Towards the efficient performance of LTE-A systems: Implementing a Cell Planning framework based on Cognitive Sensing

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***Abstract*—LTE and LTE-A have dominated as a 4G enabler protocol, adopted by the majority of the network providers worldwide. The efficient performance of an LTE network relies on the selected frequency within an operating band that the cell operates, by taking into account all the potential factors that can affect it. Since cognitive radio is targeting towards the maximization of spectrum utilization, it is crucial that it is adopted in the spectrum allocation process. In this work, we propose an efficient scheme for cell planning by employing spectrum sensing techniques. By exploiting spectral information collected by several sensing devices, we appropriately select the center frequency inside the operating band, towards maximizing the quality of the end user experience. Our algorithms are implemented for the downlink channel, considering a variety of configurations and topologies. Finally, our implemented mechanism is evaluated in the real world deployment of the NITOS Future Internet facility, using commercial LTE enabled femto cells and UEs, while USRP sensing devices are employed for high quality spectral information provisioning.**

I. Introduction

Over the last few years, large steps have been made towards increasing the efficiency and performance of wireless networks. Cellular technologies have not been the exception to this rule; from a maximum data rate of 384 Kbps using GPRS and EDGE we moved to 14.4 Mbps using HSPA+ and over 100 Mbps using the LTE technology. LTE is expected to rule the cellular technologies landscape for at least the next decade by offering high speed network connections, supporting voice operations complementary to data with reduced latency, compared to 3G technologies.

However, as cellular technologies evolve and continue to coexist, the densely populated radio spectrum is in many cases proven not to suffice for all of them. For example, the frequency bands of 700, 900 1800, 2100 and 2600 MHz designated in many countries for LTE operation are very close or even overlapping with the bands that GSM and UMTS protocols are operating. This fact can have a detrimental impact on the available spectrum for each technology and a significant performance degradation. Moreover, the need for seamless connectivity in places with low coverage by a macro-cell, has created fertile ground for the development and the proliferation of smaller scale solutions such as pico- or femto- cells. In most of the cases, the output transmission power that these cells are configured to use is only a small fraction of the power used by a central base station unit. As it is expected, the concurrent operation of a macro-cell is deteriorating the overall performance that can be achieved by a small cell solution by inducing external interference (usually in a common spectral area) to the end user. In the same fashion, a femto cell which allows only a predefined number of subscribers (Closed Group Subscribers - CSG) to register on the network through it, might raise significant performance issues for the neighboring clients communicating through a macro cell.

These two last problems have been identified in the LTE specifications and a proposed solution has been adopted by the LTE release 8 and further enhanced in LTE release 10 (LTE-A). Intercell Interference Coordination (ICIC) is trying to deal with the cases where such problems may occur, by allocating different frequency resource blocks to the edge users. Furthermore, dynamic power adaptation is employed to mitigate cell-edge interference from neighboring cells. Complementary to the aforementioned measures, enhanced ICIC (eICIC) in release 10 introduces the Almost Blank Subframes (ABS), which are issued by the base station unit of a cell (Figure 1). During an ABS subframe, UEs registered to femto cells can transmit any data, thus avoiding the interference induced by the base station.

Another field of research community which cope with spectrum access techniques is Cognitive Radio (CR). One of the advantages of this technology is that CR helps to mitigate the spectrum congestion by utilizing unused portions of the spectrum, resulting in improvement of network operation and end-user data rates.

In this work we try to cope with such problems by using a congitive sensing approach; We configure commercial LTE femto cells as an access network and a sensing device that periodically measures the energy over the LTE access network. By using interfering transmissions, we create artificial congestion in a predefined portion of the operating band. We develop and apply our algorithm in a real setup, which appropriately selects the center frequency within the specific band that the femto cell is using, minimizing the total interference in the operating cell and maximizing the total throughput that the client can achieve.

The rest of the paper is outlined as follows; section II presents some former work conducted in this field. In section III, we describe an initial set of experiments that motivated our work and present our frequency selection policy. Section IV illustrates our experimental setup and the different hardware components employed for our real world experimental scenarios. In section V we experimentally evaluate the performance of our implementation. We conclude in section VI and discuss our future work.

II. Related Work

Since the introduction of wireless technologies, efficient cell planning has been a crucial factor in the successful deployment of a network. The research community has been motivated towards this goal, as the spectrum resources are not infinite and an overall end-to-end performance has to be ensured. Cell planning usually takes place prior to a cell deployment, by performing site surveys in order to identify the external interference factors that may affect the available spectrum in which every technology is designated to operate [1]. However, most of the cell planning approaches are aiming at resolving performance issues in former technologies, such as GSM and 3G ([2], [3]).

Since the 4G technologies were expected to be based on several and different cell sites and sizes, a lot of work has been conducted in this field trying to identify all the cell planning configurations that can mitigate the intercell interference. Several algorithms have been proposed, such as for example [4], [5] which take into consideration these aspects. In [6], the Intercell Interference Coordination (ICIC) is discussed and its value, after an extended set of simulations.

The introduction of the enhanced ICIC function with LTE-A, has further enhanced the LTE standard by adding the ABS subframes as already mentioned, to enable interference free operation of the small cells inside a macro cell's coverage area, and a separate power control method for the users that operate on the cell edge. In [7] and [8], some performance results are presented on eICIC enhancements introduced by the authors for the LTE standard. Finally, in [9], based on the eICIC coordination functions, algorithms for different resource allocation are presented.

Although the ICIC and eICIC seem to be a solution that is currently adopted, they need a very extended configuration in order to be fully functional and require to make use of the X2 interface of the Evolved Packet System (EPS) for communicating with the components involved. Closed Subscriber Group (CSG) small cells, i.e. cells which only allow a specific set of UEs to attach, are a threat for operating UEs not belonging to the group of the cell's subscribers and might complicate the frequency allocation process. ETSI identifies the following use cases for the operation of femto or pico cells in conjunction with a central base station unit or neighboring small cells [10]:

- CSG with a dedicated frequency channel and fixed/adaptive power
- CSG with a shared channel with the macro cell and adaptive power
- Partial reuse of a subset of the frequencies used by the macro cell

In the cases of sharing the frequency channels, interference from neighboring small cells or the macro cell could bring significant performance degradation. Topologies like these could significantly benefit when using a Dynamic Frequency Planning approach, like for example [11], where the authors introduce such a scheme for WiMAX cellular networks. In our work, we create a Dynamic Frequency Planning scheme using a CR approach for commercial LTE equipment. We use two experimental USRP devices for our experiments, along with a commercial LTE femto cell and a UE; the first USRP is playing the role of the interferer (femto or macro cell, depending on our configuration) and the second device is used for performing the sensing part and instructing the target femto cell for applying the optimal frequency. We evaluate it under different topologies and prove that our scheme manages to achieve more than 3 times better throughput under certain topologies.

III. Motivation and Policy

Towards proving the necessity of efficient frequency planning in LTE, we perform a test experiment and present some results, which provide insights for our policy design and its evaluation.

A. Motivating Experiment

In this experiment, we seek to investigate the impact of external interference on throughput performance in the case of LTE networks. Within the coverage area of a test femto cell, we activate an interferer, based on the USRP platform (USRP N210), configured to transmit in the same center frequency as the femto cell. Our indicative setup is presented in Figure 2. Our femto cell and its respective UE are configured to operate at 2625 MHz with a 10 MHz bandwidth. We measure the downlink (DL) throughput performance for UDP traffic that can be achieved for different values of the Received Signal Strength Indicator (RSSI) of the interfering signal perceived at the femto cell. Moreover, we tune the central frequency of the femto cell in steps of 5 MHz away from the interferer, and showcase the results of our first set of experiments in Figure 3a.

Our second set of experiments is designed to demonstrate how the varying traffic activity of the interferer affects throughput performance. In this experiment, we keep the transmission power of jammer constant and equal to the maximum value of 20 dBm, while the Duty Cycle of the generated data is varied for several frequency separation values. As it is clearly shown in Figure 3b, the activity of the interferer and the corresponding throughput at the affected UE are related. These observations lay the motivation for building an analytical model that detects the combined effect of partial overlap

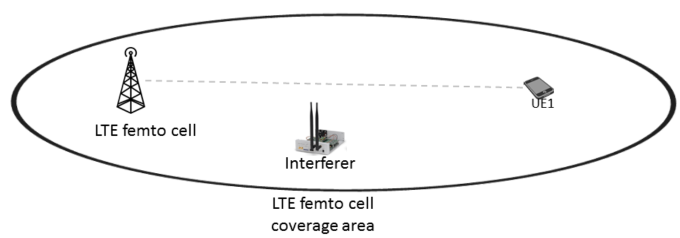


Fig. 2: Motivation experiment: Base Station transmitting within the range of an interfering cell.

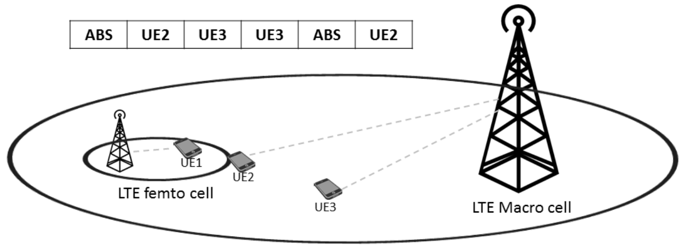
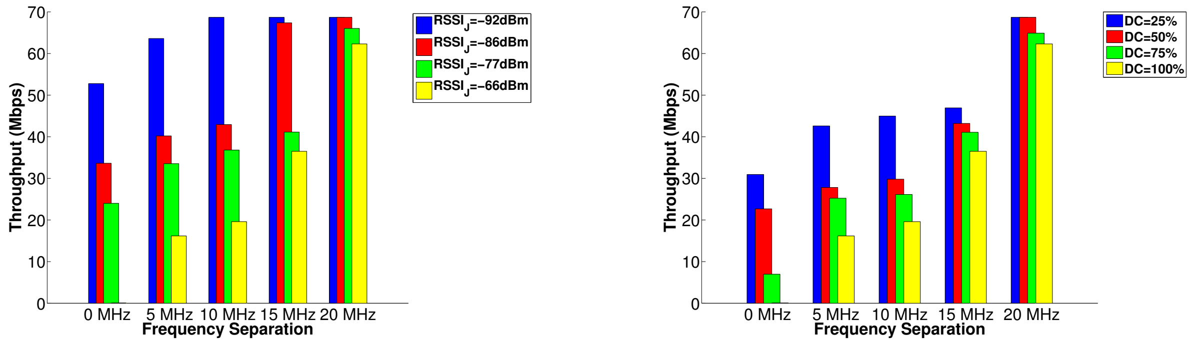


Fig. 1: Base Station scheduling of requests with eICIC; during an ABS subframe, UE1 can transmit interference-free to the femto cell.



(a) UDP DL throughput with respect to varying interfering signal RSSIs

(b) UDP DL throughput with respect to varying transmitting rates of the interfering device

Fig. 3: Throughput performance of out motivating experiment.

among adjacent channels, as well as the varying traffic activity of UEs in range under different topologies.

B. Proposed Policy

Based on our experiments, we develop and propose a Frequency Cell planning approach that is trying to alleviate the external interference which deteriorates the throughput performance of an LTE client. We contribute by designing and developing a policy based on Cognitive Radio Sensing, which appropriately instructs the target femto cell to use the operating frequency that can maximize the total access network throughput which can be achieved by the UEs in the cell. Our cognitive sensing approach relies on the energy detection method that we developed for the LTE bands, based on the USRP Hardware Driver (UHD) [12]. The evaluation of several experimental results drove our policy, which decides the best operating frequency for our target femto cell. Our algorithm consists of determining the operating central frequency of the femto cell in a predefined LTE band, based on the channel occupancy sensed by our cognitive method. Our proposed policy is presented in Algorithm 1.

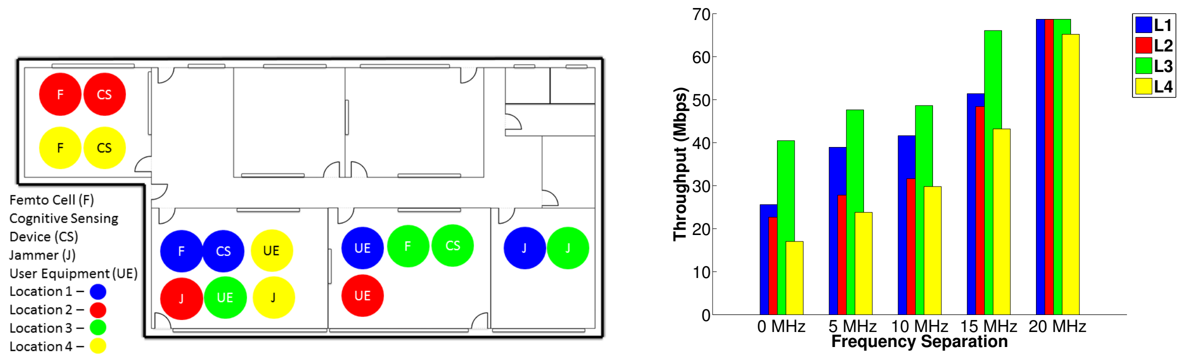
In section V we provide some experimental results that prove the efficiency of our approach with respect to the total UDP DL throughput achieved by a UE.

IV. Experimental Configuration

In order to evaluate the performance of the Dynamic Frequency Planning framework that we developed, we employ the NITOS testbed [13]. NITOS is large-scale wireless testbed in the premises of the University of Thessaly campus building, consisting of 50 RF-isolated indoor and 50 outdoor nodes, featuring multiple wired and wireless interfaces. NITOS testbed has been recently enhanced with two LTE femto cells and their respective EPC network, that has enabled experimentation with commercial LTE devices. In this work, we exploit both the LTE devices and the SDR equipment offered by the indoor NITOS testbed.

Algorithm 1 Frequency Selection Policy

$Threshold = Init$
$Interval = t$
while 1 **do**
  while InterferenceDectected $>= Threshold$ **do**
    Do Energy Detection in the Femto Cell Operating Frequency
    if Transmissions are Detected **then**
      Scan the band
      Determine the least occupied channel
      Instruct Femto to use to this channel
    else
      Use the current Frequency
    end if
    Readjust($Threshold$, $Interval$)
  end while
  sleep($Interval$)
end while



(a) Experimental Topologies.

(b) DL UDP throughput for each tested topology.

Fig. 4: Throughput Performance in different locations.

More specifically, in this section we present the setup employed in our experimental evaluation and our implementations which conclude to a comparative performance analysis with and without our proposed Dynamic Frequency Planning scheme.

A. Femto Cell

As our serving cell solution, we use one ip.access LTE 245F femto cell [14], which is a single mode LTE FDD Access Point (AP). The LTE APs offered by the NITOS testbed are dual band, enabling the operation of each one in bands 7/13, supporting a 2x2 DL MIMO interface with an output power of +13 dBm per port. The LTE APs cooperate with an EPC network implementation provided by SiRRAN Communications [15], allowing a predefined by the experimenter set of subscriber UEs to attach to the network.

B. UE

As our LTE client, we use one Samsung Galaxy S4 mini device, able to operate in LTE FDD/TDD bands, interoperable with NITOS's LTE APs. Samsung Galaxy S4 mini device is based on the Qualcomm Snapdragon 400 MSM8930AB [16], able to achieve a maximum DL rate of 100 Mbps and an UL rate of 50 Mbps.

C. USRP N210

The Universal Software Radio Peripheral (USRP) is a commercial Software Defined Radio (SDR) platform that utilizes a general purpose processor and has been used widely for PHY-related research. We developed our cognitive sensing approach using the USRP Hardware Driver (UHD), by building on its default reception functions to perform our energy detection. Since the SBX daughterboard [17] that they are equipped with is able to operate between 400 MHz and 4.4 GHz, we have been able to use it as both a sensing device and an interferer.

V. Experimental Evaluation

In this section we showcase our experimental results from our frequency selection algorithm, in four different topologies (Figure 4a), which cover the majority of possible everyday scenarios. In all of our topologies we use one femto cell, a UE and two USRP devices, one configured as a signal jammer and one as our spectrum sensing device. In order to measure how the interferer affects the communication between the femto cell and the UE, we disable the Adaptive Modulation and Coding (AMC) scheme instructed by the femto cell, and configure our UE to operate with the maximum MCS profile (MCS 28) for the link under evaluation. We setup the jammer (USRP N210) to transmit using 20 dBm signal power, and set to occupy the medium for the 50% of the time (Duty Cycle). In order to generate traffic of a specific rate over the network, we use the Iperf [18] tool which provides us with network performance statistics.

We perform our experiments for various channels, with a 5 MHz step, based on a 10 MHz LTE transmission channel and a 25 MHz interfering signal. The interfering signal that we use for all of our experiments is more dense in its central frequency with a span of 5 MHz, and has almost equally distributed energy in the remaining occupied spectrum.

Figure 4a illustrates the different topologies used (with the respective color for each topology), while Figure 4b demonstrates the total achieved throughput for each case. As the results indicate, for all the topologies, the achieved throughput is significantly degraded with respect to the maximum achievable, when the interferer is operating in the same frequency with the LTE femto cell. When we configure our femto cell to shift its central frequency by 5 MHz, we observe the total throughput performance to almost double. Further shifting by 5 MHz away from the interfering signal, brings negligible performance gain as a result of the interfering waveform that we already described. For non overlapping frequencies, we manage to achieve the maximum throughput for the specific topology.

Considering our experimental results, we decided to apply our developed policy for the worst case that we initially evaluated; we select topology 4, which is emulating the scenario of a UE registered to a femto cell and receiving severe external interference from a non eICIC conformed macro cell. In our scenario, the femto cell is operating using the central frequency of 2625 MHz, and generates UDP traffic destined to the UE. For an interference free environment, we measure

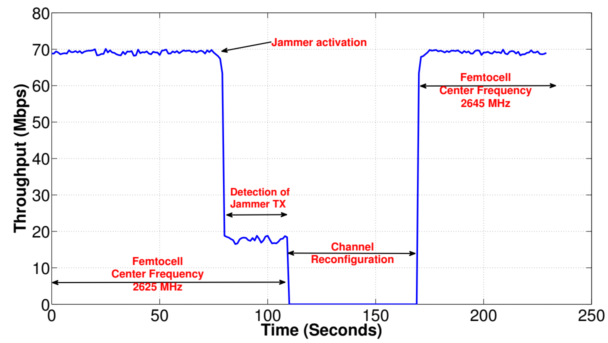


Fig. 5: Throughput variation and configuration steps when running our proposed policy.

the maximum available DL throughput ($\sim$ 69 Mbps). After 80 seconds we activate the jammer signal generator in the same center frequency. As the results indicate, the achieved DL throughput decreases below 20 Mbps. The sensing device which is attached on the femto cell, is monitoring periodically the spectrum, and determines the least occupied channel that the femto cell should operate. For our experiment, the least occupied channel inside 2620 MHz and 2690 MHz is the one with central frequency 2645 MHz. The sensing device instructs the femto to shift its operating frequency by 20MHz. Reconfiguration of the LTE femto cell is requiring a complete restart of the device, and thus the associated clients detach from it. The time interval indicated in the graph, where the throughput is set to zero is demonstrating the period until the femto cell is up and the UE is attached again (automatically). Reconfiguration via a reboot is required by this specific model of LTE femto cells, and although it initially seems that it is not optimal, the higher throughput achieved in the long term is more efficient than coexisting in a congested channel. Figure 5 presents the lifecycle of our experiment, with respect to the UE's throughput fluctuation along the different indicated events.

VI. Conclusions and Future Work

In this work, we proposed and implemented a Cell Planning framework that is able to detect and mitigate heterogeneous interference in LTE systems. The proposed framework utilizes cognitive sensing devices to collect measurements through the whole band that a femto cell operates and calculates the duty cycle for every configurable channel in the selected band. By exploiting this information, we manage to achieve higher DL throughput performance under different experimental topologies.

Our future work consists of extending our policy for optimizing the UL and DL channel, based on several UEs demands. Another direction is to tune dynamically the transmission power used by the femto node, thus minimizing the eNodeB's coverage area and subsequently the intercell interference. Finally, we intend to introduce more femto nodes and UEs and perform our experiments involving real LTE-based interferers, evaluating a real intercell interference scenario.

Acknowledgment

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