A Simulation Based Study of Mobile Femtocell Assisted LTE Networks

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Abstract—This paper investigates the impacts of deploying Mobile Femtocell (MFemtocell) in LTE networks. We investigate access delay, capacity, and feedback signalling overhead required for implementation of opportunistic scheduling in LTE cellular networks. We particularly study the impacts of deploying MFemtocell stations on the signalling overhead for opportunistic scheduling. Our system level simulation results indicate that one potential advantage of deploying MFemtocell can contribute to improve spectral efficiency by reducing the amount of feedback signalling.

Index Terms—LTE, mobile femtocell, control signaling.

I. INTRODUCTION

Long Term Evolution (LTE) is one of the prominent cellular systems that has been put forward by 3rd Generation Partnership Project (3GPP) in Release 8. It aims to provide higher data rates for future mobile applications. LTE adopts Orthogonal Frequency Division Multiple Access (OFDMA) as the base technique for resource sharing among multiple users. 3GPP further extended the original proposal of LTE, which is known as LTE-Advanced. This proposal aims to achieve data rates up to 1 Gbps and 500 Mbps in downlink and uplink, respectively.

In addition, 3GPP considers deployment of the multi-hop communications and Femtocell technology as potential extensions of LTE-Advanced to expand the coverage and capacity. The use of multi-hop communications has been investigated over the last decade. In the literature, two different types of multi-hop architecture have been discussed; namely, fixed and mobile relay. Fixed relay can be installed at different geographic locations within the network in order to support a service to a high-demanded area or cover the dark spots. fixed relays usually require a Line of Sight (LOS) link to the base station. They can have a directional antenna in order to improve the propagation quality to the base station. Mobile relay, on the other hand, is a moving node that behaves as a relay to the other mobile terminals in the network. Mobile relays have two different approaches that can be employed in the cellular systems. In the first approach, a relay is mounted on moving vehicles such as trains, buses, or private cars. The second approach is to use the other users’ terminals as relays, which is out of our interest in this paper.

Existing works related to the mobile multi-hop scenarios were considering a simple ad-hoc model where the mobile station acting as a relay to others [1]–[3]. To the best of our knowledge, the existing studies do not investigate the impacts of the deployment of Femtocell stations inside public vehicles on the feedback signalling overhead. This is particularly important problem as opportunistic resource allocation schemes are becoming increasing popular.

To this end, this paper investigates the impacts of deploying Femtocell station on the amount of feedback signalling overhead required for implementation of opportunistic scheduling. We use LTE-based comprehensive system level simulations to study the impact of MFemtocell deployment on the system performance.

The rest of this paper is organised as follows. Section II gives an overview Mobile Femtocell and how it can be integrated into LTE-Advanced system. Section III presents our system model. Section IV specifies our simulation models and presents results of our performance analysis. Finally, section V provides the summary and the concluding remarks.

II. MOBILE FEMTOCELL

The concept of MFemtocell is motivated by the concepts of mobile relays and Femtocell technology. It is a small cell which can move around and dynamically change its connection to the operator’s core network. It adopts LTE’s standard radio interface to communicate with the serving base station (eNodB) and the group of users that are served by that particular MFemtocell. A MFemtocell and its associated users are all viewed as a single unit to the eNodB. From a user point of view, a MFemtocell can be seen as Home eNodB. Home eNodB is the base station that used inside building, commercially known as Femtocell [4], and from here the name Mobile Femtocell is suggested. The MFemtocells can be deployed on vehicles such as public transport buses, trains and even private cars, as it is shown in Fig 1. To this end, MFemtocells can be considered as a practical form of deployment of mobile relays.
Deployment of MFemtocells can potentially benefit cellular networks. Firstly, as it has been shown by the existing studies, MFemtocells as mobile relay stations can improve spectral efficiency of the entire network. In addition, MFemtocells can contribute to a reduction of signalling overhead for a variety of network operations. For instance, MFemtocell can perform a handover on behalf of all its associated users, which can reduce the handover’s activities for the users within the MFemtocell. Furthermore, the battery life of the associated users with a MFemtocell can be prolonged as they will only involve in a relatively shorter range communication with their serving MFemtocell, instead of the long distant to base station. The MFemtocell traffic over the backhaul link is served like a regular UE traffic. So, it only needs a UE-like transceiver with some advanced capabilities. In principle, the MFemtocell can have the flexibility to add more than one antenna and different antenna patterns to enjoy spatial diversity and beamforming. In addition, the users only need a normal handover operation to switch from the Macro to the MFemtocell and vice versa since they see the latter as a regular base station. A MFemtocell will aggregate all user traffic into one channel and transmit the data to the macro eNodeB over an allocated transport block. On the downlink, the macro eNodeB will sum up all incoming traffic and send them to the MFemtocell over a single stream. Figure 2 illustrates the MFemtocell architecture in LTE-Advanced cellular system.

![Diagram of MFemtocell architecture in LTE-Advanced system.](image)

**III. SYSTEM MODEL**

We focus on MFemtocell-assisted multiuser communication and consider a single-cell system (no co-channel interference) with one eNodeB, several MFemtocells and users, as it depicted in Fig. 3. The terms backhaul, access link and direct link are used in this paper to denote eNodeB-MFemtocell, MFemtocell-UE and eNodeB-UE links, respectively. We use $\mathcal{N} = \{1, ..., N\}$ to denote the set of users that communicate directly with the eNodeB (Macro users), and $\mathcal{N}_j$ refer to a group of users within a MFemtocell $j$. MFemtocell $j \in \mathcal{J} = \{1, ..., J\}$ and UE $n \in \mathcal{N}$ are uniformly distributed within the cell. The MFemtocells are assumed to have omnidirectional antennas two-way eNodeB as well as within the vehicle. The eNodeB will transmit the data to the selected MFemtocell over the backhaul link. The MFemtocell will then fully decode the data, buffer it and re-transmit it to its user (Decode-and-Forward multi-hop strategy). To support the opportunistic scheduling, the eNodeB gathers the channel quality status form all users and MFemtocell. Likewise, the users within MFemtocell will feed back this information to MFemtocell station only.

The eNodeB-MFemtocell link experiences fast fading with Non-LOS (NLOS) channel. The channel of the backhaul and direct links are assumed to be constant within a sub-frame, but it changes independently in the next sub-frame, i.e. block fading channel. Within the each MFemtocell, the links between MFemtocell station and the users are assumed to be LOS with slow fading channel. The path loss model on the direct and the backhaul is based on a generic format that is relevant to the practical scenario in urban and suburban areas where the buildings are of nearly uniform height while indoor path is used on the access link within the MFemtocell [5].

The received Signal-to-Noise Ratio (SNR) for the channel eNodeB-MFemtocell and eNodeB-UE link, denoted as $\text{SNR}_B$ and $\text{SNR}_D$ respectively, on the Resource Block (RB) $k$ at time $t$ can be calculated using the Eq 1:

$$ \text{SNR}_B(t,k) = \frac{P|h_j(k,t)|^2}{N_o}, $$

$$ \text{SNR}_D(t,k) = \frac{P|h_o(k,t)|^2}{N_o}, $$

where $P$ is the transmitted power from the serving eNodeB. $h_j(k,t)$ and $h_o(k,t)$ are the complex channel gains, and $N_o$ is the noise power. It has been assumed that the backhaul link has a gain ($G$) over the direct link coming from using two antennae working in diversity mode and the outside location of MFemtocell antenna toward the eNodeB.

**A. Control Signaling in LTE Cellular System**

In wireless communication systems, as the users’ data increases in a cell, there is a performance trade-off between the radio resources for the user throughput and control signals. The amount of resources needed for control signaling depends on several factors. They are the target Bit Error Rate (BER) for the control information, and the time delay to switch from idle to active states and to handover between two base stations. It also depends on the size of transmitted data packets. Usually, small packets like VoIP will require higher signaling overhead. Therefore, minimizing overhead is the key to improve the overall system performance [6]. LTE system has a set of physical control channels in both links; these channels are defined by 3GPP to support the operation of advanced techniques such as scheduling, link adaptation and MIMO.

- **Downlink Control Channel:**
  In the downlink direction, the user data and the control signals are time-multiplexed. The first 1st, 2nd or 3rd OFDM symbols
in each sub-frame have been defined to carry the control channel information [7]. Physical Downlink Control Channel (PDCCH) is one of the control channels, which carry messages related to the scheduling assignment/granted. Each user, who is scheduled in downlink or has a scheduling grant in the uplink, is instructed via control messages to the relevant downlink/uplink resources. A Control Channel Element (CCE) is the minimum frequency/time resources allocated for control channels. It is used to send the PDCCH messages from the eNodeB to the scheduled users. The size of each CCE is 36 contiguous subcarriers, and it is loaded using QPSK modulated with different coding rate [7]. The number of the required CCEs for each user is subject to the channel quality of that user. So, if a user is in a very good radio condition, only 1 CCE is likely to be assigned to transmit the control messages. Otherwise an aggregate of 2, 4 or even 8 CCEs are required if the user has a low signal-to-noise ratio to increase the robustness [8]. It is important to note that the total number of scheduled users per sub-frame in downlink and/or uplink direction is completely dependent on the CCE limitation. Usually for 5 MHz and 10 MHz system bandwidth the total number of CCEs is approximately 20 and 40 respectively, those CCEs would be shared by uplink and downlink scheduled users. Figure 4 shows the required CCEs with respect to cell coverage.

- Uplink Control Channel:

The users feed back their downlink channel quality i.e. Channel Quality Indicator (CQI) to the eNodeB to support the channel-dependent scheduling and link adaptation. Moreover, the users employ HARQ scheme to inform eNodeB about their successful/failure transmission. Two other types of feedback information are also used to support MIMO operation, the MIMO rank information and the precoding information [9]. In LTE, a dedicated Physical Uplink Control Channel (PUCCH) is used to transmit the feedback information when the user has no data to transmit. However, when the user is granted the permission to transmit on uplink sub-frame and due to signal carrier constraint of uplink, the control information is time multiplexed together with user data prior to Discrete Fourier Transform, DFT-spreading [7]. It is very important to maintain the performance of the control channel on the specified target level by using variable modulation and variable coding rate to avoid retransmission to optimally utilize radio resources. It is also very essential to minimize the overall overhead of control signals as much as possible so that the resources could be used to transmit more user data. In [10], the formula (2) has been introduced to determine the size of control information:

\[ C_z = \left\lfloor \frac{N \times C_{ctr}}{B_s} \right\rfloor, \]  

where \( C_z \) is the size of the control signal in unit of symbol/sub-frame, \( N \) is the number of control signaling bits, \( B_s \) and \( C_{ctr} \) are bit per symbol and coding rate of the selected modulation and coding scheme MCS respectively. \( \lfloor \cdot \rfloor \) is the rounding function. It is clear that the size of control information depends on the assigned MCS for the uplink shared data channel PUSCH [10]. A discrete adaptive modulation schemes that corresponds to quaternary phase-shift keying (QPSK), 16 quadratic-amplitude modulation (QAM), and 64-QAM and each modulation scheme with different coding rate is supported in this work when the uplink SNR is above a respective predefined SNR thresholds which have been taken from Ref [10]. Thereby, the number of the required uplink control signals is determined using Eq. (2).

Our simulation results in Fig 5 shows the size of resource elements that should be reserved for three versions of CQI (5, 10 and 30 bit) as function to the SNR of uplink channel for 10% target Block Error Rate (BLER). These results are fully inline with 3GPP findings [10].
B. User selection and Resource allocation

Multiuser scheduling is assumed in this work where the macro users and MFemtocell are served over $K$ Resource Blocks (RB) indexed by $k=1,\ldots,K$. Moreover, the MFemtocell are scheduled over a dedicated time-frequency zone in such a set of MFemtocell is selected based on scheduling criterion, as it is shown in Fig 6 [11].

As mentioned earlier, the scheduler in the eNodB should takes into the account the limitation of the CCEs when allocating the RBs to the users in both direction. So, The users scheduling has two successive scheduling decisions; candidates selection followed by frequency domain resources allocation to assign the RBs among the selected users. In the first step, the time domain scheduler will prioritize the users based on a given priority criterion (e.g. round robin, proportional fair, etc.), then it selects only $N_{\text{max}} \leq N$ users (or $J_{\text{max}} \leq J$ MFemtocells) with highest scheduling priority taking into account the total CCEs constraints as well as the number of available resource blocks. Proportional Fair (PF) scheduling policies has been considered in this work. In the first step, the scheduler first sorts the users in descending order according to proportional fair metric ($PF$) then it picks up only some of the users depending on the availability of CCEs and PRBs. In second step, the scheduler allocates the RB $k$ to user $n$ (MFemtocell $j$) according to the following criterion:

$$\bar{n}_k = \arg \max_{n \in N} \frac{R_n(t, k)}{R_n},$$

where $R_n(t, k) \propto \text{SNR}_n(t, k)$ is the instantaneous achievable rate on RB $k$ and it calculated according to Shannon formula:

$$R(t, k) = \frac{B}{K} \log_2(1 + \text{SNR}(t, k)), \quad (4)$$

$\bar{R}_n$ is the average delivered rate in the past, measured over a fixed window of observation. It can be calculated using an exponential average filtering, which will be updated using the following formula [12]:

$$\bar{R}_n(t) = (1 - \frac{1}{T})\bar{R}_n(t - 1) + \frac{1}{T} \sum_{k=1}^{K} R_n(k, t) \cdot d_n(k, t), \quad (5)$$

$T$ is the time window constant, $d(k, t)$ is a binary indicator that is set to the 1 if the user $n$ is scheduled on resource block $k$ at time $t$ and to the 0 otherwise. Inside the MFemtocell, It has been assumed that the users are served according to round-robin policy.

IV. Simulation Results

The performance of the MFemtocell in the LTE system is evaluated using a dynamic system level simulator which is compliant with 3GPP LTE specification [13]. The simulation consists of several iterations each has 5000 sub-frames. LTE frame structure is considered, which consists of a blocks of a twelve contiguous subcarriers in frequency domain and seven OFDM symbol in the time domain. One sub-frame (1ms) is regarded as scheduling period. The carrier bandwidth is fixed at 5 MHz with 25 RBs. The number of MFemtocell is assumed to be 10. The processing delay in MFemtocell required to decode encode the received signal is assumed to be 2 ms. All UEs are equipped with a single antenna while the MFemtocells have two antennas working in diversity mode. The gain on the backhaul link ($G$) is assumed to be 8 dB. The number of CCEs is assumed to be 20 in this work and they are equally shared between downlink and uplink messages allocation. A full eNodB buffer is considered where there are always buffered data ready for transmission for each node. The Uplink transmitted power for users and MFemtocell is equal to 20 dBm. Other relevant simulation parameters are summarised in Table 1.

The performance of the MFemtocell in downlink and uplink is evaluated in terms of average access delay, the number of the scheduled users per sub-frame and the signalling overhead reduction in the uplink.

A. Access Delay

The average access delay of buffered packets as a function of direct $\text{SNR}_D$ is shown in Fig 7. The access delay can be

<table>
<thead>
<tr>
<th>Parameter</th>
<th>eNodB-MFemto</th>
<th>eNodB-UE</th>
<th>MFemto-UE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna height (m)</td>
<td>20</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Shadowing (dB)</td>
<td>8</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
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<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Transmitted power (dBm)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Time sharing ($\alpha$)</td>
<td>30%</td>
<td>50%</td>
<td>20%</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>&gt;100</td>
<td>&gt;100</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>
defined as the time that the head-of-line packet has to wait in eNodB buffer before it has been transmitted. It can be seen that with MFemtocell deployment the access delay is reduced significantly especially at low SNR (e.g. cell edge). This is because with MFemtocell, the eNodB needs to schedule fewer users since it sees the MFemtocell and its users as one user. Additionally, near the eNodB a fewer CCEs are required (Fig 4) which leads to increase in the number of scheduled uses.

B. Number of Scheduled User

Figure 8 shows the histograms of the frequency distribution of total scheduled users per sub-frame (normalised by the total number of data points) with and without MFemtocell. It can be observed that with MFemtocell implementation, the number of scheduled users is higher, with the mean distribution increased from 4.2 to 6.5 users/sub-frame. Also, the probability of less than three scheduled users is decreased from 16% to 6%. The probability of more than nine scheduled users also increased significantly from 2% to 10%. This improvement is due to the way MFemtocell aggregates multiple users into one channel. As mentioned earlier, the number of scheduled users is subject to the CCE constraint. It’s also observed that the effect of this constraint reduced significantly with MFemtocell deployment because of the aggregation of multiple users into only one channel. In this work, it is assumed that the minimum rate for each user in MFemtocell is 200 Kbps.

C. Uplink Control Signal Overhead

In the uplink, the MFemtocell can decrease report information of its associated users (ideal and active) over the backhaul link significantly. Figure 9 illustrates the signaling overhead reduction (normalised to max value) as function to the percentage of number of users registered with the MFemtocell. As it is shown, the overhead is reduced compared with the case where there are no users associated with MFemtocell. Thus, the feedback reports between users and MFemtocell station do not add to the total system overhead because the MFemtocell will cut off all these messages and send only its feedback to the eNodB. The saturated occurs due to constraint in number of scheduled user in the uplink. In the case where only half (or 80 %) registered users, the signaling overhead will consist of the signalling that coming from the users that communicating directly to the eNodB in a addition of the MFemtocel signaling. So, the amount of the reduction in signaling overhead can be replaced with useful data and hence improvement in the users and the system throughput.

V. Conclusion

In this paper, we have studied deployment of MFemtocells in LTE cellular networks. We investigated the performance for mobile Femtocell deployed in term of access delay, number of served users, and signalling overhead reduction scenario in LTE-advanced system in presence of opportunistic schedul-
The simulation results demonstrate that the implementation of MFemtocells in an LTE network can reduce the signaling overhead resulting in an increased system performance especially in the uplink.

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