Abstract—In this paper we address the deployment of a temporary cognitive secondary LTE Femtocell network in order to supplement and enhance the coverage of a regular LTE network for public safety communications. We propose a novel approach in deploying such cognitive secondary network by exploiting the latest LTE-Advanced HetNet capabilities. We also present two interference mitigation techniques for mitigating the interference caused by the presence of the cognitive LTE network. Simulation results are presented to show the enhancement in the coverage when such a secondary network is deployed together with the proposed interference mitigation techniques.

Index Terms—LTE-Advanced, D2D, DMO, relay node, Femtocell, Public Safety Networks, TCFN.

I. INTRODUCTION

Bandwidth, performance, reliability and cost effectiveness, are all favorite traits in modern wireless telecommunication systems that encouraged the unmatched acceleration in industry, education, and economy. Also it opened the doors for the new era of online entertainment and socialization. Those same traits in mission critical system has much more crucial role, they could be decisive in life-or-death situations the public safety personnel repeatedly encounter.

Long Term Evolution (LTE) will enable the firemen and police forces to stream high quality real-time videos of live operations back to the command and control center. In addition to that, LTE will allow multimedia and file sharing, facilitating the sensitive time dependent tasks of the dispatched resources in the field. Policemen could download suspects pictures, firemen can share the layout plan of a building, and ambulance vehicles will be fitted with live video stream connection to the hospitals, allowing doctors to give lifesaving instructions. In fact LTE has been endorsed by US major public safety organizations as the technology of choice for the 700 MHz band [8].

To deliver those applications, public safety LTE network has to feature a wide and reliable RF coverage deployment, however there are several situations where network coverage is limited or absent, areas could be left without proper coverage for many reasons such as cost, lack of grid power or technical difficulties. Those areas include remote rural lands, the inner region of large buildings and subway tunnels and stations. Another situation is during the unfortunate event of natural disasters like earthquake, tsunami and forest fires, where public safety network could become completely paralyzed, causing a total failure to the rescue operations.

The need for direct device to device communication, or as it is realized in TETRA system as DMO and LST [7], is vital for the public safety, since it allows the direct communication between handheld devices in certain proximity overriding the failed or low coverage network. This direct connection can bring up voice and low throughput data communication. The simplicity of TDMA in TETRA allowed such feature, while the situation in LTE is quite different due to the complexity of the air access technology and resource scheduling process.

The realization of direct mode feature in LTE system requires special considerations and enhancements for several technical aspects, especially in interference management between the parent network and devices engaged in the direct mode.

In this paper we are introducing the concept of Temporary Cognitive Femtocell Network (TCFN), as a secondary supplement for the main LTE Network (that is referred as the Parent Network). Cognitive radio networks [5][6] with intelligently acquired radio environment maps using sensing and localization [15]-[21][25] is the key enabler in our proposed solution. TCFN will provide the needed platform to enable the direct mode (D2D) [25] in LTE that will allow devices to communicate between each other without the need to route the traffic via the parent network.

Several challenges are associated with TCFN deployment; this paper is discussing, as well as suggesting suitable solutions for each. Those challenges could be summarized as below:

- **TCFN Enabling Mechanism:** discussed in section III.
- **Cognitive Interference Mitigation:** In order to achieve a bandwidth efficient overlay system that mitigates interference impact on parent network users, exploiting the latest recommendations in Rel. 10 in regards to HetNet and eICIC. This topic is discussed in section IV.
- **Cognitive Relaying Mechanism:** for enabling the communication between the TCFN and the parent network is discussed in section V.
- **TCFN Disabling Mechanism:** is discussed in section III.

At the end of this paper (section VI), simulation results are presented for a typical indoor scenario showing that the
coverage provided by a conventional network deployments (standalone parent network) is insufficient for establishing a reliable public safety inside city buildings, and then illustrating the improvements resulting from TCFN implementation.

II. NETWORK MODEL

In this section we present the network model adopted in this paper; two main distinct types of networks are proposed:

- The Parent Network (Network A): Based on conventional macro eNBs, providing the coverage for the intended geographic area.
- The Temporary Cognitive Femtocell Network (Network B): That constitute of several coverage spots called TCFN Clusters (discussed in sub-section A below.)

However, we also consider a third type of network which is the Emergency Supplementary network (Network C), in proposing the TCFN concept, which is deployed in the case of a total failure of the parent network, e.g. disaster situations. Such emergency networks are rapidly deployed, in afflicted areas, ABSOLUTE is a good example project for such networks[14]. The concept of TCFN and the three considered networks (A, B, and C) are depicted in Figure-1. As we see in the figure the TCFN clusters can exist (i) within the parent network coverage area where outage is observed, (ii) at the edge of the parent network coverage area and (iii) outside the parent network's coverage area.

III. TCFN ENABLING / DISABLING

The decision to commence (Enable) a certain TCFN cluster is taken by the chUE and depend on several triggers, one of them is the automatic service threshold trigger which is defined as the following Boolean expression:

\[
Service\ Threshold = \begin{cases} 
0, & SINR_{UE} > SINR_{th} \\
1, & SINR_{UE} \leq SINR_{th} 
\end{cases}
\]

Where \( SINR_{th} \) is given by \( SINR_{th} = SNIR_{min} + \rho \)

A. The TCFN Clusters

The TCFN has a cluster head UE (chUE) and a set of cluster member UEs (cUE) that are attached to the chUE (refer to Figure-2) . The cUEs can access the E-UTRAN of the parent network only through the chUE, moreover the intra cluster communication between the cUEs is also managed by the chUE in order to minimize the signaling within the cluster [9]. Note that the intra cluster communication can be performed between the cUEs directly using the D2D mode, however the chUE is responsible for the local Radio Resource Management (RRM).

Seeing TCFN Cluster from a user perspective, all UEs belonging to a certain TCFN Cluster are mesh connected using the D2D links, i.e. any device can share, transmit and receive information to/from any other member of the same TCFN Cluster.

The cluster head is an advanced user piece of equipment that has the capability of acting as a femto cell in addition to its role as a UE, and, it constitutes the heart of the TCFN coverage cluster.

The cluster will occasionally include some associated relays denoted as rUE that will fill coverage gaps and connect farther users to the TCFN cluster.

SNIR_{min} is the SNIR of the minimum decodable LTE MCS and \( \rho \) is a tuning parameter. Other triggers include:

- Specific local high bandwidth group communication (Automatic), e.g. streaming video locally to the firemen team leader.
- User initiated TCFN Cluster (Manual).
- Search & Rescue operation that expects victims outside the parent network service cell radius (Manual).
Figure 3 shows the various operational stages of a public safety LTE network. Accordingly TCFN will have the below operational status:

**Status (1)** TCFN could be optionally initiated anytime, however it will be frequently used in low coverage areas.

**Status (2)** TCFN will fill the considerable gaps left by network (A) and (C) and it is very essential at this point.

**Status (3)** TCFN will still fill the coverage gaps left by networks (A) and (C), gradually becoming as less vital.

**Status (4)** TCFN will go back to normal operation; similar to status (1).

If a UE inside the affected areas detects an established TCFN and opts to join the cluster, it should synchronize with it, and then attachment is done through the normal random access procedure.

Terminating (Disabling) the TCFN cluster could be triggered by several conditions:

- Parent coverage is restored and is above the SINR_th level for a certain predefined period of time (Automatic).
- chUE is not capable of maintaining the TCFN due to battery drain (Automatic).
- User decision (Manual).
- Parent network decision, e.g. severe interference caused by the TCFN (Automatic).

IV. DOWNLINK INTERFERENCE MITIGATION

Thanks to the new Intercell Interference Coordination techniques presented in Release 10, that overtook the implicit inefficiency in previous releases [10] especially when dealing with new elements introduced as part of the heterogeneous network (HetNet) such as relay nodes, Femtocells and remote radio heads.

Those techniques as seen from the time-spectral resource space are categorized into two distinct groups, a time domain group and a frequency domain group, the former concentrates on controlling the transmission of the subframes/Symbols of the overlaid eNBs (such as Femtocell and Picocell), while the latter focuses mainly on fractional frequency reuse (FFR) methods [13]. The commonality between all techniques is that they lay inside the constraints triangle of bandwidth efficiency, dynamicity and implementation complexity. For instance, one technique might result in a high spectrum efficiency but at the same time will require a massive exchange of signaling information between the different network nodes.

In this paper we are proposing a resilient solution that will try to utilize both interference coordination groups.

A. Time Domain Solution

Time domain interference mitigation requires reliable signaling between the parent network eNB and the TCFN chUE.

The proposed interference mitigation approach is OFDM symbol *muting* with *shift* [12], where subframes of the chUE are *shifted* forward by 5 symbols compared to the parent eNB subframes (refer to Figure-5), shifting will mitigate the interference caused by the parent eNB's PDCCH on chUE's PDCCH, while *muting* will mitigate the interference by chUE's on parent eNB's cell-specific reference signal CRS that are quite important for UEs to perform radio link monitoring measurements [1], in particular, to carry out the RS-SINR calculations. Low value of RS-SINR will result the UE to falsely consider the radio link as un-usable and terminate the connection with the eNB [12], another reason to protect the reference signals is that they play a vital role in channel estimation and OFDM demodulation within the UE.

Furthermore, the parent network will report to chUE if any of the cell edge UE has a severe interference caused by the TCFN; in this case the chUE will configure the interfering subframes as almost blank subframes (ABSFs) [10] in order to further mitigate the interference on both PDCCH and PDSCH (See Fig. 4).

B. Frequency Domain Solution

Different techniques such as "dynamic power control", "dynamic fractional frequency reuse" and "formation of groups" [13] are implementable in OFDM, however in this paper we are discussing the static Fractional Frequency Reuse (FFR) since it requires less cross-tier coordination (i.e. less coordination between the parent network and TCFN) and even it can be used in the case of the total absence of cross-tier signaling that is in contrary to the dynamic FFR methods.

DFFR could be smoothly used in the current LTE commercial deployments since eNBs has excellent mutual interface X2 allowing ICIC/eIC IC information exchange, a privilege might not exist in the case of chUE-eNB link.

Soft FFR is a static type FFR that has a high spectrum efficiency [13]; its principle is to divide the available spectrum to N sub-bands, where N is the number of cells in a frequency reuse cluster. Figure 6 illustrates the proposed reuse pattern, where the available sub-carriers are divided into three groups (designated as R, G, and B); the parent eNB cell center is assigned two groups while the cell edge is
assigned only one. The chUE will be free to select from carriers in R or G in the edge region of cell 1, the selection will depend on the existing level of interference caused by the macro coverage of neighboring cells.

Outer cell areas where service threshold condition is reached (i.e. $SINR_{UE} \leq SINR_{th}$), the TCFN will have more freedom in the utilization of the spectrum, since the cross-tier interference probability is much lower. On the other hand, users that manually create TCFN in the cell center will have to utilize the time domain interference mitigation technique in addition to adhering FFR pattern as well.

V. COGNITIVE RELAYING MECHANISM

TCFN exploits the standardized relay nodes concept [23] in LTE-A Rel. 10, and further elaborated in Rel. 11 documentations [2]. In addition to that each chUE in TCFN will be switching intra-TCFN Cluster traffic locally without the need to relay it to the parent network, however, in the case of a cluster user (cUE) have some data targeted to the parent network; the chUE will then function in a similar fashion to a Layer-3 relay node, by backhauling the cUE traffic towards the parent network donor eNB via the standardized Un link.

While regular relay nodes are operator deployed, and favor directional antennas, chUEs are meant to be mobile, unplanned, and having smart antennas instead, which will allow better relaying throughput.

TCFN requires relay nodes cascading for further coverage extension, however this scenario is not standardized in LTE-A, and in order to achieve this important feature, we assume a layer-2 (Decode and Forward type relay [22]) that will act in a much simplified manner than the Layer-3 (relay node) RN and without the need for full RRM and user data recognition which we refer to as the rUE. Reference [3] further explains this concept.

VI. SIMULATION MODEL

The goal of the presented simulation is to illustrate the need for TCFN, in order to encourage further researches and studies concerning this domain, and meant to reproduce the regular LTE coverage difficulties in indoor environment.

The simulation model is partially derived from guidelines recommended by 3gpp for indoor and home femto cell simulation scenarios [11]. Results compare the spatial-probability performance of three coverage scenarios:

- First Scenario represents the performance of a conventional standalone network represented by an eNB placed 250m in the north-east side of the subject building, with no TCFN capabilities.
- The second scenario shows the results of introducing a TCFN Cluster inside the building, with one cluster head and one relay, without the proper interference coordination with the parent network.
- While the third, demonstrates the effect of using the cross-tier interference mitigation as suggested in section IV, so the indoor UE has the freedom to attach to either the Parent network directly or to the TCFN.

The building is assumed to have dimensions of 50mx50m with 25 apartments inside it, 10m x10m each [2], UEs are assumed to be placed randomly inside the building. Figure 7 illustrates the target building location within the parent network cell, which has an antenna radiation pattern as the following [2]:

$$Gain(\theta) = \text{Gain}(\theta_0) - \min \left[ 12 \left( \frac{\theta}{\theta_{3dB}} \right), FBR \right]$$

Where $\theta_{3dB} = 70^\circ$ is the half power beam width, and $FBR = 20 \text{ dB}$ is front-to-back gain ratio.

The antennas of chUE and rUE are assumed to have 0 dBi gain (on the access side) that would be the most probable feasible realization in the future.

Propagation model has been approximated to WINNER II Indoor model, type A1 (Room to Room) [24], assuming thick walls of 12 dB penetration loss each.

We define the service outage probability of a Receiver (r) for certain scenario (s) by:

$$P_{r,s}(Outage) = P_{r,s}(SINR_{r,s} < SINR_{th})$$

SINR_{th} depends on the target application minimum throughput and on application requirements. And in our
simulation we used $\text{SINR}_{th} = 10$ dB [2] which is the LTE commonly-acceptable value for a minimum-level service.

**TABLE I**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular Layout</td>
<td>Hexagonal grid, 3 sectors per site</td>
</tr>
<tr>
<td></td>
<td>Simulation is performed for a single sector</td>
</tr>
<tr>
<td>Target Building</td>
<td>250m from the eNB South-West</td>
</tr>
<tr>
<td>eNB antenna max gain</td>
<td>17 dBi [11]</td>
</tr>
<tr>
<td>UE Antenna gain</td>
<td>0 dBi [11]</td>
</tr>
<tr>
<td>UE Noise Figure</td>
<td>9 dB [11]</td>
</tr>
<tr>
<td>Total eNB TX power</td>
<td>46 dBm [11]</td>
</tr>
<tr>
<td>eNB Antenna Port Tx power</td>
<td>Approximated to WINNER model NLOS Case A1 [24] given by:</td>
</tr>
<tr>
<td></td>
<td>$\text{PL} (\text{dB}) = 38.44 + 20 \log (d) + n \cdot P_{\text{wall}}$</td>
</tr>
<tr>
<td></td>
<td>Where, $d$ in meters, $P_{\text{wall}}$ is the penetration loss caused by walls, $n$ number of walls.</td>
</tr>
<tr>
<td>Inner walls Penetration Loss</td>
<td>12 dB (heavy walls) [11]</td>
</tr>
</tbody>
</table>

Figure-8 depicts the coverage resulting from a conventional stand alone LTE network (simulation scenario 1) inside the target building illustrated as Reference Signal Received Power (RSRP) values; white areas indicate a level below the service limits. It is very clear that the service can barely reach the second raw of apartments, leading to a very high service blockage as shown in Figure-12.

Figure-9 shows the coverage resulting from implementing simulation scenario 2 (a TCFN with no interference coordination). From the figure we observe a moderate enhancement in the coverage area due to the deployment of the temporary network TCFN. Note that having more number of relays may improve the coverage in this sense however the improvement may only be incremental due to the interferences.

On the other hand, Figure-10 shows much better RSRP compared to Figure-9, due to the enabling of the interference coordinating between the deployed TCFN and the Parent Network. Only fractional area is left without proper service, while most of the apartments are well covered. The enhancement of blockage probability is clear in Figure-12.

Figure-11 Spatial RS-SINR CDF Comparison. A CDF plot of the Reference Signal-SINR (RS-SINR) in Figure 10 shows a significant enhancement when deploying the coordinated TCFN, this enhancement will be reflected.
as a better D2D throughput as well as enhanced cluster-to-parent overall throughput.

The blockage probability improvement is quite clear in Figure-12 since the difference between scenario 1 and scenario 3 is 46.9%, almost 5.5 times less blockage probability.

![Figure 12 Spatial service blockage probability.](image)

**VII. CONCLUSION**

In this paper we have presented the concept of deploying a temporary secondary cognitive LTE based femto-network for supplementing and enhancing the network coverage, also we have showed that significant enhancement was achieved by implementing a supplementary network to the conventional LTE network. We also presented two feasible mechanisms for cross-tier downlink interference management to further improve the signal to interference ratio by mitigating the interference. The next step in our research is to simulate the entire proposed model in a PHY/MAC Monte-Carlo signal level simulations to further provide the proof of concept.

**ACKNOWLEDGMENT**

The research was partially funded by the ABSOLUTE project from the European Commission’s Seventh Framework Program (FP7-2011-8) under the Grant Agreement FP7-ICT-318632 [14].

**REFERENCES**