A Simulation Study of the LTE Interference on WiFi Signal Detection

Yao Ma, Daniel G. Kuester, Jason Coder, William Young
Communication Technology Laboratory, NIST
325 Broadway, Boulder, CO, USA

***Abstract*—** To address the spectrum scarcity problem and enhance spectrum utilization efficiency, spectrum sharing and coexistence of different wireless communication systems are important ongoing research topics. Unlicensed use of the ISM band by the long-term evolution (LTE) wireless cellular system is expected to bring large performance enhancement to users of LTE, but its coexistence with incumbent Wi-Fi users must be carefully considered. In this paper, we implement a simulation-based study to investigate the effect of LTE interference on an IEEE 802.11a system, in terms of physical-layer packet error rate (PER) and throughput. Simulation results show that the considered LTE interference waveform generates colored-noise like effect on Wi-Fi receivers, and is less harmful on Wi-Fi detection performance than full-band white noise, given the same power.

I. Introduction

With increasing user demand for wireless voice, data and multimedia services, the available fixed spectrum assignment method, in which one licensed system fully occupies a given frequency slot, becomes very inflexible and inefficient. To meet today's wireless service demand, high efficiency spectrum sharing and coexistence research is required, in which interference measurement and impact analysis is an important subtask. The unlicensed LTE use in the industrial, scientific, and medical (ISM) bands (such as the 5 GHz UNII band) and at 3.5 GHz radar band is currently being studied to enable multiple-system coexistence [1-5] among radar, LTE and Wi-Fi systems.

To avoid harmful mutual interferences among multiple tiers of wireless systems (or users), there are two major types of coexistence methods: spectrum overlay and spectrum underlay. In spectrum overlay spectrum sensing is required, and one system stops transmission or channel access when it senses the spectrum occupancy and activity of another system. For example, the recently proposed LTE unlicensed (LTE-U) spectrum access method uses listen-before-talk (LBT) or carrier-sensing adaptive transmission (CSAT) techniques [3] to avoid harmful interference to incumbent Wi-Fi users at the unlicensed ISM band.

In spectrum underlay, two or more systems can transmit on the same spectrum simultaneously under condition that the required quality of service (QoS) of the primary (or incumbent) system is maintained. To enable successful underlay, the effects of interference power and waveform types must be carefully studied. Wi-Fi systems typically use carrier-sense multiple access with collision avoidance (CSMA-CA) plus exponential back-off mechanism, which is conservative. The LTE-U system has more advanced scheduling than Wi-Fi in physical and media access control (MAC) layers, and thus is more robust against mutual interferences than the Wi-Fi counterpart. For example, LTE transmission and scheduling without self-restraint can significantly reduce Wi-Fi spectrum access opportunity and degrade its performance. Thus it is important to evaluate the effect of LTE-U on incumbent Wi-Fi system.

In this paper we study the effect of LTE interference on the physical layer detection performance of the IEEE 802.11a system (a popular Wi-Fi system) at the 5 GHz ISM band. The performance metrics studied include the physical-layer packet error rate (PER) and data throughput (accounting only packets with zero PER or decoding error) for time-selective Rayleigh multipath fading channel. In this simulation study, the LTE signal is shown to cause less interference than a white Gaussian noise signal of equal power.

II. Model: Coexistence of WiFi and LTE-U Systems

It is envisioned that the LTE unlicensed or license-assisted system will be deployed and coexist with incumbent Wi-Fi users, in unlicensed small cell setup. Referring to Fig. 1, where an LTE-U system has evolved node-B (eNB) and multiple user equipment (UE) units, and a coexisting Wi-Fi system has access point (AP) and Wi-Fi users.

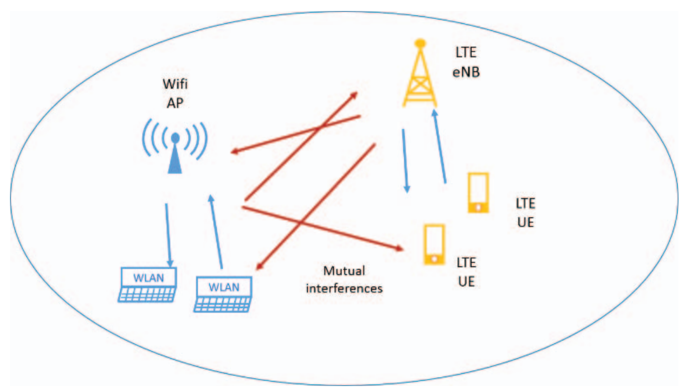

Fig. 1. Model of an unlicensed small cell where an LTE-U system and a Wi-Fi system coexist and generate mutual interferences.

For both spectrum overlay and underlay methods, there is a chance of collisions between LTE and Wi-Fi transmissions, and the negative impact shall be studied. For simulation of Wi-Fi, we consider IEEE 802.11a system operating at 5 GHz. Then we treat selected LTE signals as interferences and check their effect

Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the simulation procedure. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

on the performance of Wi-Fi signal detection. It is interesting to find out whether the LTE interference is more or less harmful than the white noise, given that they have the same power in the transmission bandwidth.

III. Simulation Results And Conclusion

Assume that the LTE-U and Wi-Fi systems coexist in an uncooperative manner with spectrum underlay. LTE uses orthogonal frequency division multiple access (OFDMA) for downlink modulation and single-carrier orthogonal frequency division multiplexing (SC-OFDM) for uplink. LTE has 3 major types of channels: logical, transport and physical channels, and each channel type has many subchannels. Physical channels provide data transmission and control/feedback information exchange between eNB and UEs. It is difficult to study the impact of all LTE physical channels, and thus we picked a few representative channels for interference assessment.

Here we use the LTE downlink E-UTRA test mode (E-TM) waveforms (with 6 modes '1.1', '1.2', '2', '3.1', '3.2', '3.3') generated by use of the Math works LTE Toolbox as interference waveforms. To simulate the Wi-Fi performance, we use the IEEE 802.11a Physical layer Mathworks Simulink model, and made several revisions:

- Generate and add LTE interferences at Wi-Fi receiver.
- Use per-sample SNR for the Wi-Fi payload part.
- Throughput is computed only for packets that have zero decoding error (ARQ not considered).
- Compute the average PER and throughput as a function of SNR and SIR.

We also set the following parameters: the fading channel is simulated with Jakes fading spectrum and 200 Hz Doppler-frequency. Block-wise time-selective Rayleigh fading with 2 paths, which have delay (0, 0.05 μs) and relative average power (0,-3 dB). Each Wi-Fi data block has duration 224 μs with preamble, header and payload. There are 8 modes of adaptive modulation and coding (AMC) schemes, with SNR thresholds 10, 11, 14, 18, 22, 26, and 28 dB, where the lowest active mode (6 Msps) is selected when SNR < 10 dB. The Wi-Fi signal considered has 20 MHz signal bandwidth and 20 Msps sampling rate. A total of 1 s of data is used (2×10^7 samples) for each SNR point.

The LTE E-TM signals are generated based on 20 MHz bandwidth with sample rate 30.72 Msps. They are resampled to 20 Msps to match the sampling rate of Wi-Fi signals. We assume that either white noise (20 MHz bandwidth) or LTE interference alone affects the Wi-Fi link, but not both. Results were averaged over 6 modes of LTE E-TM signals. The SNR and SIR are, respectively, defined as

$$\mathrm{SNR} = \frac{E_{S,WIFI}}{N_0}, \quad \mathrm{SIR} = \frac{E_{S,WIFI}}{I_{LTE}}, \qquad (1)$$

where $E_{S,WIFI}, N_0$, and I_{LTE} are the average received signal power (for the Wi-Fi payload part), white noise power and the average LTE interference power at Wi-Fi receiver, respectively.

Fig. 2 shows that the Wi-Fi signal has larger throughput under the LTE interference than under the white noise. We notice that this holds true also for nonfading and flat-fading channels (results not shown here).

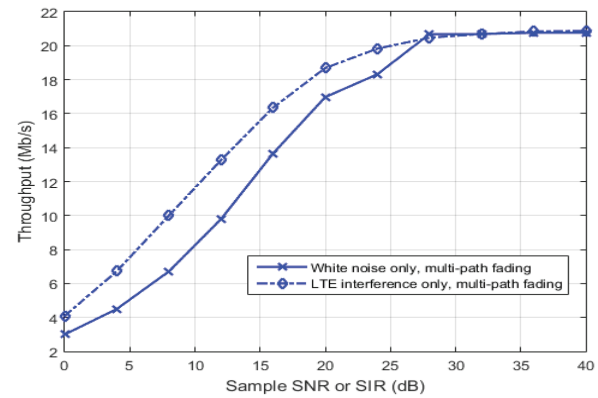

Fig 2. Throughput vs. SNR (or SIR) of the IEEE 802.11a signal, affected by white noise and LTE interferences, respectively.

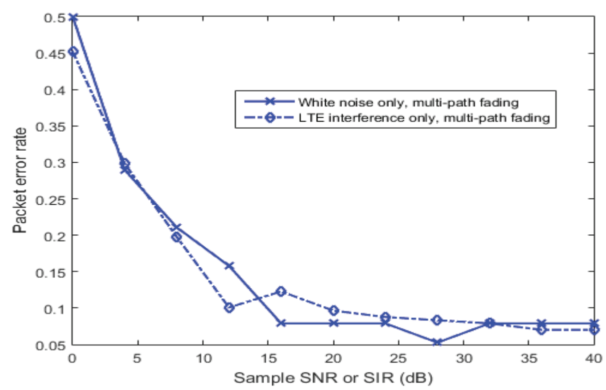

Fig 3. Packet error rate vs. SNR of the IEEE 802.11a signal, affected by white noise and LTE interferences, respectively.

Fig. 3 shows that the PER under both cases are comparable to each other. In this simulation study, the LTE signal caused less harmful effect than white Gaussian noise of equal power. Our spectrum analysis shows that these LTE signals have effective bandwidth of about 18 MHz only, and thus are colored noise-like in the 20 MHz Wi-Fi transmission bandwidth. In future work, we will study the effect of Wi-Fi interference on LTE signal detection and the cooperation of both systems for spectrum sharing. We also plan to conduct a radiated measurement for verification of this simulation.

References

[1] Federal Communications Commission, "Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band," Report and Order and Second Further Notice of Proposed Rulemaking, April 21, 2015.

[2] Frank H. Sanders, John E. Carroll, Geoffrey A. Sanders, Robert L. Sole, "Effects of Radar Interference on LTE Base Station Receiver Performance," NTIA Report 14-499, Reissued May 2014.

[3] R. Zhang, M. Wang, L. Cai, Z. Zheng, X. Shen, "LTE-unlicensed: the future of spectrum aggregation for cellular networks," in IEEE Wireless Communications, vol.22, no.3, pp.150-159, June 2015.

[4] H. Zhang, X. Chu, W. Guo, and S. Wang, "Coexistence of Wi-Fi and heterogeneous small cell networks sharing unlicensed spectrum," in IEEE Communications Magazine, vol.53, no.3, pp.158-164, March 2015.

[5] A. Al-Dulaimi, S. Al-Rubaye, N. Qiang, and E. Sousa, "5G Communications Race: Pursuit of More Capacity Triggers LTE in Unlicensed Band," in IEEE Vehicular Technology Magazine, vol.10, no.1, pp.43-51, March 2015.