On the Performance of Decentralized Cell Edge Coordinated Scheduling in Small Cell Clusters with Different Densities

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***Abstract*—With the expected increase in data traffic by multiple hundredfolds in the coming years, future networks will experience more and more deployment of small cells with or without detailed network planning to increase the network capacity. Networks populated with such dense clusters of small cells will likely encounter very high interference. Thus there is an urgent need to develop strategies that could help to avoid such high interference especially for cell edge users in small cell clusters. In this paper, a decentralized cell edge coordinated scheduling (CECS) has been investigated for the performance of users at varying inter-site distance especially in the overlapped regions. For certain cluster densities CECS brings significant increase in the per cell edge user throughput. It is also observed that for a certain guaranteed bit rate (GBR) the coordinated approach outperforms the other schemes such as Full Reuse (FR) and fractional frequency reuse (FFR) in the sense of the mean user throughput and the amount of satisfied users in all the considered scenarios.**

I. Introduction

[1] User data traffic in future (5G) cellular networks is expected to increase even by a factor of 1000 from 2010 until 2020 [1]. It is also widely acknowledged that an essential factor in answering this demand is via cells which are smaller in size, aiming comparatively fewer connected user equipments (UE) per cell, with their locations closer to the base station in order to have good received signal strength. The 3GPP standardization body recommendation to use frequency reuse factor one for the future LTE wireless networks would bring interference within the clusters of small cells via densification, especially for the cell edge users, as will be shown later in the text.

3GPP standard documents do not define any exact method in order to avoid this interference. Rather there are recommendations for using coordination based approach with the help of certain parameters that the base stations could share on X2-interface [2]. Actual implementation of such coordination based scheme is now up to the vendors to develop their own strategies for avoiding interference by sharing certain parameters among the base stations.

Several different strategies such as FFR [3] have been investigated a lot for interference avoidance with or without coordination. The major drawback in FFR is the inefficient utilization of the spectrum as the frequency reuse factor increases. There is also Co-operative Multipoint (CoMP) [4] scheduling technique which has been heavily investigate in recent years, briefly discussed later in the text.

However, to the best of authors knowledge most of the prior published work address the interference avoidance problem in small cells together with the higher tier network. However, there is an urgent need to investigate a simple coordinated scheduling with a special focus on the scenario when a macro cell is not transmitting and only the small cells in a cluster are transmitting. The main focus of this work is to investigate the scenarios where the achievable gains for the edge user throughput are significant. It is dynamic in the sense that the frequency reuse factor used is one. The resource scheduling follows the traffic demand and user location in the cells. The possible drawback of this approach could be the signalling overhead to share the scheduling information among the cells. However, in the future cellular networks the small cells are expected to have good back-haul connectivity either wired or wireless. Sharing the scheduling information should not be a problem even if it is done in the order of hundreds of milliseconds. However, to find a good trade-off this aspect is needed to be further investigated and is not included in the scope of this work.

Results have been compared with FR and FFR for clusters with different densities in order to identify the cases where coordination based approach brings more benefits.

The paper is organized as follows. Section II explains in detail the interference problem, when the frequency reuse is one. Section III presents some of the related work, which has been thoroughly investigated by the research community. In Section IV the CECS approach is presented with the comparison of results. Section V concludes the presented work.

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II. Inter-cell interference in small cell cluster

For a user in a cellular network the achievable maximum throughput depends on the ratio of its received signal power from the serving small cell base station (SBS) and the received signal power from the neighbouring SBSs as

$$SINR = \frac{S}{(\sum_{n=1}^{k} I_n) + N} \quad (1)$$

where *'S'* is the power of the received signal from the serving BS, *'I'* is the received power of the interfering signal and *'N'* is the noise power. The better the value of *SINR* the better is the system capacity and performance. The value of *'S'* depends mainly on the distance of the user from the serving base station and the propagation environment. Typically, for the users at the cell edge the value of *'S'* is smaller and they experience more interference which limits the capacity of cell in those regions. In Fig. 1 an *SINR* map for a cluster consisting of nine small cells with 50m horizontal/vertical inter-cite distance is presented. The significant interference especially for the cell edge users is clearly visible.

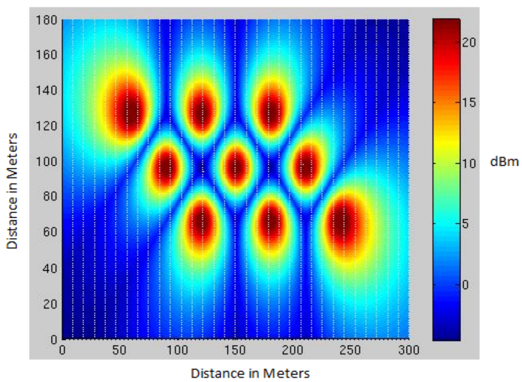


Fig. 1. The SINR map for the cluster with nine cells with frequency reuse one

III. Related Work

In this section we will briefly explain the background work, which has been investigated intensively such as CoMP and FFR. Related items are also active in standardisation.

A. CoMP

It is one of the core features of LTE release 11. As the name suggests the idea is based on a UE which is connected to multiple transmission points, which could include multiple radios or multiple antennas connected to single radio for simultaneous transmission and reception. In CoMP the question is always to select the best transmission point for a UE. It brings improvement to QoS but could also bring the overheads both in the control and data plane. Network infrastructure and its related cost are also important aspects. There is a need perhaps to evolve the networks starting with simplified coordination schemes. One such scheme is investigated in this paper for its usefulness in different network densities.

B. Fraction Frequency Reuse

In this approach the spectrum is divided into two or more fractions which are allocated to different regions in the network such that the interference is reduced [3]. There are *static, semi-static* and *dynamic* approaches, which can act either in a *centralized* or *decentralized* manner.

1) Static FFR: In static type FFR the radio resources are typically divided between the center and edge regions [3] at the time when the network is planned. This leads to inefficient spectrum utilization since fewer resources are available for scheduling a user. The inner regions could use low-transmission power with a small reuse factor. The cell edge users are served with higher transmit power and higher reuse factor, leading to further reduction in available resources for cell edge users.

Adding some flexibility to the strict approach results in *soft frequency reuse*. The flexibility is such that the free resources primarily dedicated to be used at the cell edges could be used at the inner regions to increase the inner region's capacity [5], [6].

2) Semi-static FFR: In this approach typically traffic related KPIs are taken into consideration. In the edge regions the total number of subbands are allocated depending on the traffic while simultaneously maintaining the orthogonality of subbands among the neighboring cells to keep the interference lower [7]–[9]. The adjustable parameters may include the total number of subbands and the allocation proportion of subbands for the center and edge regions.

3) Dynamic FFR: In this approach the radio resources are managed in a centralized or decentralized manner without any prior frequency planning of the network. The fundamental concept is based on the fact that each cell tries to maximize a certain utility function, as proposed in [10]–[12]. Solving the optimization problems require complex algorithms whose decisions may be difficult to disentangle, and adopting such methods by the operator can face challenges.

IV. Cell Edge Coordinated Scheduling

A very simple decentralized coordinated radio resource management scheme per resource block (RB) [13] with frequency reuse factor 1 has been investigated in this work to increase the cell edge user throughout within a cluster of small cells. It is similar to dynamic FFR, but does not make use of any utility functions thus avoiding some system complexity and comparatively reducing signalling overhead.

The general overview of the concept has been presented in Fig. 2 with the help of two small cells overlapping each other. In each cell, there are two users connected to its serving SBS indicated by the dashed lines, with one of the users located in the overlap region. For simplicity assume that only three RBs are available to the cluster for scheduling. The users located in the non-overlapping regions are not potentially interfered and thus could be scheduled by the two neighbours on same resources in the same time event. However, if a cell has scheduled certain resources for its user in the overlapped region, the neighbouring cell will avoid scheduling its users

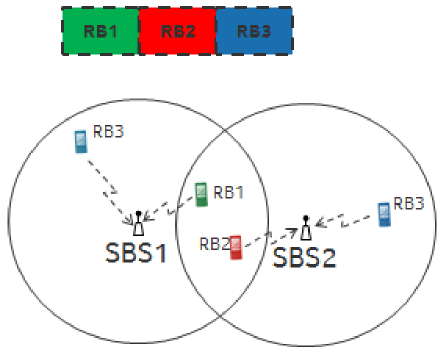


Fig. 2. General overview of the CECS resource sharing between two cells in the cluster

TABLE I
SIMULATION PARAMETERS

Parameter	Value
No. of Cells	5
Cell Load	Balanced (14 UEs/cell)
User Distribution	Random
Traffic model	GBR (1.5Mbps per User)
System Bandwidth	20MHz
SBS Tx Power	30dBm
Simulation Time	100 Sec
Inter-Site Distances	30m
	50m
	100m

on those resources and will probably use other free resources for scheduling, if available. In Fig. 2 the users in the non-overlapping region in both cells are scheduled with RB3, whereas in the overlapping region SBS1 and SBS2 use RB1 and RB2 to schedule their users, respectively.

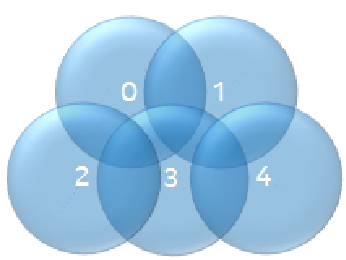
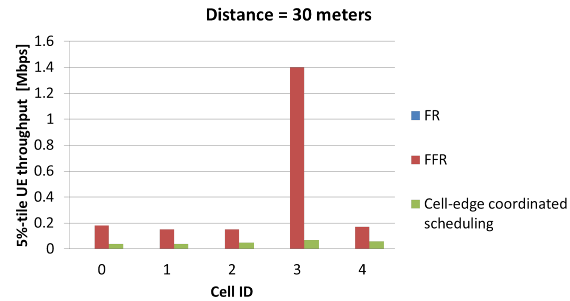


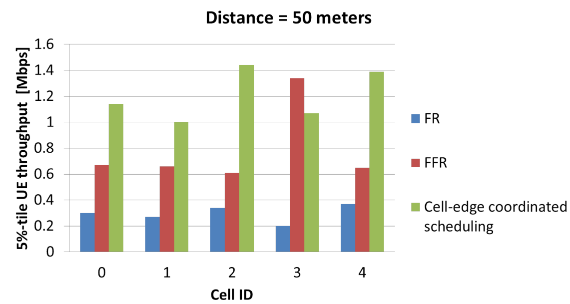
Fig. 3. Simulation scenario of a cluster with five small cells

A. Implementation Strategy

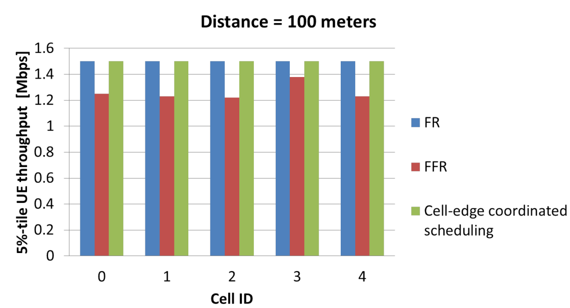
One way to implement CECS is to use the neighbouring SBS received signal power (RSRP) measurements sent by the user equipment to the serving SBS. The SBS could identify the RBs with RSRP above a certain threshold to avoid scheduling its users in the overlapped region on those RBs. An example pseudo-code for the algorithm is shown in Algorithm 1 on the next page. The scheduling is executed on per-cell basis in random order to avoid unfair resource allocation.



(a)



(b)



(c)

Fig. 4. 5-*th* percentile throughput at inter-site distance (a)30m (b)50m (c)100m

Another way is to exchange *Relative Narrow Band Tx Power (RNTP)* [14] value over X2-interface among the SBSs. This information simply consists of flags for each RB either with the value 1 or 0 to indicate whether the downlink transmission power is lower than a certain threshold. The RBs for which the RNTP is set to 1 are most likely the ones used at the cell edge. The neighbouring SBS could share this RNTP map in order to define its scheduling events in the time and frequency domain. The scheduling policy among the cells could follow a greedy approach or a fair approach based on the needs of a cell. The policy followed in this work is a fair approach in which the cells probably get the same probability to occupy certain RBs. In the CECS approach the frequency reuse factor is one. It is more dynamic and robust following actual traffic variations and user locations in the network. All the cells have equal access rights to the spectrum followed by the scheduling policy.

TABLE II
CELL EDGE INTERFERENCE IN dBm

	30m			50m			100m		
Cell	**FR**	**FFR**	**CECS**	**FR**	**FFR**	**CECS**	**FR**	**FFR**	**CECS**
0	-20.9	0.97	-13.6	-5.9	11.1	-1.11	9.2	19.7	10.1
1	-20.6	0.15	-12.8	-6.0	10.6	-0.45	9.0	19.5	9.8
2	-19.7	0.04	-10.9	-5.6	10.2	-0.2	9.5	19.3	10.3
3	-22.15	21.9	-15.2	-6.4	21.9	-1.9	8.3	21.9	9.3
4	-19.5	0.48	-10.5	-5.1	10.7	0.39	10.1	19.5	10.7

Algorithm 1 Function: Schedule(rbList, userList)

for $rb \in rbList$ **do**
  for $user \in userList$ **do**
    if $Needs\_More\_Resources(user)$ **then**
      if $\neg Is\_Allocated\_By\_Neighbor(user, rb)$ **then**
        $allocate(user, rb)$
      end if
    end if
  end for
end for

Function: Is_Allocated_By_Neighbor(user, rb)
for $cell \in get\_neighbors(user)$ **do**
  if $Is\_Allocated(cell, rb)$ **then**
    $return\ true$
  end if
end for
$return\ false$

Function: get_neighbors(user, rb)
$C := \{\}$
$sc := get\_serving\_cell(user)$
$prx := get\_rx\_power\_dBm(sc, user)$
for $cell \in get\_all\_cells()$ **do**
  if $get\_rx\_power\_dBm(cell, user) > prx - 10$ **then**
    $C := \{C, cell\}$
  end if
end for
$return\ C$

B. Experiments and Results

A cluster consisting of five small cells as in Fig.3 is used as test case scenario for experiments. The simulation parameters are shown in the Table I. The inter-site distance refers to the horizontal and vertical spacing between the adjacent cells. The overall throughput demand for each cell is 21Mbps. On LTE DL with 4.8bps per hertz the total traffic that could be generated theoretically is around 63.36Mbps with 100 RBs having no interference and noise. Analytically, it is easier to predict that one third of the total band without any interference should be enough for each cell to serve its users.

For simulating FFR case the spectrum is divided into three equal subbands. Each cell in the cluster under consideration share its sub-band with the farthest neighbor. In the simulation scenario cell 0 and 4 share a subband. Similarly, cell 1 and 2 share a subband. The middle cell 3 is the most overlapped cell and hence is allocated a dedicated subband. Otherwise it could both be a potential victim and an interferer to other cells. As shown in Fig. 4 for cell 3 with the given number of users per cell and non-interfered dedicated resources, it achieves slightly less than the targeted throughput per user. If the band is further divided into more subbands to allocate interference free resources to all the cells, then by simple analysis the per user throughput in each cell is expected to be around 0.8Mbps. This means that none of the users would be satisfied and this would still be less than what is achievable by the investigated approach especially in 50m and 100m cases. If a lower frequency reuse factor such as two is used in order to make more resources available to each cell, the interference would increase. It will eventually contributes to a lower achievable throughput as will be discussed in FR case. Hence, frequency reuse factor of three is a good value to simulate the FFR case in this scenario.

1) Inter-site distance 30m: All the cells experience very high interference for the FR and the coordinated approach, as shown in the Table II. Due to very high overlap most of the users are expected to be located in the overlapped region. In the coordinated approach there are not enough resources left on average for the cells, and thus results are not good enough for the cell edge users as in Fig. 4. For the FR case, the obvious reason is the very high interference leaving edge users without scheduling or even the loss of connectivity. In the case of FFR, cell 3 in comparison to other cells has a very good edge user throughput since the band allocated to this cell is not shared with any other cell. However, other cells share their subbands and experience high interference, but less than the FR and CECS case. The edge users in these cells are able to get a very low bit rate with a sustainable connection.

2) Inter-site distance 50m: In this case the cells still have a significant overlap. For FR approach there is an improvement in the throughput of cell edge users, but it is still significantly lower than the per user throughput demand, as the interference level is still significant. There is a significant improvement in the cell edge interference for the FFR case. However, the edge user throughout per user is still well below the per user demand. The main reason is the inefficient utilization of the spectrum, since every cell is allocated only one-third of the total resources. This fact also clarifies why frequency reuse one has been proposed in the 3GPP standardization for future wireless networks, such as LTE. In the case of CECS, there is a significant improvement in the edge user throughput as

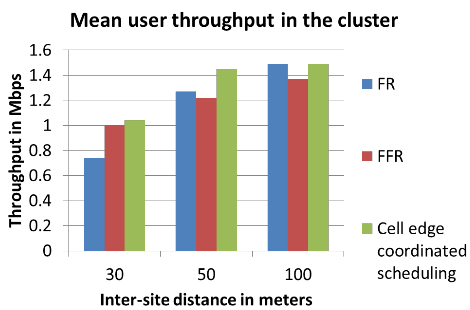


Fig. 5. Mean user throughput in the cluster

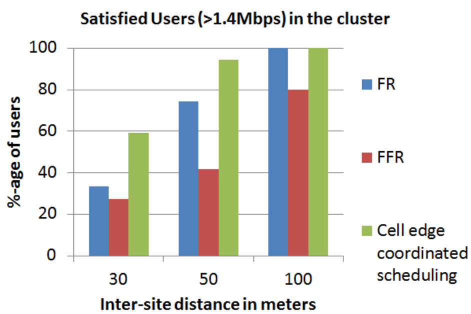


Fig. 6. Number of satisfied users in the cluster

compared FR or FFR case. This is due to the fact that the cells do not schedule their edge users on the same resources in a certain time to keep the interference level lower. Due to this reduction in overall mean interference level, the average resource utilization per user to achieve a certain GBR may also reduce. Thus, a cell is able to free some more resources on average, which could be used by its neighbour in a coordinated manner.

3) Inter-site distance 100m: When the SBSs are located further apart, there is a significant improvement in the interference level at cell edges. Apparently the cells are not overlapping in this case. There is practically no coordination happening among the cells for scheduling. For this reason the CECS approach becomes similar to that of FR case. Thus the results of the CECS and the FR case are quite similar. Since the cells have access to full spectrum they seem to have enough resources to schedule their users and thus meeting their throughput demand. However, for the FFR case there is apparently no interference among the cells [ref. Table II], and cells do not have enough resources to meet the throughput demand of their users.

It is also observed that in the overall mean throughput as shown in Fig. 5, the CECS scheme outperforms the other two approaches at all inter-site distance scenarios. Similarly, as shown in Fig. 6 there are more satisfied users in the cluster for CECS approach comparing with the other approaches. The satisfied users are considered as the ones who get more than the 90 percent of their throughput demand.

V. Conclusion

Interference within a dense cluster of small cells is a key challenge, especially for cell edge users. A simple decentralized coordinated approach CECS has been investigated in order to analyse the scenarios, where it could bring potential benefits to the edge users. Comparing with other techniques, coordination brings significant gain for the edge user throughout by improving *SINR* level in the cell edges for clusters with the studied densities. It has also been observed that for the densest scenarios coordination is not able to bring significant gains to the edge users. However, coordination outperforms other approaches in terms of per user average throughput and the average number of satisfied users in the cluster.

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