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Self-organized Spectrum Chunk Selection Algorithm for Local Area LTE-Advanced

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Abstract: -
This paper presents a self organized spectrum chunk selection algorithm in order to minimize the mutual inter-cell interference among Home Node Bs (HeNBs), aiming to improve the system throughput performance compared to the existing frequency reuse one scheme. The proposed algorithm is useful in Local Area (LA) deployment of the Long Term Evolution-Advanced (LTE-A) systems, where the HeNBs are expected to be deployed randomly and without coordination in distributed manner. The result shows that the proposed algorithm effectively improves the system throughput performance with very limited signaling exchange among the HeNBs,

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

I. INTRODUCTION

The LTE-A which is generally recognized as the evolved Long Term Evolution (LTE) system, aims to provide high capacity for improving user experience [1]. It is also expected to be flexible in terms of deployment. The Local Area deployment scenarios such as in home or office environment provide services to users in a limited geographical area [2]. This deployment scenario has been considered as an important research area in the latest International Mobile Telecommunications-Advanced (IMT-Advanced) workshop [3]. Keeping this in view it becomes important to investigate techniques to be suitable for such deployment scenarios in order to improve the throughput performance.

Fixed frequency reuse schemes have been considered as effective means to improve throughput performance for many systems by reducing inter-cell interference [4, 5, 6]. In traditional Wide Area (WA) deployment scenarios, this is achieved by a proper network planning, including frequency reuse plans, base station location, controlling transmit power levels and antenna radiation characteristics. In contrast to such scenario the deployment of HeNBs for LA of LTE-A cannot be planned before hand by the operators, because of the random and uncoordinated deployment, since the owner of the each HeNB device will be responsible for the deployment. Hence, such network planning is absolutely not feasible. Therefore the network has to operate in random deployment scenario. It is also natural to envision the lack of coordination between operators providing services over the same geographical area in distributed manner. Moreover, it is also expected that such deployment scenario will lead to a possible environment where all HeNBs share the available radio spectrum based on certain physical layer mechanisms and higher layer policies. Keeping these aspects in view, a mechanism is required to assign spectrum in self organized manner to the HeNBs deployed in the local area. The algorithm should help HeNBs to adapt to the suitable set of the spectrum chunks in order to minimize the mutual interference and improve the system throughput performance.

In the previous study [11] it has been outlined that the fixed frequency reuse scheme with reuse factor two helps to achieve the highest throughput performance compared to all other fixed frequency reuse schemes in the LA deployment scenario. However, the frequency reuse two, like other schemes requires beforehand network planning for spectrum assignment in order to minimize the mutual interference. As an example, fig. 1 shows an optimal frequency plan with reuse two in an indoor office environment with 4 cells, where different colors are used to represent different spectrum chunks. Here a chunk is defined as the part of the available spectrum band for allocation to a HeNB, following a frequency reuse scheme. In our example reuse two has been considered, hence only two spectrum chunks are shown here. In this figure the x and y dimensions have been indicated in meters.

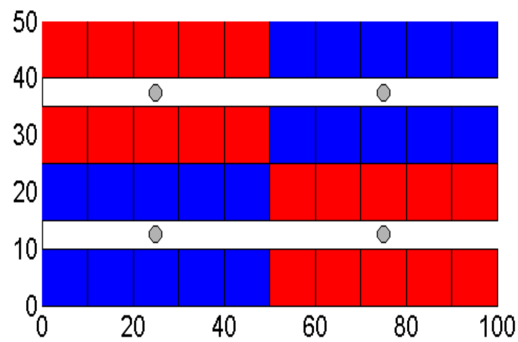

Fig. 1. Spectrum allocation for frequency reuse two with optimal plan.

When we can plan a network beforehand, this configuration can be easily achieved. However in the assumed LA scenarios of LTE-A such planning is not feasible, because of random and uncoordinated deployment. Therefore a mechanism is required to be developed for such scenario in order to assign spectrum in self organized manner and achieve nearly the same performance as is achievable with the planned network deployment. Keeping this in view, a Self-organized spectrum chunk selection has been proposed in this paper. The algorithm starts with random chunk selection for each cell, which may lead to one of the following configurations, considering four cells. In this figure the x and y dimensions have been indicated in meters.

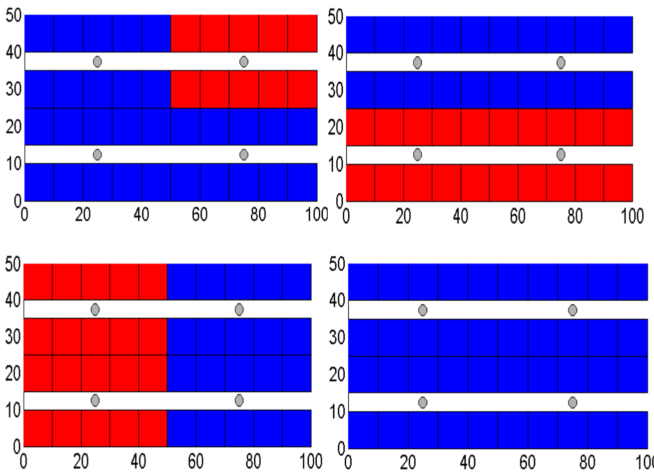

Fig. 2. Possible spectrum allocation for frequency reuse two with random chunk selection

The aim of the proposed algorithm is to tend to reach to the optimal spectrum assignment as shown in the figure 1 from any of the possible configuration obtained in figure 2, due to selection of chunks in random manner. The details description of the algorithm is given in section II.

The rest of the paper is organized as follows: Section II describes in detail the proposed spectrum selection algorithm; Section III describes the considered scenario, assumptions and used methodology. Section IV presents the result obtained by the proposed algorithm under different traffic conditions, compared with different frequency reuse schemes. The conclusions are provided in section V.

II. ALGORITHM DESCRIPTION

The proposed self organized spectrum chunk selection algorithm aims to achieve the performance close to the planned frequency reuse two scheme. Therefore, we consider the whole spectral bandwidth to be divided in two spectrum chunks of equal size. However, this algorithm can be suitably used to give performance close to any other frequency reuse schemes. The flow chart for the algorithm is shown in fig. 3. The algorithm works in the following steps.

Step 1: Initialization phase

As a HeNB is powered on, at first, it randomly selects a spectrum chunk to establish the communication with its users. In this step a HeNB is also initialized with a sequence number and a switch over number. The sequence number determines its position in the queue of HeNBs, and thereby controls the turns of the HeNBs to update their chunk selection. We considered that each HeNB has to wait for its turn to update the spectrum assignment and while waiting for its turn it keeps the previously selected chunk for communication. The switch over number is used to enforce a HeNB to switch over to another spectrum chunk selection in order to avoid the dead lock situation, in which all the HeNBs may become stable over the same non-optimal spectrum assignment. In fact the switch over number indicates the maximum number of times a HeNB is allowed to retain the same spectrum chunk selection. Whenever this number reaches a pre-defined value, the HeNB switches over to the other chunk selection. After this the switch over number is again initialized

.

Step 2: Condition to update the chunk selection

After the initialization phase is over, the HeNB reduces its sequence number by one in each update interval, until it reaches 0, which indicates the turn for the HeNB to update its spectrum chunk selection. After this the sequence number is reset to the pre-specified value.

Step 3: Interference consideration for chunk selection

At each turn, the spectrum chunk selection is based on the information available to compare the level of interference over the two chunks. The uplink (UL) Receive Interference Power (RIP) over a chunk is considered as the interference measurement yard stick. The UL RIP is a well established LTE feature, which is defined as the total power received over the spectrum chunk by a base station.

The following expression is used to determine the spectrum chunk selection

$$\text{Abs}(RIP1 - RIP2) > P\_Threshold.$$

Where, RIP1 an RIP2 indicate the interference levels on the first and the second chunk in dB. Abs indicates the absolute values. The absolute values of the difference of two is compared against the specified threshold (P_Threshold), which ensures a sufficient amount of difference in the interference level of the two chunks before making a decision for chunk selection. This interference threshold may be a tradeoff with regards to how much interference can be tolerated against the increased signaling requirement in case of switching over to the another chunk. Therefore there is a consideration that a HeNB will not switch over the other chunk, unless there is a significant gain for doing so.

If the difference is very small between the two chunks (i. e. < P_Threshold), then the HeNB will not switch to the other chunk for a specified number of times, specified by the switch over number. But when the maximum possible value for the switch over number is reached then the HeNB is forced to switch over to the other chunk. In this step even if the spectrum chunk currently in use may be more suitable, even then a changeover is forced by the switch over number, this helps to avoid the dead lock situation. This step increases the possibility for more appropriate spectrum chunk selection in the subsequent steps.

Step 4: Switching over to other Chunk

If the difference in the RIP of the two chunks is very significant (>P_threshold), the eNB will choose always the chunk with minimum RIP.

The proposed self organized spectrum assignment algorithm has the following features:

1. It operates based on the UL RIP measurement, which a currently used feature in LTE system
2. It works in a random and uncoordinated deployment scenario with very little requirement for the signaling exchange among HeNBs.
3. It allows the HeNBs in sequencer, one after the other , for spectrum chunk selection thereby it avoids the complexity in interference assessment at the time of spectrum allocation.
4. It provides a scalable solution. However, when the number of HeNBs is very high, a long convergence time is required, as only one HeNB is allowed to change its allocation at one time. However, during this convergence time, the transmission within each HeNB still continue.
5. The performance of this algorithm is upper-bounded by the performance of fixed frequency reuse two scheme, since only two spectrum chunks have been considered for this algorithm.
6. The assigned spectrum is used for both Uplink (UL) and Downlink (DL) transmissions.

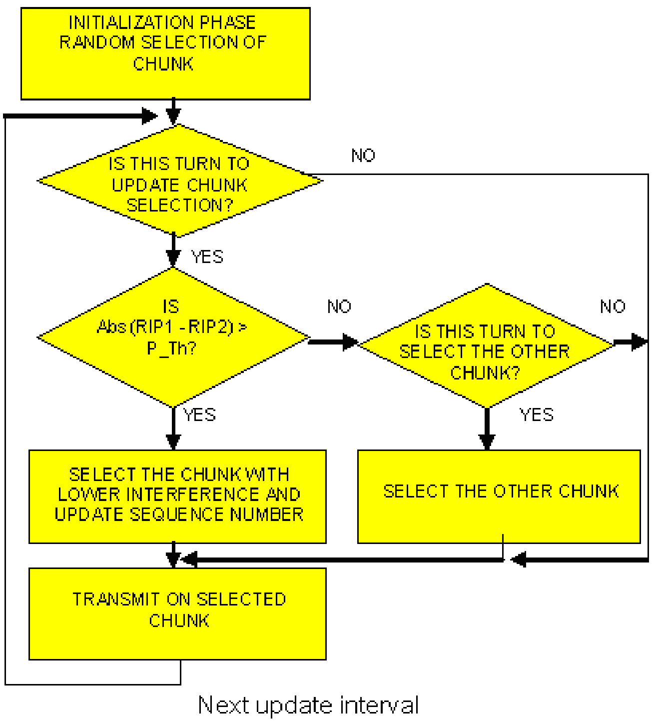

Fig. 3. Flowchart of the Self-organized Spectrum Assignment Algorithm

III. SCENARIO DESCRIPTION, SIMULATION METHODOLOGY AND ASSUMPTIONS

The indoor LA office scenario described in [7] has been used to model the scenario. It contains 4 HeNBs, located at the center of each cell. Each HeNB provides services for the coverage area of 50 meter X 25 meter, consisting of 10 rooms, as shown in fig. 1.The performance has also been examined, when the location of HeNBs are randomized, i. e. the locations of the HeNBs are not assumed at the centers of the cells.

In order to investigate the performance, the snap-shot based simulation method has been used where,

1. within each snap-shot, the cell layout is generated according to the scenario,
2. users are generated with uniformly distributed locations,
3. Signal to Interference and Noise Ratio (SINR) is calculated according to the received signal power and interference level,
4. Throughput is obtained by mapping SINR according to the LTE link-level capacity [8].
5. A few thousands of snap-shots are simulated to get the averaged performance.

As discussed in Step 4 above, for a SINR value within $[SINR_{\min}, SINR_{\max}]$, the capacity has been estimated using [8], given as

$$S = BW_{eff} * \log_2(1 + SINR / SINR_{eff}) \qquad (1)$$

Where, S is the estimated spectral efficiency in bps/Hz. For a Single Input Single Output (SISO) system, if SINR is less than $SINR_{\min}$, then *S=0* is considered and if SINR is larger than $SINR_{\max}$ then S=*5.4* is considered. The BW_{eff} and $SINR_{eff}$ indicate the effective bandwidth and the effective SINR respectively. The assumed values for the above said parameters are given in following table 1.

Table 1. The Assumed Tthrough Mapping Parameters for LTE Link Level Capacity [8].

	BW_{eff}	$SINR_{eff}$	$SINR_{\min}$	$SINR_{\max}$
DL	0.56	2.0	-10 dB	32 dB
UL	0.52	2.34	-10 dB	35 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, which can be obtained by sorting the throughput for all users and taking the one corresponds to the 5% Cumulative Distribution Function (CDF) value.

3. *Chunk selection interval:* This is the time period for one chunk selection operation. It contains an integer number of transmission frames.

To simplify the computations and to mainly focus on the performance evaluation of the proposed algorithm, some simplifications are assumed, such as no power control has been exercised, the Round Robin mechanism has been used for frequency domain scheduling, and fast fading has not been considered..

IV. PERFORMANCE RESULTS

The performance evaluation of the proposed algorithm is carried out based on the LTE specifications [7, 9, 10], with parameters summarized in Table 2.

Table 2. Parameters and Assumptions for System Level Evaluation [7,9, 10].

PARAMETER	SETTING/DESCRIPTION
Spectrum allocation	100 MHz at 3.5 GHz
Access scheme	DL: OFDMA UL: SC-OFDMA
Duplexing scheme	TDD
UEs per cell	5 ~ 10 UEs
HeNB characteristics	
Total TX power	24 dBm
Antenna system	"Omni-directional", 3 dBi gain
Receiver noise figure	7-9 dB
Minimum Coupling Loss	45 dB
UE characteristics	
TX power	24 dBm
Antenna system	"Omni-directional", 0 dBi gain
Receiver noise figure	9 dB
Propagation model	
Room size	10x10 m
Corridor width	5 m
Internal walls	light attenuation, 5dB
Path loss model	Line of Sight (LOS): $18.7 \log_{10} (d[m]) + 46.8 + 20\log_{10} (f[GHz]/5.0)$ None Line of Sight (NLOS): $20 \log10 (d[m]) + 46.4 + nw \cdot Lw + 20\log10 (f [GHz]/5.0)$ 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: 3 [dB] NLOS: 6 [dB]

A. Downlink average cell throughput

Fig. 4 shows the performance of Downlink (DL) average cell throughput of the proposed algorithm compared with the fixed frequency reuse 1, 2 and 4 schemes. It is observed that the proposed algorithm presents improved performance compared to fixed frequency reuse 1 and 4 schemes. However, its performance is slightly lower compared to reuse 2 schemes. It is important to note that the fixed frequency reuse 2 scheme undergoes beforehand network planning for optimal performance. It is encouraging to have a very close performance in self organized manner in random and uncoordinated deployment scenario.

B. Downlink cell edge user throughput

Fig. 5 shows the DL cell edge user throughput performance. It can be seen that the performance of the proposed algorithm is significantly higher compared to frequency reuse 1 scheme (in the order of 200 % ~ 300 %). We observe nearly the same performance as reuse 4 scheme, however, a lower than reuse 2 scheme is realized.

C. Convergence time

As mentioned before, this algorithm requires some time to converge to the nearly optimal frequency plan. Fig. 6 shows the performance of the algorithm at different times. It can be seen that the performance is stabilized after 10 selection intervals, with significant improvement.

D. Performance in Uplink

With the same chunk allocation as DL transmission, similar performance has also been realized in UL.

E. Performance with randomized HeNB location

The results so far shown are with respect to the fixed HeNB location. However, in reality, it may be difficult to control this location, especially in home scenarios where the owner is assumed to have the main responsibility for HeNB deployment. Keeping this scenario in view, this becomes important to evaluate the performance with random locations of the HeNBs. The result of DL average cell throughput is shown in Fig. 7, where it can be seen that nearly the similar performance is realizable.

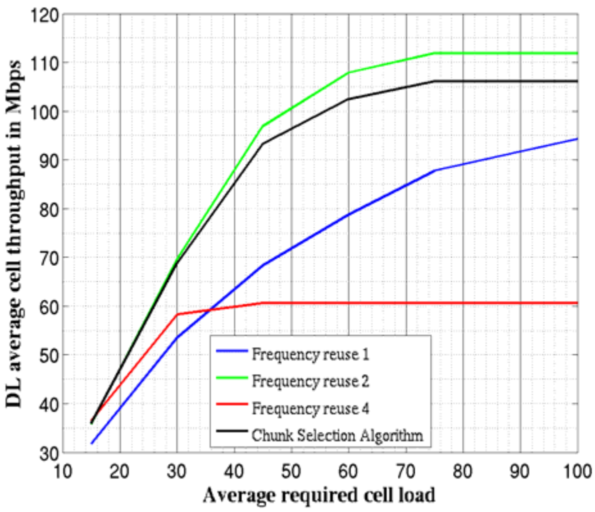

Fig. 4. Comparison of DL Average Cell Throughput

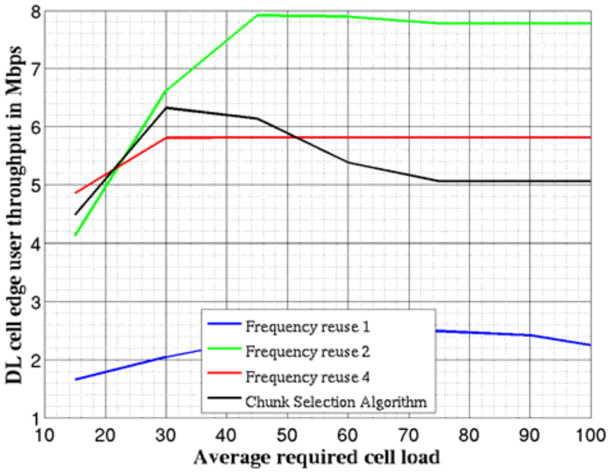

Fig. 5. Comparison of DL Cell Edge User Throughput

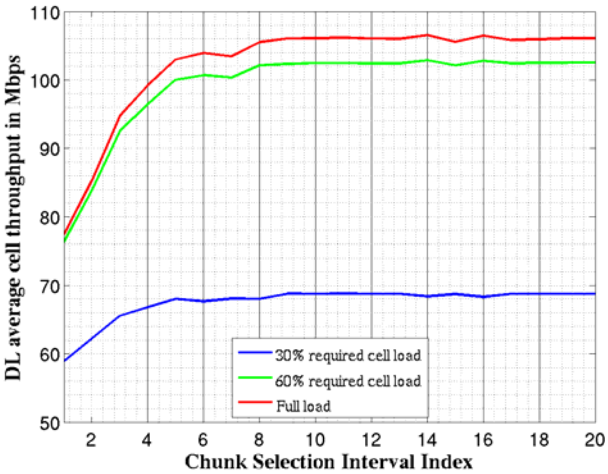

Fig. 6. Convergence Time of Algorithm

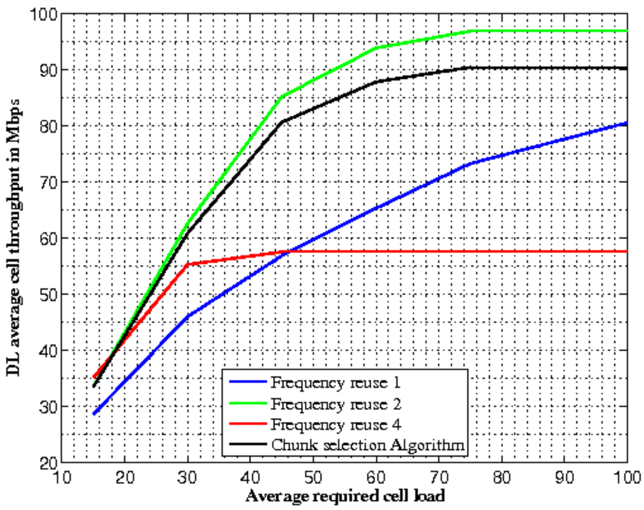

Fig. 7. DL Average Cell Throughput with Randomized HeNB locations

V. CONCLUSION

In this paper, we proposed a mechanism for self organized spectrum chunk selection algorithm. The proposed algorithm aims minimize the mutual inter-cell interference in order to improve the system throughput performance for LA deployment of HeNBs assuming LTE-advances systems deployment scenario. It works with very limited signaling exchange among the HeNBs and requires no additional measurements than what is already established for the LTE. These features make it suitable for LA deployment scenarios, where the optimal frequency plan is infeasible to realize because of the expected random and uncoordinated large scale deployment of HeNBs. Along with the features of scalability and operation simplicity, the algorithm approaches the performance of fixed frequency reuse 2 scheme and provide much better performance than other frequency reuse schemes, such as reuse 1 and 4.

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