WiPLUS
Towards LTE-U Interference Detection, Assessment and Mitigation in 802.11 Networks

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Outline

• Motivation,
• LTE Unlicensed Primer,
• Impact of LTE-U on WiFi,
• Problem Statement,
• WiPLUS
  – Design,
  – Implementation,
• Experiment Evaluation,
• Conclusion.
Motivation

- **Rapid growth** in the use of wireless devices such as smartphones and appearance of **novel applications** like multimedia streaming applications & cloud storage.
- **WiFi** is the **dominant access technology** in residential/enterprise environments and there is a strong trend towards further **densification**,
- **5 GHz ISM band** is being used by current 802.11 and future standards (.11ax).
- “**LTE in Unlicensed**” (LTE-U) constitutes a new source of interference with strong impact on WiFi in 5 GHz spectrum,
- **WiFi** will suffer **performance issues** due to **insufficient free radio spectrum** resulting in high contention/interference.
LTE Unlicensed Primer

- **LTE**
  - licensed spectrum (exclusive)
  - scheduled channel access
- **WiFi**
  - unlicensed spectrum (shared)
  - random channel access (CSMA).

- **LTE-Advanced** uses **carrier aggregation** to offload data to unlicensed spectrum
  - LTE Primary Cell (PCell) in licensed spectrum for user + control data
  - LTE Secondary Cell (SCell) unlicensed spectrum (5 GHz UNII-1/UNII-3) for DL user data (control data remains in Pcell)

- **Problem**: LTE and WiFi compete for **shared radio resources**
LTE Unlicensed Primer (II)

• Two approaches for LTE in unlicensed spectrum:
  – LTE-LAA (3GPP),
  – **LTE-U** (LTE-U Forum)
    • Rel-10/11/12 (FDD only),
    • scheduled, ON/OFF SCell access
    • **adaptive duty cycle** based on sensing of 802.11 frames / Carrier Sense Adaptive Transmission (CSAT)
    • only countries with non-LBT requirement

**LTE-U adaptive duty cycle (CSAT):**

```
<table>
<thead>
<tr>
<th>WiFi medium utilization estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
```

```
subframe punctering
```

```
Variable on, max 50 ms continuously
```

```
T_{ON}  T_{OFF}
```
Impact of LTE-U on WiFi

• The LTE-U DL signal may (or may not) impact WiFi communication in three ways:

  1. **Blocking medium access** by triggering the Energy Detection (ED) physical Carrier Sense (CS) mechanism of WiFi
     • Strong interference level (> -62 dBm)

  2. **Corrupting packets** due to co-channel interference from LTE-U.
     • Medium interference level (< -62 dBm)

  3. **No impact** due to insignificant co-channel interference from LTE-U.
Impact of LTE-U on WiFi (II)

- Impact of LTE-U with different duty cycles on 802.11a throughput
  - Lots of literature on that topic [1]-[6] => here our own results,
  - WiFi throughput widely directly proportional to LTE-U duty cycle (UL+DL)
Problem Statement

• To be able to cope with impact from LTE-U, an approach that **enables WiFi**
  • to **detect the LTE-U interference**,  
  • to **quantify** the effective **available medium airtime** of each WiFi link (DL/UL) during runtime,  
  • to obtain **timing information** about LTE-U ON and OFF phases,  

is needed.

*System model:*
Problem Statement (II)

• Desired **detector properties:**
  • Online algorithm running on WiFi AP,
  • Passive and low-complexity,
  • Using commodity 802.11 hardware,
  • Covering the whole LTE-U interference range.

*Atheros AR95xx 802.11n chip*
WiPLUS Design (I)

- Known approaches for detection of non-WiFi interference are based on analysis of spectral samples (PHY), e.g. Airshark.

- WiPLUS is based on **MAC layer monitoring**
  - .11 MAC is a finite state machine (FSM) with different states,
  - .11 MAC ARQ tracks information about frame retransmissions,
  - WiPLUS monitors and samples MAC FSM state transitions and ARQ information.
WiPLUS MAC Layer Monitoring

• Basic idea:
  – As WiFi cannot decode LTE-U frames it has to rely on ED-based CS.
    • We observe the MAC FSM state, i.e. LTE-U’s medium share equals the time share that corresponds to energy detection without triggering packet reception -> interference regime 1.
  – If LTE-U signal is weak (below ED CS), it can, without being detected by Wi-Fi’s ED CS, corrupt ongoing WiFi transmissions.
    • We observe the MAC ARQ state, i.e. analyzing the number of MAC layer retransmissions to detect packet corruption (size of packet loss burst ~ LTE-U ON phase) -> interference regime 2.
WiPLUS Detector Pipeline

- Input data is **very noisy**, 
- **Detector pipeline:**
  - Periodically sampled MAC FSM states (RX/TX>IDLE/ED state) + MAC ARQ states (missing ACK),
  - Spurious signal extraction (cleansing),
  - FFT / PWM signal detection,
  - Used to find fundamental frequency (harmonics) of interfering signal,
  - ML cluster detection (k-means):
    - Remove signals outside clusters to suppress outliers,
  - Low pass filtering,
  - LTE-U ON time estimation & calculation of eff. available airtime for WiFi.
WiPLUS Design (II)

- WiPLUS consists of **three phases**:
  - **Phase 1**: detector runs passively in background and terminates in case any interfering LTE-U signal is detected.
  - **Phase 2**: to discriminate the interference level on each WiFi DL link we switch into a time slotted access to test each link independently
    - effective available medium airtime & precise timing information of LTE-U ON/OFF phases are derived.
  - **Phase 3**: execution of various interference mitigation strategies.
WiPLUS enabled Interference Mitigation Strategies

1. Interference-aware channel selection,
2. Interference-aware Load Balancing,
3. Interference-aware Medium Access,
4. Interference-aware Channel Bonding.
WiPLUS Implementation

• WiPLUS was **prototypically** implemented & tested:
  – Raw MAC FSM/ARQ data sampling using modified RegMon [10] tool,
  – Regmon was designed for uniprocessor embedded systems (OpenWRT) → migration to SMP systems (Ubuntu 16.04 & upstream ath9k driver),

• WiPLUS online detector functionality implemented in Python using libraries
  – SciPy,
  – NumPy,
  – Sklearn,
  – Other: weightedstats, peakutils
**Experiment Setup & Methodology**

- **WiFi setup**
  - 802.11a, channel 48 (5240 MHz), no encryption
  - AP+STA: powersave disabled, ANI disabled, SISO (1x1), 15 dBm fixed
  - Traffic: iperf3, full-buffer UDP, 1470 Bytes payload, 100% UL/DL

- **LTE-U setup**
  - R&S Vector Signal Generator (VSG) at fc=5240
  - LTE-U waveform generated with Matlab
  - Evaluation with different TX power levels: 15...-33 dBm
Selected Experiment Results

- **Scenario**: 100% full-buffer DL traffic WiFi, LTE-u w/ 20% duty cycle
- **Simple Detector**
  - energy detection only
  - ~15 dB detection range
  - covers interference regime 1 only
- **WiPLUS**
  - combined energy+missing ACK detection
  - ~45 dB detection range (+30 dB)
  - covers all interference regimes
  - slight overestimation in low IF regime

![Chart showing estimated available airtimes and normalized UDP throughput vs. LTE-U TX power and WiFi TX power.](chart.png)
Conclusion

• Design and implementation of **WiPLUS**, a passive **LTE-U interference detector**, which runs on WiFi APs only and is only using **COTS WiFi hardware**, was presented and experimentally evaluated.

• **WiPLUS** works passively & in real-time.

• Experiment results showed very good LTE-U **detection accuracy** over a complete range of interferer signal strengths.

• **WiPLUS** enables novel **interference mitigation** strategies
References


