LTE-U and Wi-Fi Hidden Terminal Problem: How Serious Is It for Deployment Consideration?

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Outline

Abbreviations

- LAA : Licensed Assisted Access
- LTE-U : Long Term Evolution in Unlicensed Spectrum
- AP : Access Point
- SINR : Signal-to-Interference Plus Noise Ratio
- EDT : Energy Detection Threshold
- RTS : Request-to-Send
- CTS : Clear-to-Send
- NAV : Network Allocation Vector

Introduction

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- The Phenomenal Growth in Mobile Data demand
- Limited and costly License Spectrum
- One promising solution is to use unlicensed spectrum (LAA/LTE-U)
- Major challenge in unlicensed is fair coexistence with Wi-Fi.

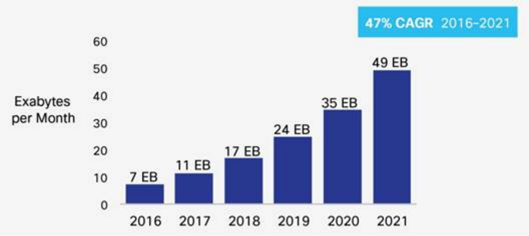

Figure 1 : Growth in Mobile Traffic[1]

[1] Reference: Cisco VNI, Mobile 2017

LTE MAC Vs Wi-Fi MAC

	LTE	**Wi-Fi**
Multiple access[2]	Multiple users served simultaneously, occupying different frequencies in channel	only 1 user is served at a time, takes up entire channel spectrum
Channel usage	Frames are contiguous, so channels are approximately always on	Channel is occupied only when packets needs to be transmitted
Channel access	Centralized scheduling on DL and UL. LTE does not contend, it simply transmits	Distributed Coordination Function (DCF), contention-based
Collision avoidance	None, b/c channel access are centrally scheduled	CSMA/CA + RTS/CTS (In principle, sense before transmit)
Co-existence	Has not had the need to be able to coexist with other technologies	Already coexists well with other technologies in unlicensed band, although with no common fairness mechanism

Coexistence Use Cases

1. LTE-U vs. unmanaged Wi-Fi
2. LTE-U vs. managed Wi-Fi
3. LTE-U vs. LTE-U among difference operators

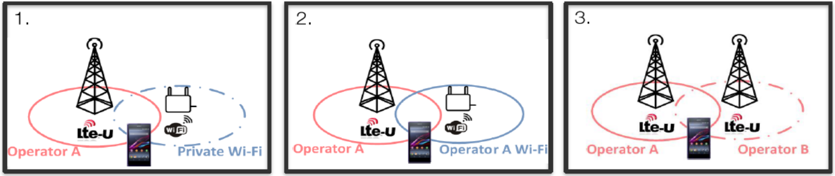

Figure 2 : Coexistence Use cases

LTE in Unlicensed: Channel Access Approaches

1. LTE-U (Without LBT)
   1. **CSAT[4] (Carrier Sensing Adaptive Transmission)**:In countries USA, Korea, India LBT is not mandatory. So mobile operator can deploy LTE in unlicensed based on 3GPP Rel. 10/11/12 (Carrier Aggregation) with CSAT like channel access scheme without LBT.
2. LAA
   1. **With LBT (FBE and LBE)**: In Europe , Japan LBT is mandatory. So mobile operator has to follow LBT channel access scheme to use unlicensed band. In Rel 13 LTE in unlicensed with LBT for channel access is explained which is called LAA[5].

[4] Reference: LTE in Unlicensed Spectrum:Harmonious Coexistence with Wi-Fi

[5] Reference: 3GPP TR 36.889 Release 13

Carrier Sensing Adaptive Transmission (CSAT)

- Observe the medium.
- According to the observed medium activities, the algorithm gates off LTE transmission proportionally.
- In particular, CSAT defines a time cycle where the small cell transmits in a fraction of the cycle and gates off in the remaining duration.

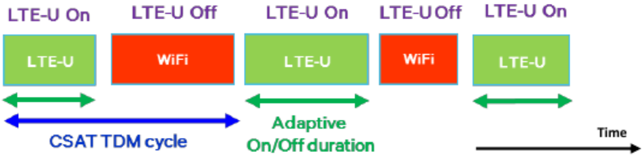

Figure 3 : CSAT ON/OFF Cycle[4].

[4] Reference: LTE in Unlicensed Spectrum:Harmonious Coexistence with Wi-Fi

LTE-U & Wi-Fi Hidden terminal problem

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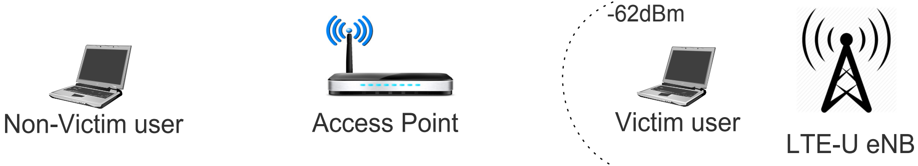

Figure 4 : LTE-U and Wi-Fi Hidden terminal scenario.

- We define the influence zone of LTE-U as the region around LTE-U eNB where a Wi-Fi device cannot transmit or receive successfully when LTE-U is ON.
- The victim Wi-Fi user is inside the influence zone of LTE-U; and the non-victim Wi-Fi user along with Wi-Fi AP are outside the influence zone of LTE-U.

Contribution

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Contribution of the paper

- We analyze the considered hidden terminal scenario on a testbed setup, and study the performance of Wi-Fi users in the presence of duty cycled LTE-U.
- We observe the unfairness caused to the victim users in terms of throughput and also study the effect of the presence of these victim users on a Wi-Fi network. The lack of comprehensive literature for such scenarios using real hardware makes our study novel.
- We study the beacon lost phenomena of victim users and present the effects of beacon losses. We also propose beacon loss analysis and provide a mathematical expression to calculate the beacon loss percentage. Finally, we validate the analytical results using simulation and the testbed.

Experimental Testbed Setup

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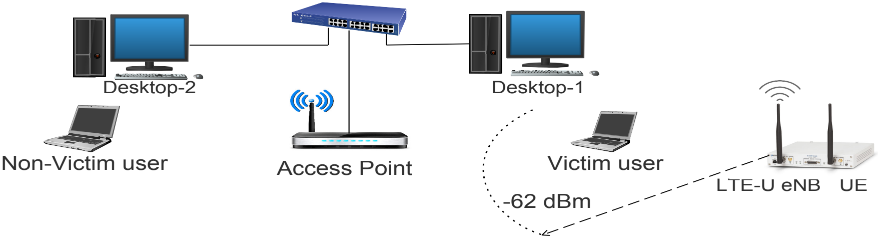

Figure 5 : LTE-U and Wi-Fi Hidden terminal scenario.

- Experimental testbed setup demonstrating the Wi-Fi network partially overlapped with the LTE-U network, with additional two Desktops used for sending and receiving iPerf traffic to/from the Wi-Fi users.

Equipment Used in Testbed

Figure 6 : Equipment used in Testbed.

- Equipment used in the testbed: (i) Netgear N600 wireless dual band router WNDR3400v3 used as Wi-Fi AP. (ii) USRP RIO board with LTE-U eNB and LTE-U user operated using LTE-U/LAA Application framework.

Experimental Results

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Throughput

1. DL traffic.
2. UL + DL traffic.

Beacon loss

1. Beacon loss analysis
2. Beacon loss results.

Throughput Results

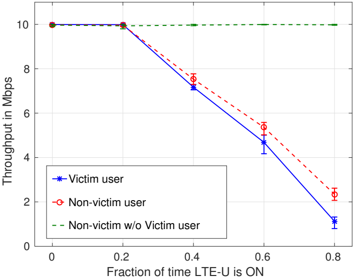

Figure 7 : Throughput of victim and non-victim users for UDP datagram size of 200B.

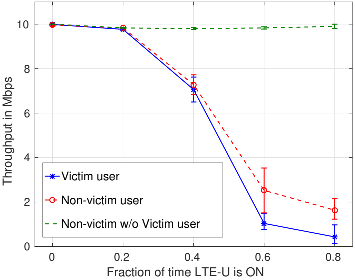

Figure 8 : Throughput of victim and non-victim users for UDP datagram size of 1500B.

Observations

- With increase in LTE-U duty cycle throughput of victim and non-victim user decreases.
- In the absence of victim user throughput of non-victim user is not decreasing.

Throughput Results Cont..

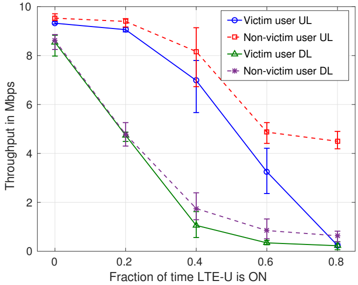

Figure 9 : Throughput of victim and non-victim users in UL and DL.

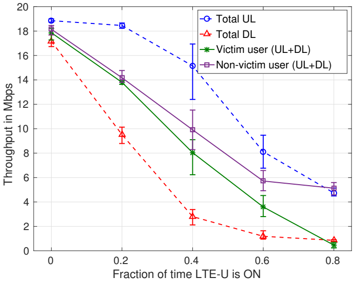

Figure 10 : UL and DL throughputs and victim and non-victim users throughputs.

Observations

- UL throughput is better than DL throughput (DL is loosing channel access oppotunity due to victim user).
- User unfairness as well as UL/DL unfairness can be observed.

Throughput Results Summary

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DL traffic

1. Substantial retransmission losses leading to a decrease in throughput of victim as well the non-victim users.
2. Disproportionate throughput distribution among victim and non-victim users.
3. Restriction on the packet size meant for victim users.

UL + DL traffic

1. Preferential Uplink transmissions over Downlink transmissions.
2. Decrease in UL throughput for all users with increasing LTE-U ON period.
3. A proportional effect on DL throughput for all users.

Beacon Loss Results

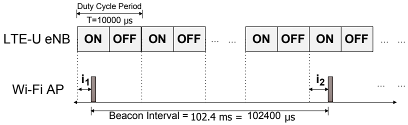

Figure 11 : Illustration of beacon arrival with respect to LTE-U duty cycle period.

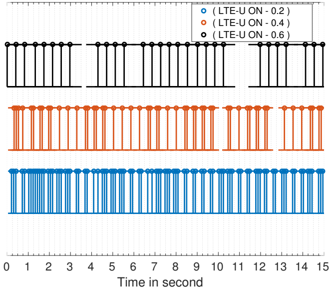

Figure 12 : Beacons received over time for different LTE-U ON-OFF fractions.

Observations

- Victim users are unable to receive beacons transmitted in LTE-U ON period.
- Number of beacon losses increases with LTE-U ON fraction.

Beacon loss results cont..

Table 1 : Consecutive beacon Loss (%) of victim users for the Experimental (Expt) and Simulation (Simu) results.

No. of Consecutive Beacon Losses	**LTE-U ON Fraction=0.2**		**LTE-U ON Fraction=0.4**		**LTE-U ON Fraction=0.6**	
-	Expt	Simu	Expt	Simu	Expt	Simu
1	**30.84**	**33.65**	3.65	0.47	0	0
2	**66.08**	**66.35**	**37.89**	**33.17**	10.98	0
3	1.76	0	**53.88**	**66.35**	**74.05**	**80.00**
4	0.88	0	1.82	0	2.0	0
8	0	0	0	0	**11.39**	**19.43**

Beacon Loss Problems

Problems

1. Increased association delay.
2. Increased disassociation frequency as a result of losing Channel Switch Information.
3. Increased awake time and data latency for power-saving stations.

- To mitigate the above effects, a quantification of beacon losses is necessary.
- Therefore, we develop an analytical framework to determine the percentage of beacon losses and finally provide a mathematical expression for the same.

Beacon Loss Analysis

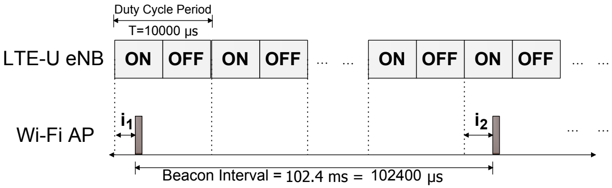

Figure 13 : Illustration of beacon arrival with respect to LTE-U duty cycle period.

- If i_1 is the first BST, then the time at which the second beacon would arrive $i_2 = (i_1 + B) \bmod T$ Similarly,

$$i_3 = ((i_1 + B) \bmod T + B) \bmod T = (i_2 + B) \bmod T$$

- Hence the n^{th} beacon arrival would arrive at

$$i_n = (i_{n-1} + B) \bmod T \qquad (1)$$

- The BST returns to the first BST (i_1) after every T beacon intervals, i.e., $i_{T+1} = i_1$.

Cont..

- If the BST lies anywhere in the LTE-U ON period (*i.e.*,$(0, T_{on})$) and if the BST is in OFF period, but a part of beacon transmission overlaps with the upcoming ON period (due to the non-zero beacon air-time – $B_{air-time}$) then beacons can be considered as lost.
- The average beacon loss fraction is given by

$$L_{frac} = \frac{T_{on} + B_{air-time}}{T} \tag{3}$$

- Finally

$$L_{frac} = \begin{cases} 0 & if \quad T_{on} = 0 \\ 1 & if \quad T_{on} > T - B_{air-time} \\ \dfrac{T_{on} + B_{air-time}}{T} & otherwise \end{cases}$$

Beacon Loss Results

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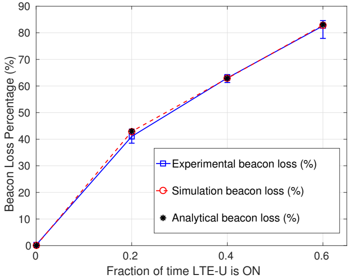

Figure 14 : Validation of analytical beacon loss percentage (%) of the victim user through testbed experiment and simulation results for an LTE-U duty cycle period of 10ms with varying ON fraction.

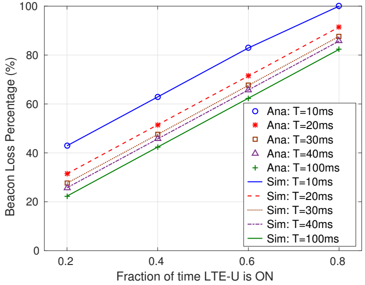

Figure 15 : Analytical (Ana) and Simulated (Sim) beacon loss percentage (%) of victim user for different LTE-U duty cycle periods with varying ON fraction.

Observations

- Beacon loss percentage increases with LTE-U ON Fraction.
- The analytical results matches with testbed and simulation results.

Beacon Loss Summary

- Victim users are unable to receive Wi-Fi periodic beacon due to ongoing LTE-U transmission.
- These beacon losses were quantified by performing a testbed experiment and then was throughly validated using simulations and mathematical analysis.
- In addition, issues related to successive beacon losses like delay in association, frequent disassociation, etc were also highlighted.

Potential Solution to address LTE-U and Wi-Fi HTP

- Although hidden terminal problem has been well studied for the Wi-Fi deployments, the presence of a different RAT, makes this problem challenging.
- Our analysis makes us believe that an elementary step towards this problem would be to employ the existing RTS and CTS mechanism, which a Wi-Fi network extensively uses, within the competing RAT as well, with necessary changes.
- The above solution requires some modifications in LTE operation as LTE-U has to transmit and receive Wi-Fi RTS/CTS frames.

Potential Solution Cont..

- A simple solution without modification in LTE-U operation would be adding Wi-Fi transceiver along with LTE-U eNB to send Self-CTS or CTS-To-Self.
- Hence, whenever LTE-U want to start its transmission, it sends Self-CTS frame using Wi-Fi transceiver with NAV value equals to the LTE-U ON period.

Conclusions

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- We have shown the impact of duty cycled LTE-U on the performance of Wi-Fi users in the hidden ter- minal scenario, using testbed experiments.
- The users were classified into two groups, with one group, apart from receiving lower throughput, was also deprived from listening to periodic beacons.
- These beacon losses were quantified by performing a testbed experiment and then was throughly validated using simulations and mathematical analysis.

Future Work

- We showed that the channel access schemes for LTE in unlicensed, like duty cycled LTE-U or LBT based LAA need additional functionality to address these hidden terminal problems.

- As a part of future work, we intend to solve this issue to ensure a better and fair coexistence of LTE-U and Wi-Fi in the unlicensed spectrum.

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