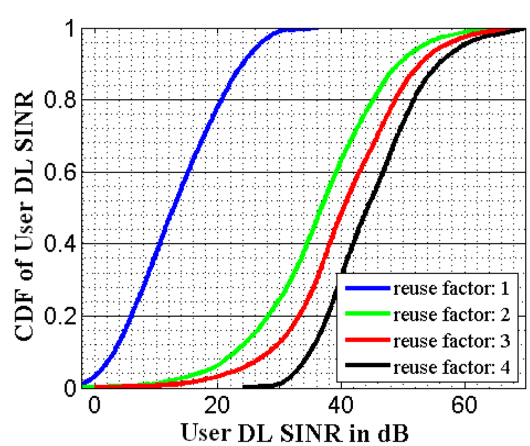
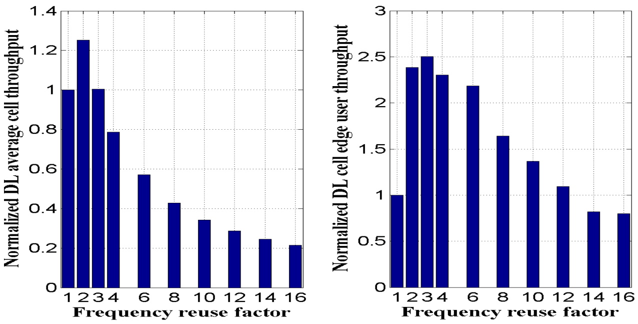
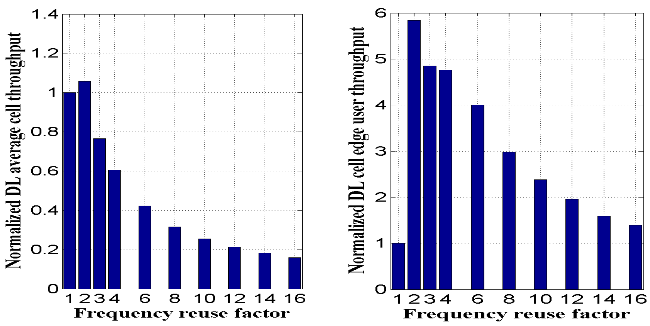


Fig. 6. SINR distributions with different frequency reuse factors in office scenario with 4 cells.



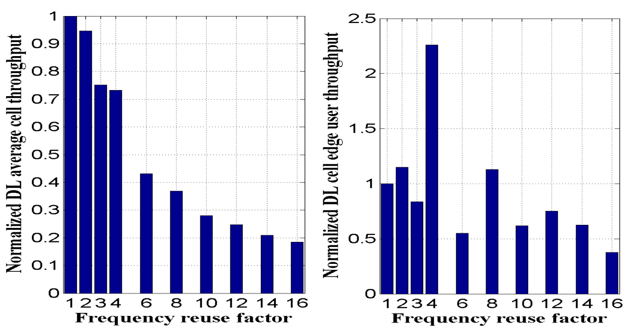
(a) (b)

Fig. 7. Frequency reuse in office scenario with 16 cells.
a) Average cell throughput; b) Cell-edge user throughput.



(a) (b)

Fig. 8. Frequency reuse in home scenario with 16 cells.
a) Average cell throughput; b) Cell-edge user throughput.



(a) (b)

Fig. 9. Frequency reuse in Manhattan scenario with 36 cells.
a) Average cell throughput; b) Cell-edge user throughput.

V. CONCLUSION

Based on the performance shown in the previous section, in order to maximize cell/user throughput, frequency reuse factor should be chosen according to inter-cell interference level, which is highly dependent on the cell size. High interference favors a high reuse factor and vice-versa.

For large cell sizes, e.g. Micro and Macro cells, due to the high path attenuation, interference is considerably low and frequency reuse factor 1 provides the highest average cell throughput among all reuse factors. For small cell sizes, e.g. LA networks, reuse factor 2 offers in most cases higher cell throughput than the other reuse factors. If the target is to improve cell edge user performance, frequency reuse factor 2 is optimal or close to optimal in LA networks. However, in Micro or Macro cells, a much higher factor of 4 is needed to maximize the cell edge user performance. In this work the most representative layouts for LA scenarios are selected for evaluation, but we should be aware that the actual performance is highly dependent on the exact layout, and the findings in this study cannot be applied to all LA scenarios.

Other than interference level, another important issue that will affect cell performance is traffic condition, which affects the spectrum load and gives a different interference pattern. How to autonomously adjust the frequency reuse factor considering both interference level and traffic condition is an interesting area for future work. Although TDD is used in this study, the conclusion is drawn independently of the duplexing scheme, thereby is also valid for FDD systems.

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