WiPLUS

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

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Outline

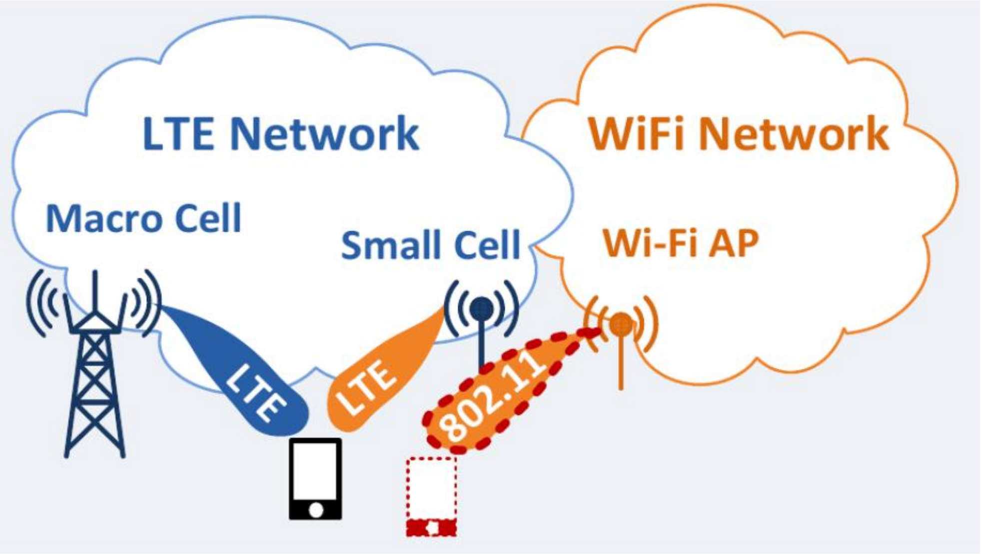
- Motivation,
- LTE Unlicensed Primer,
- Impact of LTE-U on WiFi,
- Problem Statement,
- WiPLUS
  - Design,
  - Implementation,
- Experiment Evaluation,
- Conclusion.

Motivation

- **Rapid growth** in the use of wireless devices such as smart phones and appearance of **novel applications** like multimedia streaming applications & cloud storage.
- **WiFi** is the **dominant access technology** in residential/enterprise environments and there is 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).



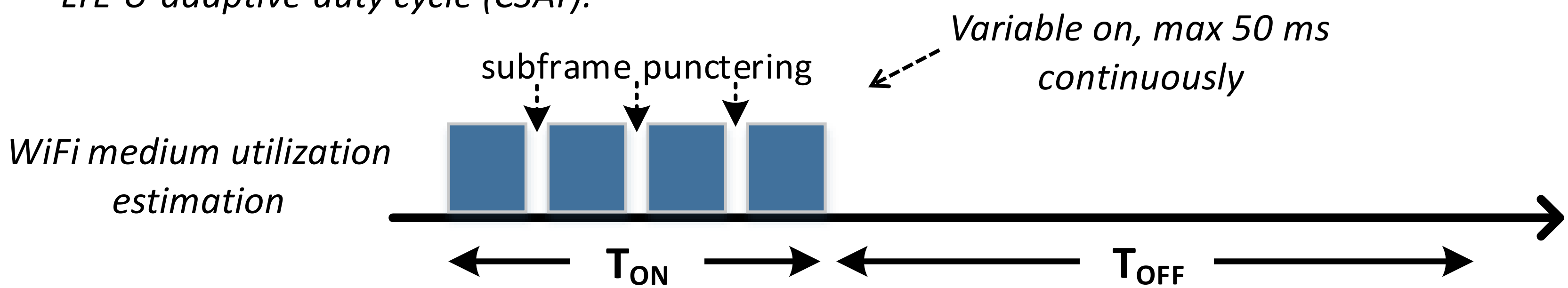
Source: Korea Communication Review, Jan. 2015

- 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

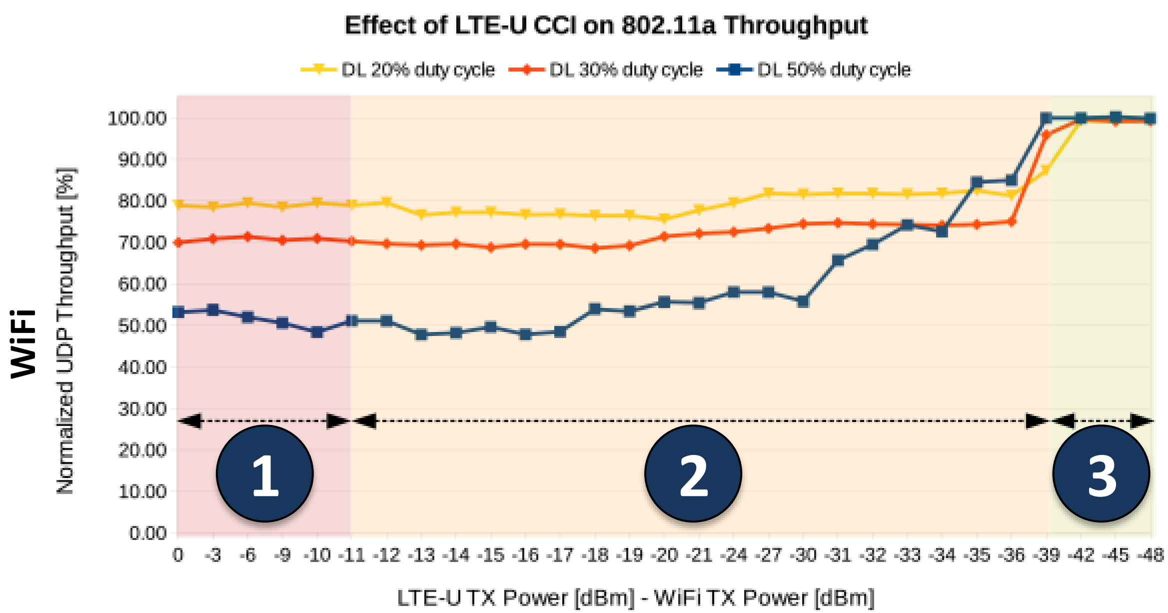
LTE-U adaptive duty cycle (CSAT):

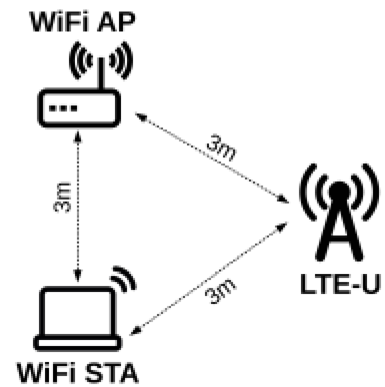


Impact of LTE-U on WiFi

- 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)





full-buffer downlink UDP traffic
LTE-U TX power 15... -33 dBm

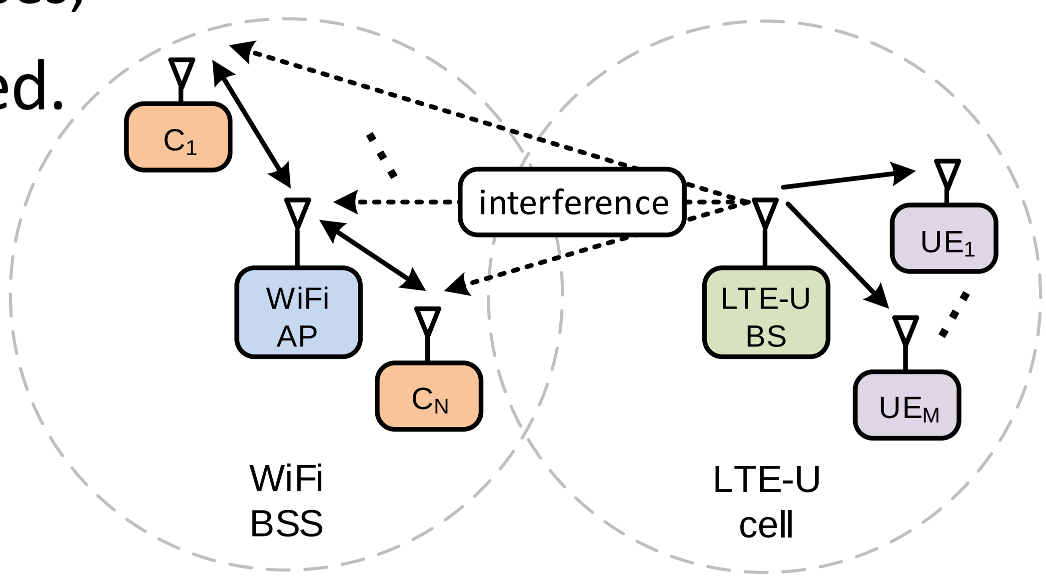
- Impact of LTE-U with different duty cycles on 802.11a throughput
  - Lots of literature on that topic [1]-[6] => here our **own results**,
  - WiFi throughput widely directly proportional to LTE-U duty cycle (UL+DL)

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)

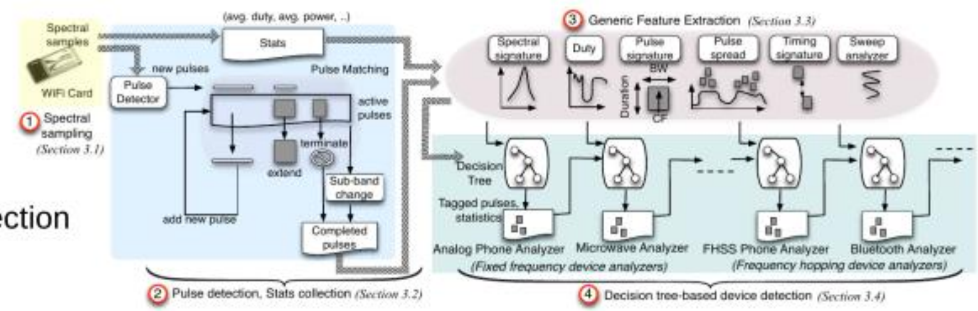
- Desired **detector properties:**
  - Online algorithm running on WiFi AP,
  - Passive and low-complexity,
  - Using commodity 802.11 hardware,
  - Covering the whole LTE-U interference range.

Atheros AR95xx 802.11n chip

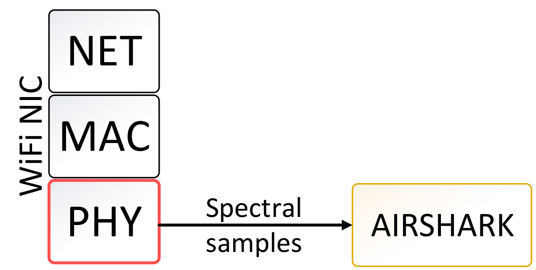
WiPLUS Design (I)

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

Airshark detection pipeline:

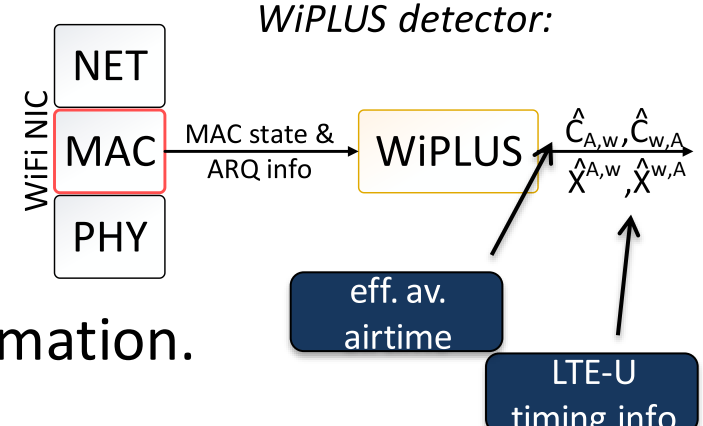


Interference detectors:



- 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 detector:

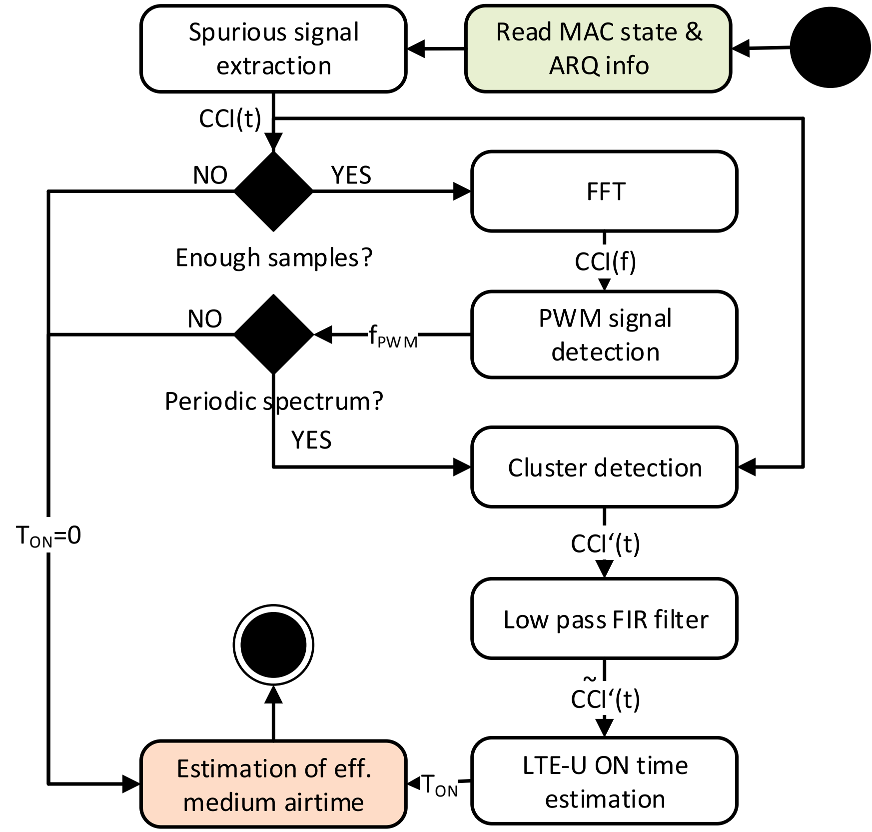


WiPLUS MAC Layer Monitoring

- Basic idea:
  - As WiFi cannot decode LTE-U frames it has to rely on ED-based CS.
    - We observes 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 observes 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

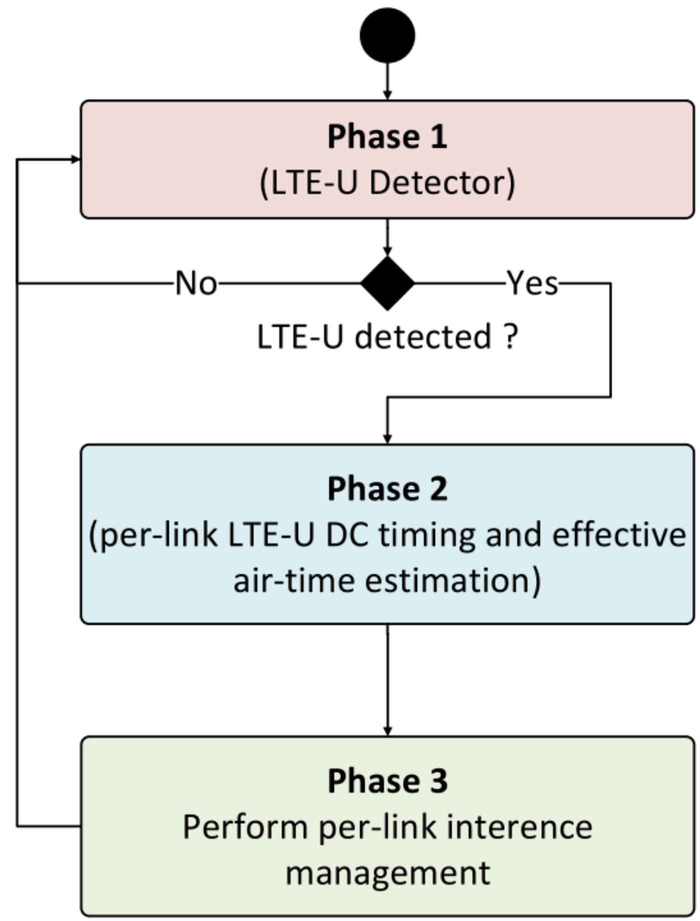
- Input data is **very noisy**,
- **Detector pipeline**:
  - Periodically sampled MAC FSM states (RX/TX/IDLE/ED state) + MAC ARQ states (missing ACK),
  - Spurious signal extraction (cleansing),
  - FFT / PWM signal detection,
  - Used to find fundamental frequency (harmonics) of interfering signal,
  - 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 detector pipeline

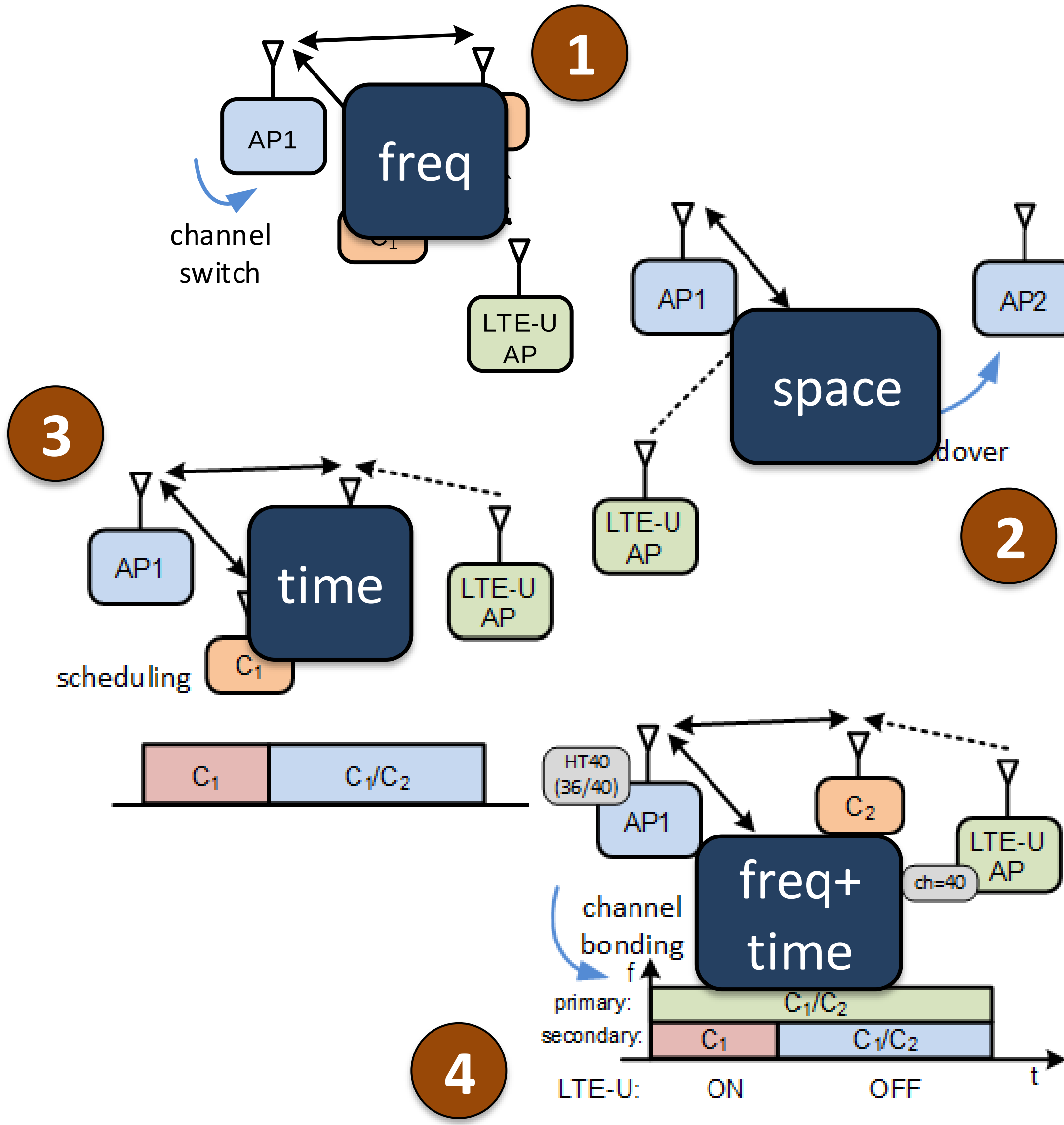
WiPLUS Design (II)

- 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

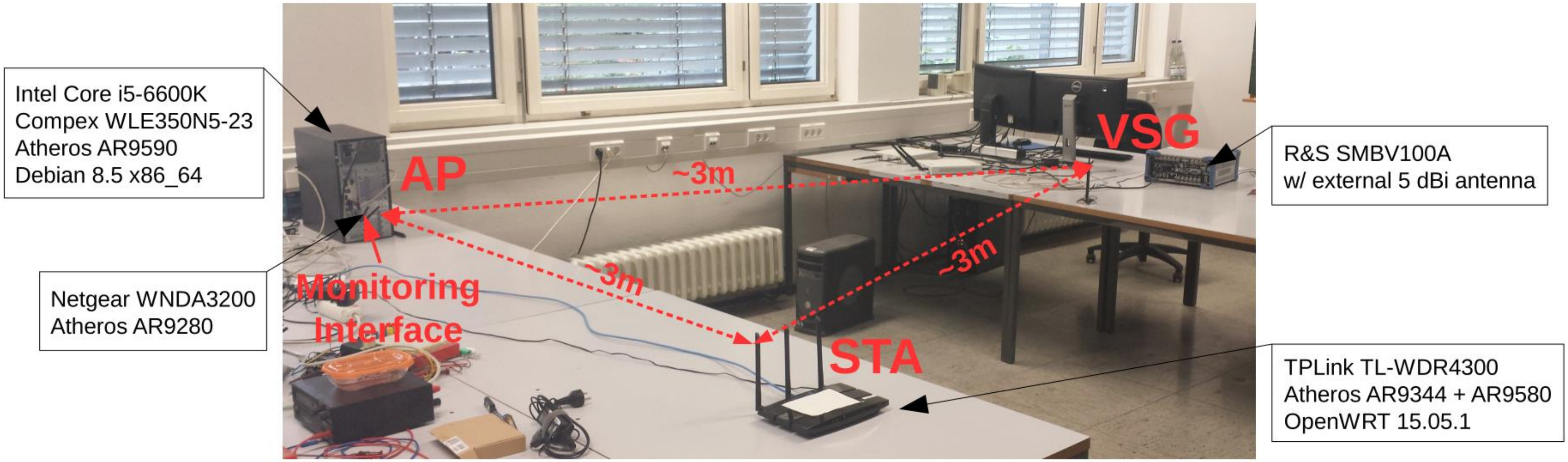
1. **Interference-aware channel selection,**
2. Interference-aware Load Balancing,
3. Interference-aware Medium Access,
4. Interference-aware Channel Bonding.



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

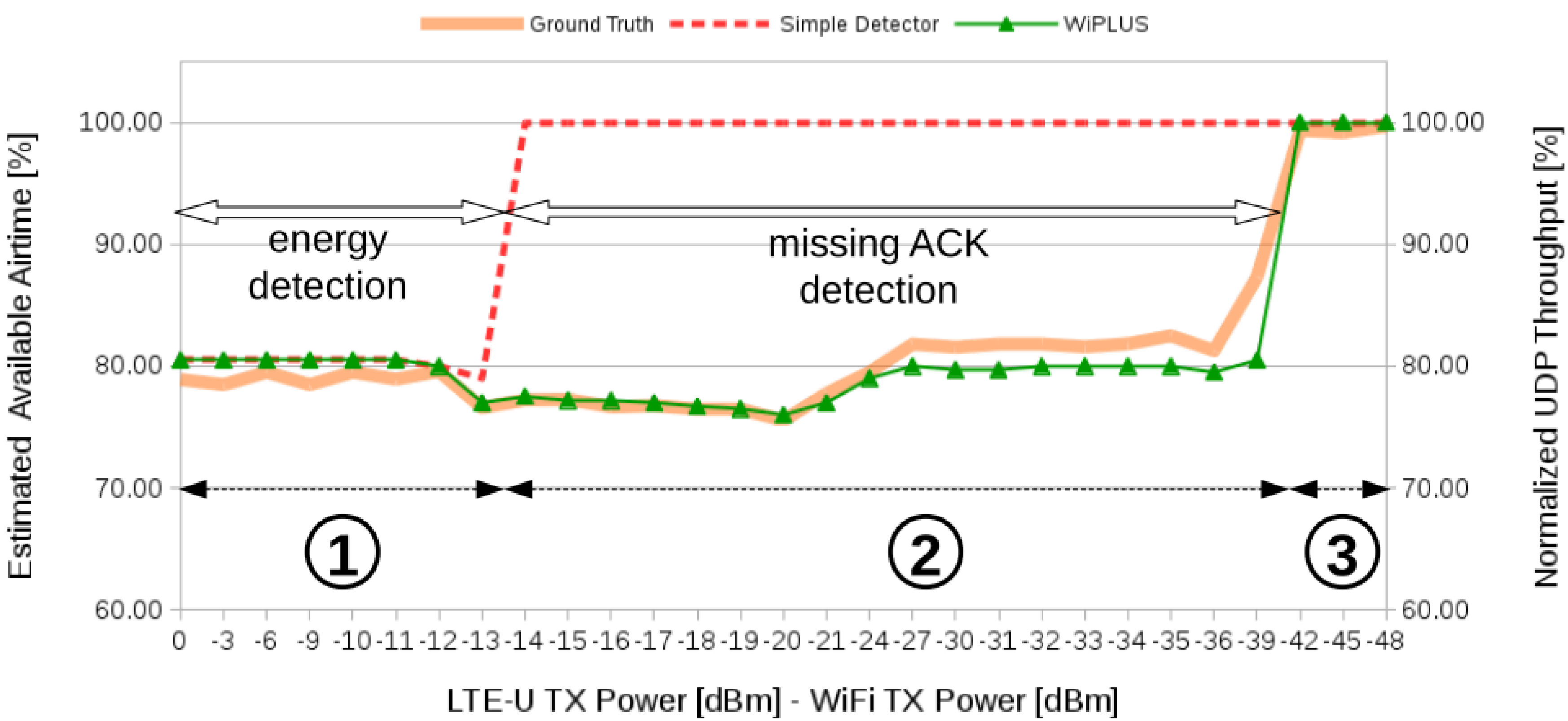
Experiment Setup & Methodology



- 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



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

[1] N. Jindal and D. Breslin, "LTE and Wi-Fi in Unlicensed Spectrum: A Coexistence Study," Google, 2015. [Online]. Available: http://apps.fcc.gov/ecfs/document/view?id=60001078145

[2] A. Babaei, J. Andreoli-Fang, and B. Hamzeh, "On the impact of LTE-U on Wi-Fi performance," in 2014 IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC), 2014, pp. 1621–1625.

[3] P. S. Cristina Cano Douglas J.Leith, Andres Garcia-Saavedra, "Fair Coexistence of Scheduled and Random Access Wireless Networks: Unlicensed LTE/WiFi," 2016.

[4] C. Capretti, F. Gringoli, N. Facchi, and P. Patras, "LTE/Wi-Fi Co-existence Under Scrutiny: An Empirical Study," in Proceedings of the Tenth ACM International Workshop on Wireless Network Testbeds, Experimental Evaluation, and Characterization, New York City, New York, 2016, pp. 33–40.

[5] S. Choi and S. Park, "Co-existence analysis of duty cycle method with Wi-Fi in unlicensed bands," in 2015 International Conference on Information and Communication Technology Convergence (ICTC), 2015, pp. 894–897.

[6] A. M. Voicu, L. Simić, and M. Petrova, "Coexistence of pico- and femto-cellular LTE-unlicensed with legacy indoor Wi-Fi deployments," in 2015 IEEE International Conference on Communication Workshop (ICCW), 2015, pp. 2294–2300.

[7] LTE-U Forum, "LTE-U CSAT Procedure TS V1.0," Oct. 2015.

[8] Qualcomm Technologies, Inc., "LTE-U Technology and Coexistence," LTE-U Forum Workshop, 28 May 2015. [Online]. Available: http://www.lteuforum.org/workshop.html.

[9] S. Rayanchu, A. Patro, and S. Banerjee, "Airshark: Detecting non-WiFi RF Devices Using Commodity WiFi Hardware," in Proceedings of the 2011 ACM SIGCOMM Conference on Internet Measurement Conference, Berlin, Germany, 2011

[10] T. Hühn, "A Measurement-Based Joint Power and Rate Controller for IEEE 802.11 Networks," Technische Universität Berlin, FG INET Prof. Anja Feldmann, 2013.