LTE/WI-FI COEXISTENCE ON A FLEXIBLE SOFTWARE DEFINED RADIO TESTBED

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ABSTRACT

The rapid rise in usage of mobile devices have not shown any signs of flattening or slowing down. Some efforts in the standardization bodies are underway to define new ways to boost data rate, network capacity and lower the latency by enhancing existing 4G technologies and by incorporating new technologies in 5G. Since lower spectrum has fewer resources, the LTE of unlicensed spectrum LTE-U is being proposed to extend LTE to unlicensed spectrum. Streaming data traffic for licensed spectrum on LTE-U can improve the performance of the system significantly. In this paper LTE-U deployment by the LAA is implemented using the LBT mechanism on a flexible SDR testbed

INTRODUCTION

This paper describes efforts to exploit unlicensed spectrum to optimize cellular networks. Unlicensed spectrum, specifically in the 5 GHz band, can be tapped through existing technologies (Wi-Fi) or through modification of current cellular networks directly into PHY and MAC layer. Due to this latter approach, cellular and Wi-Fi ecosystems disagree about how it will affect existing and future Wi-Fi networks. For the best understanding of performance trade-offs in disruptive technologies, prototyping should take place using a realistic testbed [1]. Hence, neutral modifiable prototyping platforms that enable engineers and researchers to evaluate and compare performance trade-offs of such algorithms in realistic environments are valuable. The best way to understand the performance trade-offs in disruptive technologies is by prototyping on a realistic testbed [2]. Researchers and engineers should be able to evaluate and compare performance trade-offs in realistic settings by means of modifiable prototyping platforms [3]. This paper describes such a testbed platform based on National Instruments (NI) software defined radios (SDR) USRP RIO hardware and NI LabVIEW Communications System Design Suite located at the University of Texas at El Paso (UTEP), El Paso [4].

A testbed is an essential tool in the development of new technologies and systems [5]. They facilitate rapid prototyping and testing of research results and help to interact with students to provide a valuable learning experience. Although 4G/LTE services are now readily available, LTE research and education have yet to reach saturation [6]. This research is driving innovation in 4G cellular technology into new spectrum areas and applications towards 5G. This testbed is developed to enable research on LTE evolution as well as rapid prototyping and testing of new protocol features, a controlled RF environment with custom-tailored channel conditions, and support for other co-existing communication formats.

The rest of the paper is organized as follows. Section II starts with an overview of the university testbed in use to support the cellular networks research and education to take advantage of unlicensed bands. This section offers a detailed overview of the design of the testbed for two major approaches under discussion in the wireless communications ecosystem: long term evolution unlicensed (LTE-U) and licensed assisted access (LAA) [1]. It further describes how the NI LabVIEW Communications System Design Suite and the included 802.11/LTE Application Frameworks to create a prototyping platform for this use case [7], [8]. In Section III, a selection of results obtained using the platform concerning the performance of LTE-U and its impact on Wi-Fi are discussed. The testbed data for LTE-U is used to create a database for deeper analysis. This database consists of parameters like signal power, signal frequency, bandwidth, and time stamps. Power spectral density (PSD), spectrogram, and throughput results are derived from the database.

BACKGROUND ON LTE/WI-FI COEXISTENCE

Many universities and research centers have their own LTE testbeds in support of specific research objectives. An exhaustive list of popular university LTE testbeds can be found here [9]. Most of them are standalone installations at a single location or spread across multiple locations. Unlicensed spectrum is already being exploited by cellular network providers through opportunistic offloading of traffic to Wi-Fi networks, especially in public hotspots [10]. 3GPP's LTE/Wi-Fi aggregation (LWA) work item implemented in Release-13 of the LTE standard allows aggregation of LTE and Wi-Fi at the Packet Data Convergence Protocol (PDCP) layer. In both cases, unlicensed Wi-Fi air interfaces are used. In the sections following, we explore unlicensed LTE-based air interface technologies. The ISM bands are the most common choice for testbeds to operate due to ease of licensing and interoperability with other systems. Some testbeds use open-source software, such as GNU Radio, while others use closed-source software, such as LabVIEW and MATLAB. Figure 1 shows the UTEP SDR testbed physical setup.

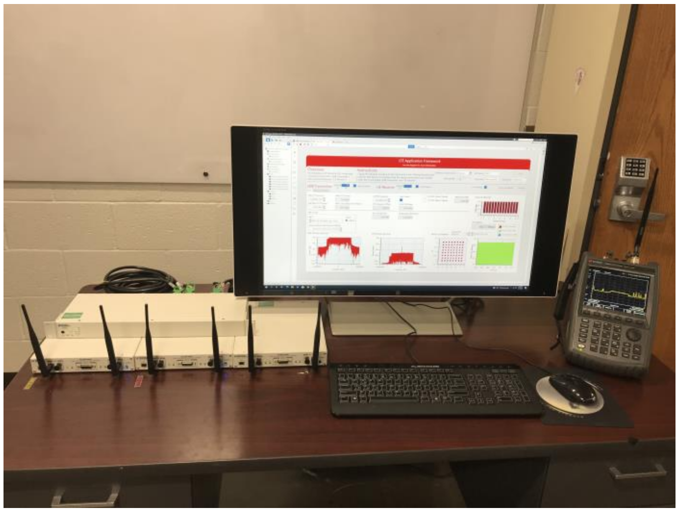

Figure 1 UTEP SDR testbed.

LTE-U

LTE-U uses the unlicensed band as a secondary cell in LTE carrier aggregation, while the licensed bands serve as primary cells. Under the current specification, the unlicensed band is used only for downlink traffic (DL). Uplink (UL) capability will also be supported in the future.

Figure 2 shows how LTE-U takes advantage of a duty cycled version of LTE waves to access the unlicensed spectrum. This will enable better coexistence between LTE-U networks and wireless networks. The LTE-U access point (AP) actively receives Wi-Fi and other LTE-U transmissions to identify the network usage patterns. Receiving Wi-Fi transmission implies that it can determine the channel type (primary/secondary), packet type, and packet length, among other attributes.

By using this information, dynamic channel selection and adaptive duty cycling can be achieved. A carrier sense adaptive transmission (CSAT) algorithm is utilized by LTE-U to calculate the duty cycle and adjust it [1]. TON and TOFF values could be adjusted by changing them appropriately or by skipping some TON periods periodically resulting in longer TOFF periods. Duty-cycle resolution is based on LTE subframe (1ms) boundaries.

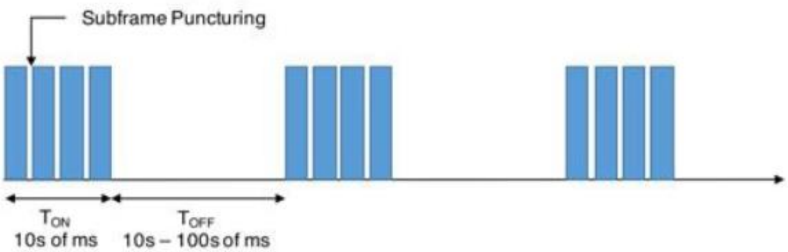

Figure 2 LTE-U waveform duty cycle.[1]

[1] https://www.ni.com/en-us/innovations/white-papers/16/real-time-lte-wi-fi-coexistence-testbed.html

Researchers have shown that LTE-U networks do not significantly degrade Wi-Fi network performance. There has been evidence that LTE-U deployment does not significantly impair Wi-Fi network performance [11]. Regulatory regimes in Europe, for example, require LBT in unlicensed bands, so LTE-U cannot be deployed in these regions. LAA is a global technology that differs from LTE-U in that it is designed for worldwide operations, since it incorporates LBT. Since LTE-U has a controversial nature, regulators such as the FCC in the US, where LTE-U can be deployed without LBT, are reviewing input from the ecosystem and determining whether further regulation is necessary [12].

There are various options under consideration, with the most popular being a Wi-Fi-like system with an initial deferral period and exponential back-off. An example of a waveform using the LBT procedure is shown in Figure 3 where the operator senses channel and obtains transmission opportunities for up to ten LTE frames.

Figure 3 LAA LBT Waveform.[1]

Wi-Fi service providers are favoring LAA over LTE-U as it allows them to participate in the open standards development process with an expectation to achieve good coexistence performance with the implementation of LBT. While LTE and other cellular standards have operated in licensed spectrum where continuous transmission has been available, discontinuous transmission adds a series of design challenges.

Application Framework

This LTE/Wi-Fi coexistence prototyping example is built on the 802.11 and LTE application frameworks. The LabVIEW Communications LTE Application Framework [7] provides a configurable real-time LTE application that includes both TDD and FDD support for PHY and MAC layer IPs. LabVIEW Communications LTE Application Framework provides a real-time physical layer LTE implementation that is open and modifiable. It conforms to a selected subset of the 3GPP LTE Release 10 specification. Researchers can quickly get their prototypes running on the LTE standard based on this compliance, concentrate on the aspects of the protocol that need improvement, modify the designs, and compare them to the existing standard.

In LabVIEW Communications 802.11 Application Framework, a real-time orthogonal frequency division multiplexing (OFDM) physical layer is provided with a lower medium access control (MAC) layer aligned with IEEE 802.11 standard [13]. With this framework, wireless researchers can quickly set up real-time prototyping setups to test their designs just like the LTE Application Framework.

This paper assumes that the reader has a basic understanding of the LTE application framework architecture and implementation, details are included in the getting started guides [7][8].

DESIGN METHODOLOGY

For the testbed, a simple setup is shown in Figure 4. It has one USRP RIO for LTE-U eNB and UE, and a second USRP RIO dedicated to Wi-Fi/802.11, although a commercial Wi-Fi router could be used as well. A third USRP RIO was assigned as a spectrum analyzer to capture the data from the LTE/Wi-Fi coexistence testing, which contributed to the creation of the database.

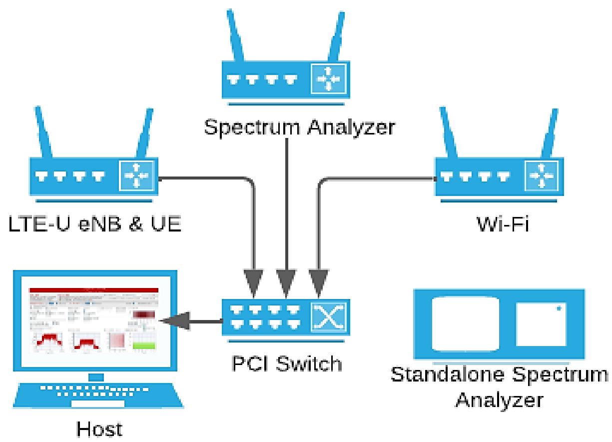

Figure 4 LTE/Wi-Fi coexistance experiment setup.

Table 1 shows the list of SDRs utilized in the testbed with their specifications. All the USRP device supports 6GHz sub bands with bandwidths from 40-160 MHz. The testbed allows rapid prototyping for radio frequency testing and evaluation. A standalone high end commercial spectrum analyzer is incorporated into the testbed to detect radio users in the spectrum, both licensed and unlicensed.

Table 1 List of testbed equipment.

Equipment	Model
Host	Windows PC with LabVIEW LTE & 802.11 Application Framework
LTE-U eNB and UE	NI USRP 2954 160 MHz
Wi-Fi	NI USRP 2944 160 MHz
Spectrum Analyzer	NI USRP 2943 40 MHz
PCI Switch	NI CPS-8910
Standalone Spectrum Analyzer	FieldFox N9917

RESULTS

Power Spectral Density

LTE-U and Wi-Fi signals were transmitted with center frequency 2.437 GHz and span of 20 MHz. Data from the SDR testbed were processed to generate PSD and spectrogram plots as shown in Figure 5 and Figure 7 using MATLAB to see the behavior of LTE-U and Wi-Fi signal over time. The SDR platform in the laboratory provides the flexibility to generate and observe the behavior of different spectrum users.

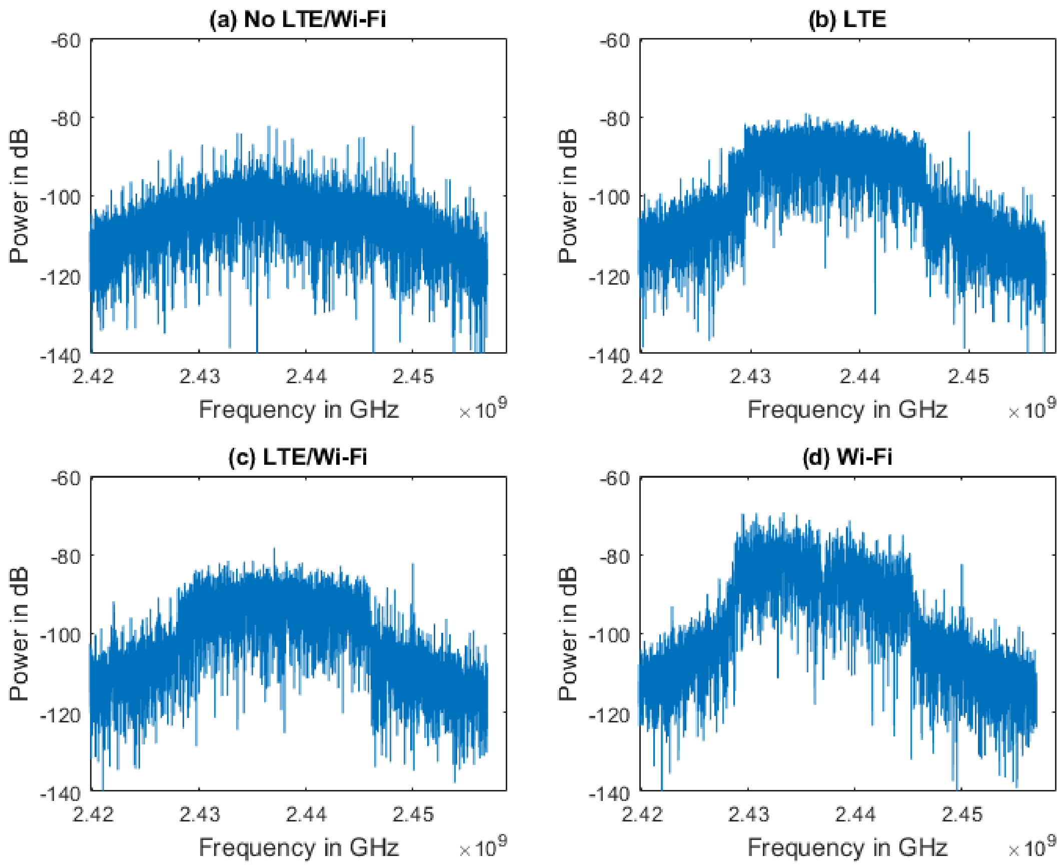

Figure 5 PSD of LTE/Wi-Fi coexistance.

When LTE-U and Wi-Fi signals are superimposed in the same plot, they can hardly be differentiated from one another as seen in Figure 6. The Wi-Fi signal is only present when there is a packet transmission, otherwise the PSD is flat line representing the reference or noise level.

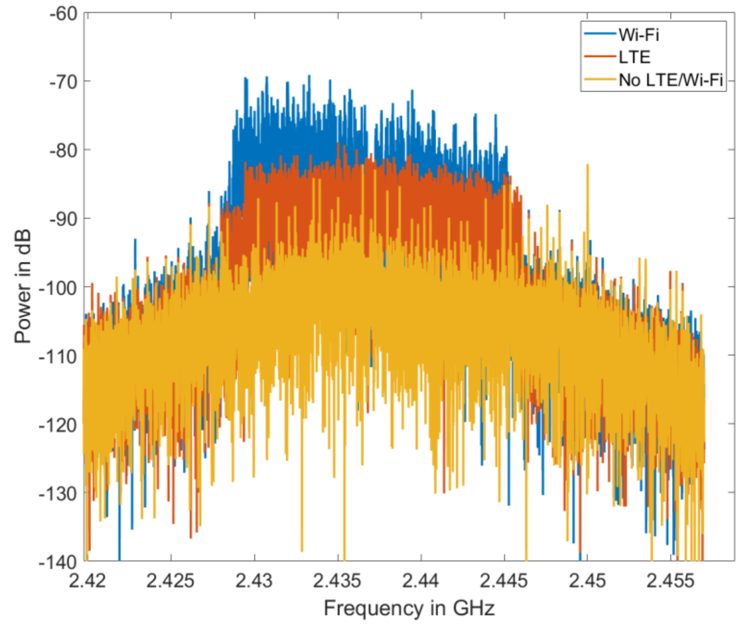

Figure 6 Superimposed PSD of LTE-U and Wi-Fi.

Spectrogram Analysis

LTE transmission was observed over time and the spectrogram resulted in a bright and solid bar as expected. Wi-Fi signal was transmitted with the same parameters as the LTE signal. The Wi-Fi transmission over time depicted faded and intermittent color bar as expected.

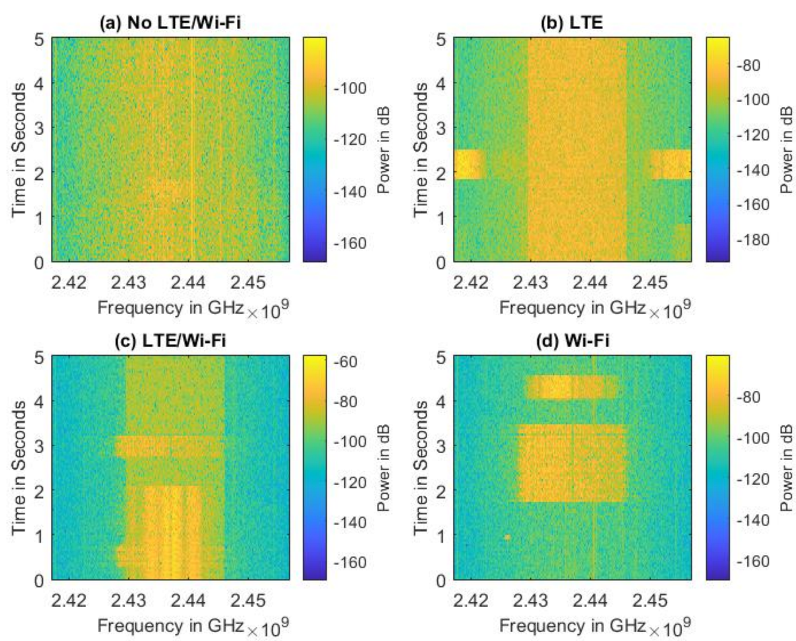

Figure 7 Spectrograms of LTE/Wi-Fi coexistence testbed data.

Throughput Analysis

Here is a comparison of the different LTE-U and Wi-Fi scenarios for throughput measurement in Figure 8. The LTE operated in TDD mode with MCS 28 in the unlicensed spectrum for optimal throughput. Although higher LTE throughput is possible with FDD, but that results in significant interference to the Wi-Fi channel. The Wi-Fi throughput significantly decreases when LTE operates with FDD. When the LTE-U and Wi-Fi are coexisting, the throughput drops about 13 Mbps for LTE-U and 3 Mbps for Wi-Fi. LTE and Wi-Fi coexistence depicts the throughput achieved when the LBT is implemented with LTE-U LAA.

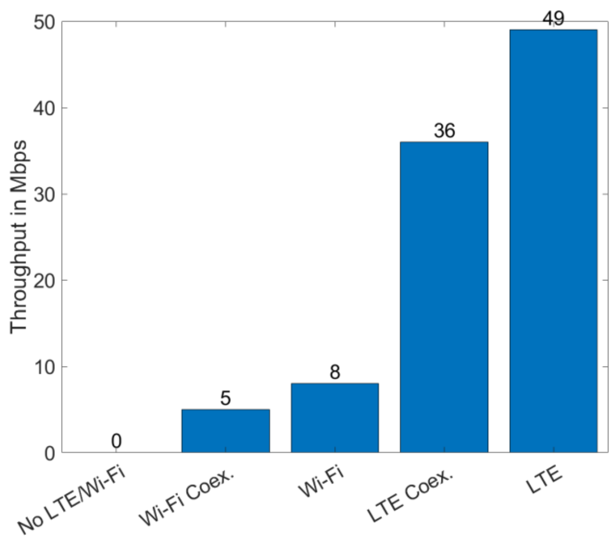

Figure 8 Throughput measurement in different scenarios.

CONCLUSION

Due to the nature of the LTE-U and Wi-Fi signal, only the PSD is not sufficient to confirm their presence, a spectrogram can easily detect and differentiate between LTE-U and Wi-Fi signal transmission. LTE uses more aggressive modulation and higher power compared to Wi-Fi signal. Data from spectrogram can be utilized to assist in the process of signal classification for dynamic spectrum access [14]. Wi-Fi as primary user has the priority to use the 2.4 & 5.8 GHz unlicensed bands, LTE-U signal as secondary user can utilize these bands whenever they are not occupied using the LBT implemented on LAA.

The NI 802.11 and LTE application frameworks have been utilized to build a platform which addresses the need for a neutral platform to handle research related to coexistence between LTE and Wi-Fi. This testbed can be used to test any such methods, whether those that have already been proposed or those that are envisioned in the future.

The discontinuous transmission protocol allows support of both LAA and LTE-U. Taking advantage of the flexibility of this feature, we can easily plug in new algorithms for control of the duty cycle of LTE-U. Discontinuous transmission together with the configurable LBT provides the backbone for the LAA channel access framework. This framework can be used in real-world experiments to test the scalability of the approach and future research. Preliminary results have proven that the testbed and the tools are ready for LTE-U as well as LAA.

With the prototype's high degree of configurability, namely the configurability of the duty cycle in LTE-U and the TXOP in LAA, a wide range of experiments can be carried out to understand how coexistence works, allowing for better optimization of parameters according to different scenarios. Using the prototype's high level of configuration flexibility, including the duty cycle in LTE-U and the TXOP in LAA, a wide range of experiments can be conducted to understand how coexistence works, contributing to a better optimization of parameters in various scenarios. With NI's open architecture, it is easy to amend or extend to more complex coexistence schemes.

A ready-to-use solution is presented for LTE/Wi-Fi coexistence prototyping, based on the NI 802.11 and LTE application frameworks that enables developers to run a neutral solution within the testbed, to identify the best operating points for use cases and scenarios specific to deployment. Multiple eNBs supporting LTE-U will be incorporated into the testbed to run further performance tests of LAA LBT and other LTE-U coexistence methods [11]. Commercial 5G gNBs are also in the process of being installed into the testbed, which will be operational very soon. Furthermore, the testbed would also incorporate algorithms to track incoming signals, such as MUSIC algorithm, in an attempt to improve bandwidth resource allocation for better coexistence between frequency bands [15][16]. This will greatly enhance the testing capabilities of UTEP testbed and provide a platform for ongoing research in spectrum management for better interference handling and reliability.

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