Enabling Cross-technology Communication between LTE Unlicensed and WiFi

P. Gawłowicz, A. Zubow, A. Wolisz

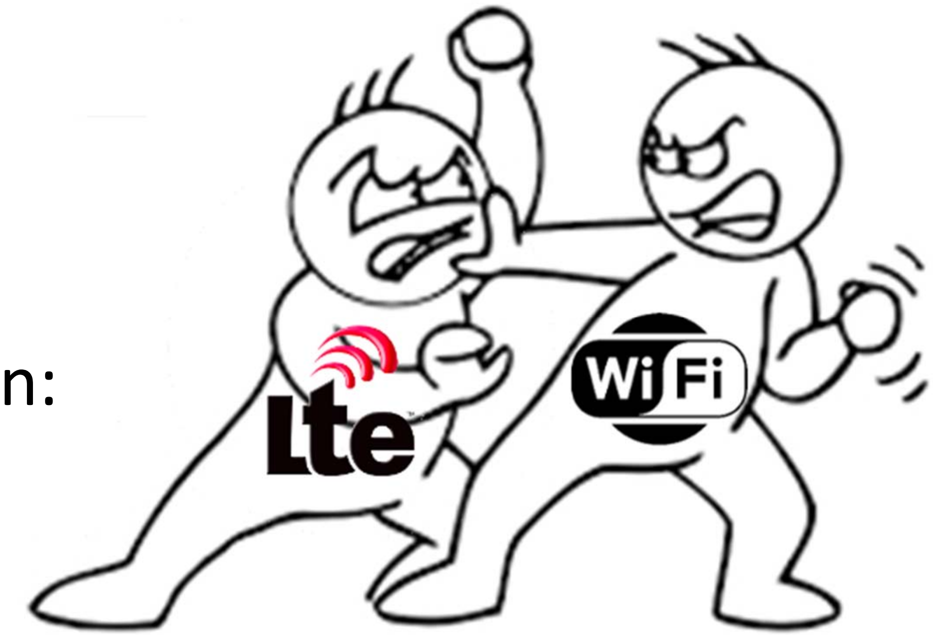
INFOCOM, 17.04.2018

Technische Universität Berlin

TKN Telecommunication Networks Group

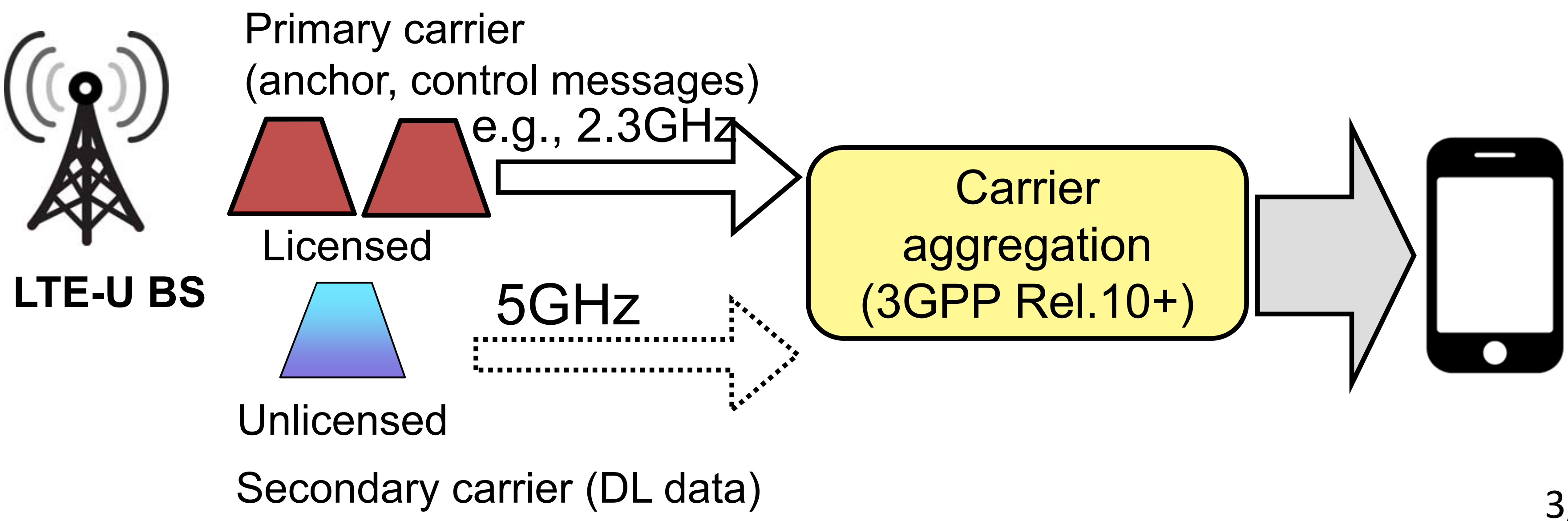
Motivation

- Massive growth in wireless traffic – new bands needed!
- IEEE 802.11 **WiFi** dominates in 5GHz band
- Telecom operators started to use 5GHz band to boost their LTE networks
  - **LTE-Unlicensed**
- Performance degradation:
  - Increased contention
  - Mutual interferences



LTE-Unlicensed Primer

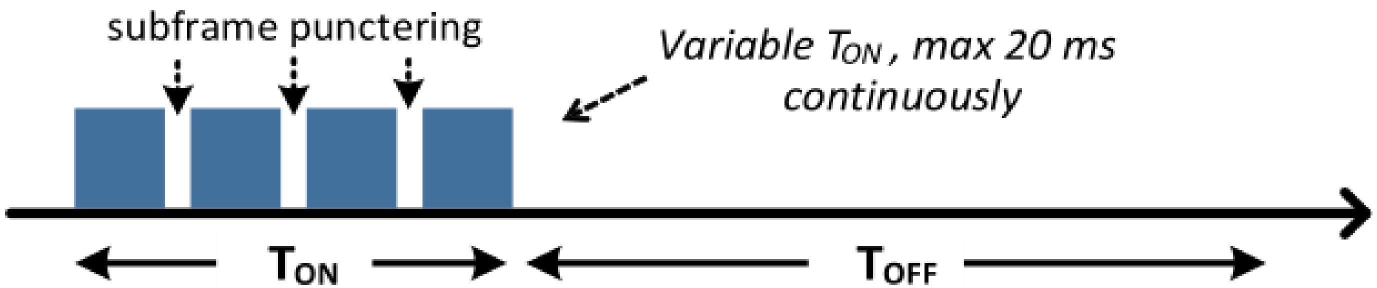
- First cellular solution for use of 5GHz unlicensed band
  - Channel bandwidth is 20MHz as in WiFi
- Two versions of LTE-Unlicensed:
  - LTE-LAA(LBT) and **LTE-U**(CSAT)



LTE-U CSAT

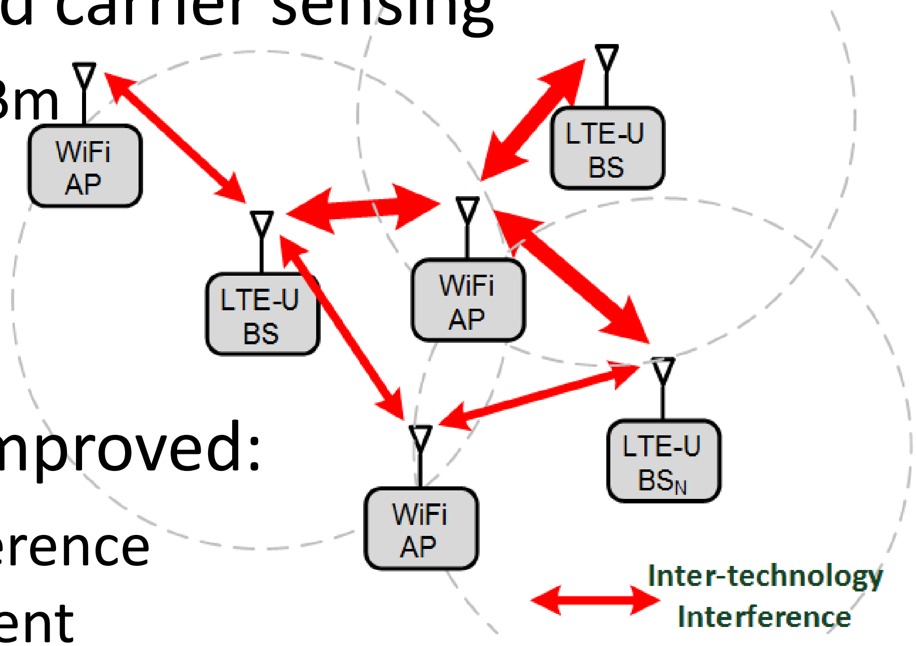
- Carrier Sense Adaptive Transmission (CSAT):
  - No Listen-Before Talk, but duty cycled channel access
  - Period: 40, 80, 160ms
  - Duty cycle adaptation based on number of WiFi and LTE nodes, max 50%

- Puncturing for low-latency WiFi traffic



Coexistence Issues

- LTE & WiFi have incompatible PHY layers
- WiFi relies on energy-based carrier sensing
  - High ED threshold, i.e -62dBm
  - Hidden/exposed terminals

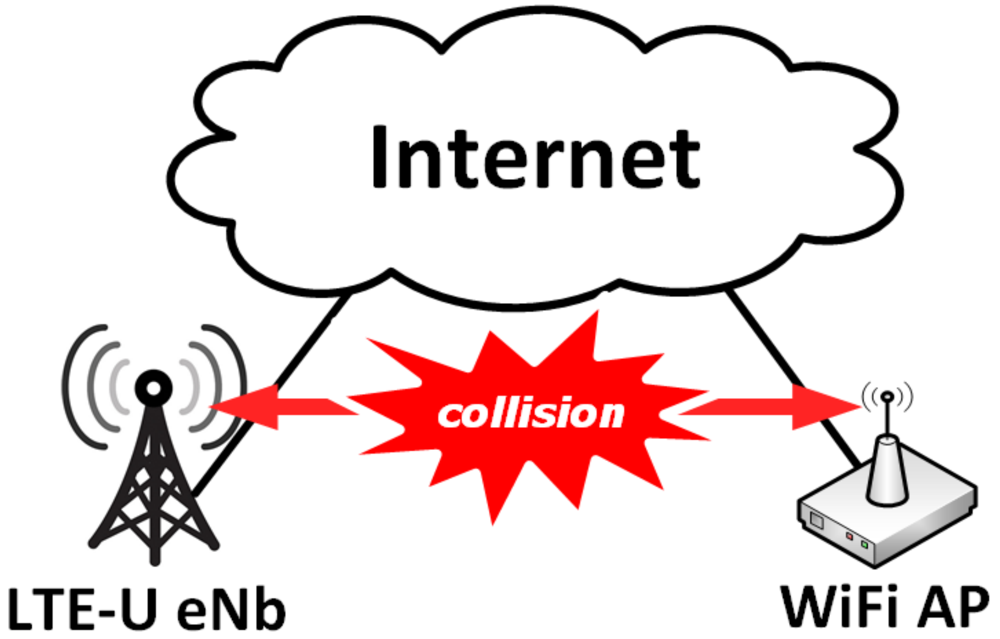


- The performance can be improved:
  - Via cross-technology interference & radio resource management

- ...but **cross-technoology control channel** is required!

How to start collaboration?

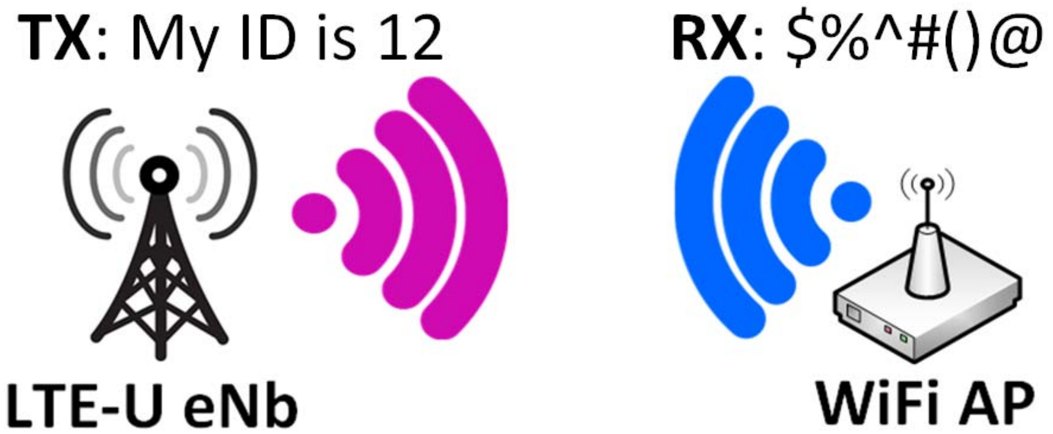
- WiFi AP and LTE-U BS can communicate over Internet



- .... but have no clue:
  - Who is in interference range?
  - How to communicate with co-located neighbors?

Over-the-air Neighbor Discovery

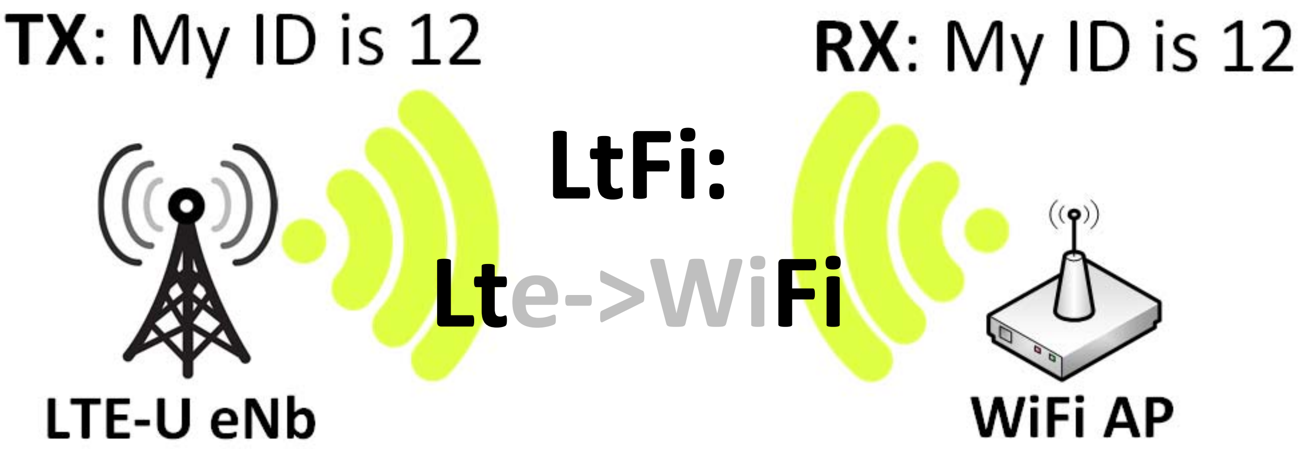
- A node advertises itself to others
- Available for homogenous technologies:
  - Automatic Neighbor Relation (ANR) in LTE
  - ResFi[1] in WiFi
- How to perform neighbor discovery between nodes of heterogenous technologies?



[1] S.Zehl *et al.*, „Resfi: A secure framework for self organized radio resource management in residential WiFi networks", WoWMoM 2016

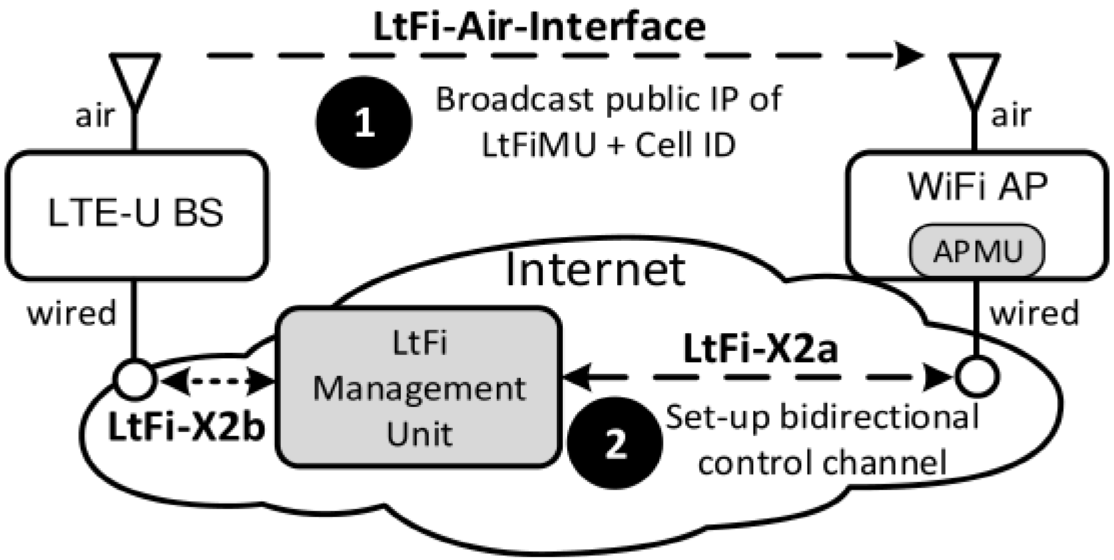
Cross-technology Communication (CTC)

- CTC enables heterogeneous devices to talk directly
  - Simple side-channel on top of normal transmissions
    - E.g. CTC data encoded in frame duration
  - Low data rates (up 100s bps), but sufficient for broadcasting **management data** (i.e. IP address, cell ID)



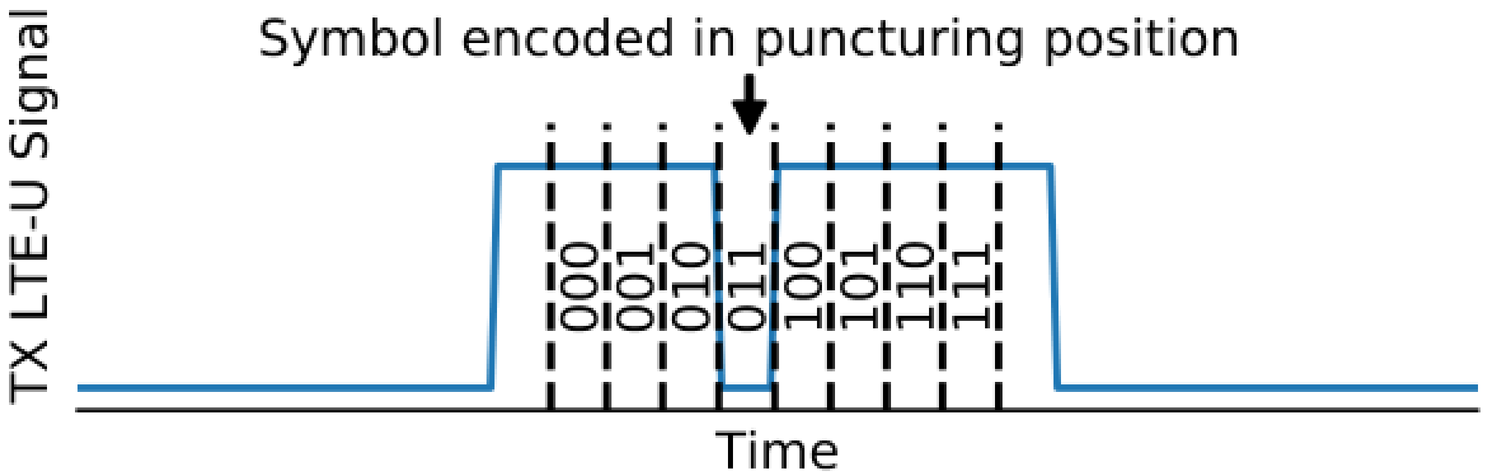
LtFi – Big Picture

- LtFi consists of two interfaces:
  - Air-Interface – over-the-air **CTC broadcast** channel
  - X2-Interface – over-the-wire **bidirectional** channel
- LtFi Management Unit (MU) manages a LTE network
- Access Point Management Unit (APMU) manages a WiFi AP



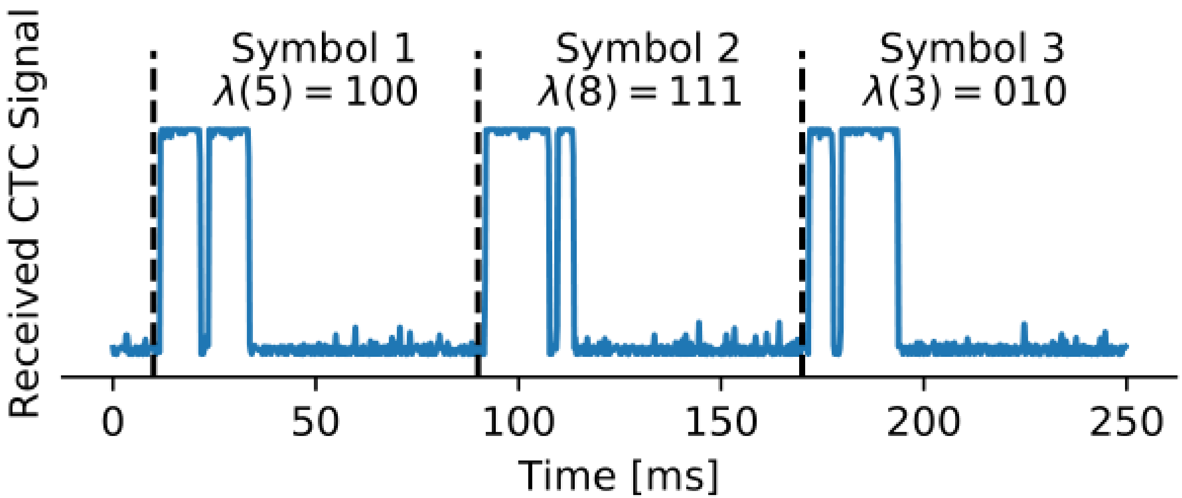
LtFi-Air-Interface: PHY Layer

- LtFi exploits the freedom to put puncture within LTE-U's on-time
- The position of the puncture encodes the data bits
  - Standard compliant
  - Introduced delay for LTE-U traffic is negligible (1-2ms)



LtFi-Air-Interface: Frame Structure

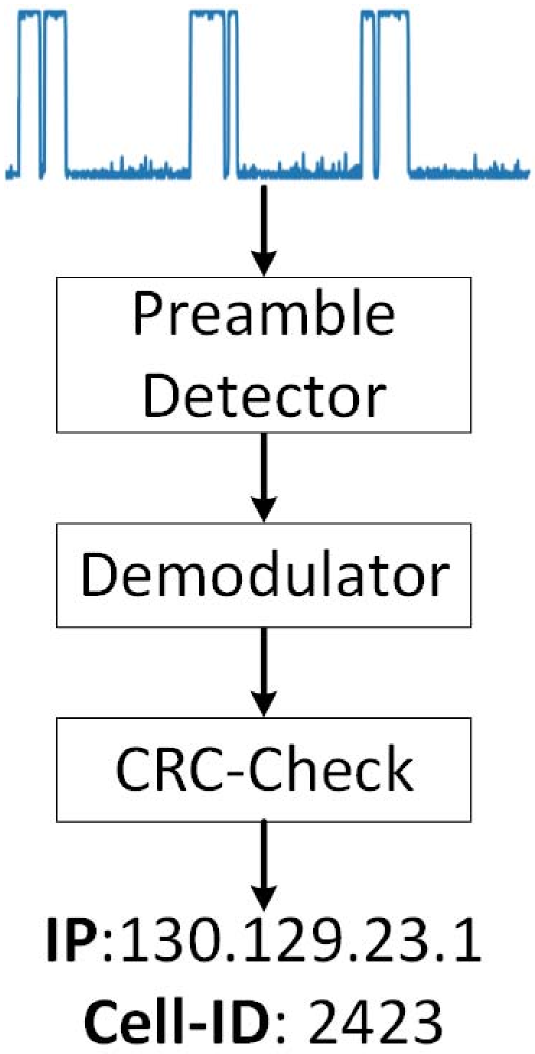
- LtFi frame consists of multiple LtFi symbols



- Frame Structure:
  - Preamble – 4 LtFi symbols - marks the start of the frame
  - Data Payload – IP address (4B) and Cell ID (2B)
  - CRC Field – error detection using CRC16

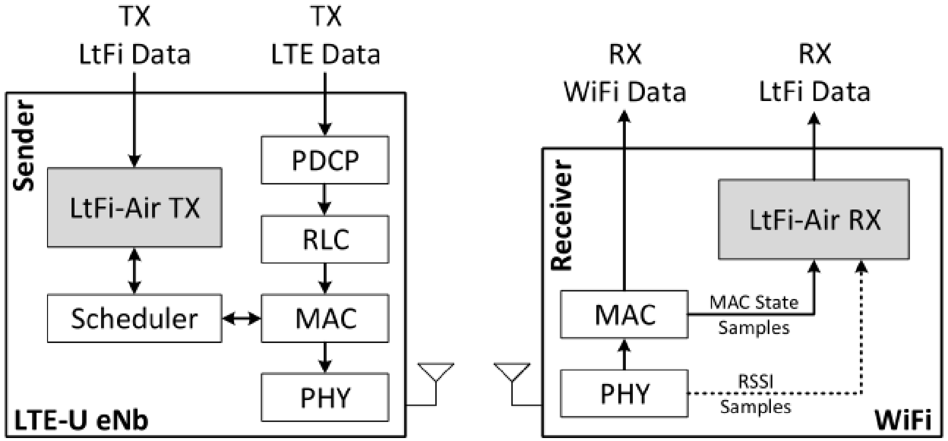
LtFi-Air-Interface: Demodulation

- Frame detection and synchronization
  - Cross-correlation based preamble detector
- Symbol demodulation using maximal likelihood detection (MLD)
- Repetition coding: LtFi frames are broadcasted in a loop



LtFi-Air-Interface: Integration

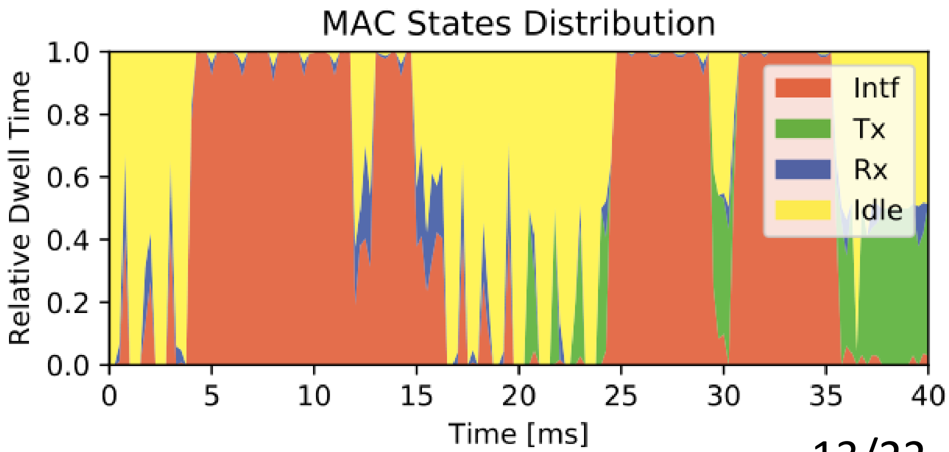
- LtFi is only a software add-on
  - No hardware changes!



- On LTE-U side, LtFi TX interacts with LTE scheduler
  - To set the punctures

- On WiFi side, LtFi RX samples MAC state distribution:
  - Interference (Intf) from LTE-U

    = time spent in energy detection (ED) state without triggering frame reception (RX)



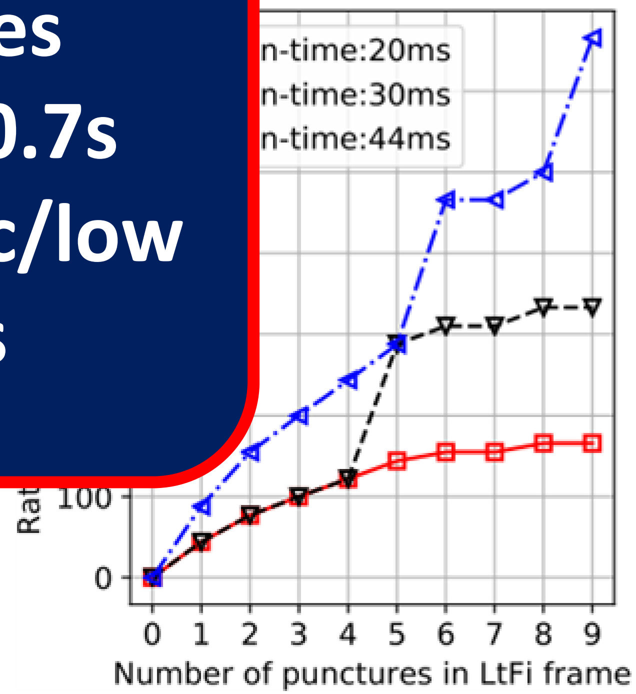
Theoretical Throughtput Analysis

- The number of available symbols **M**:

where ***n*** ...
positions ...

- Transm...

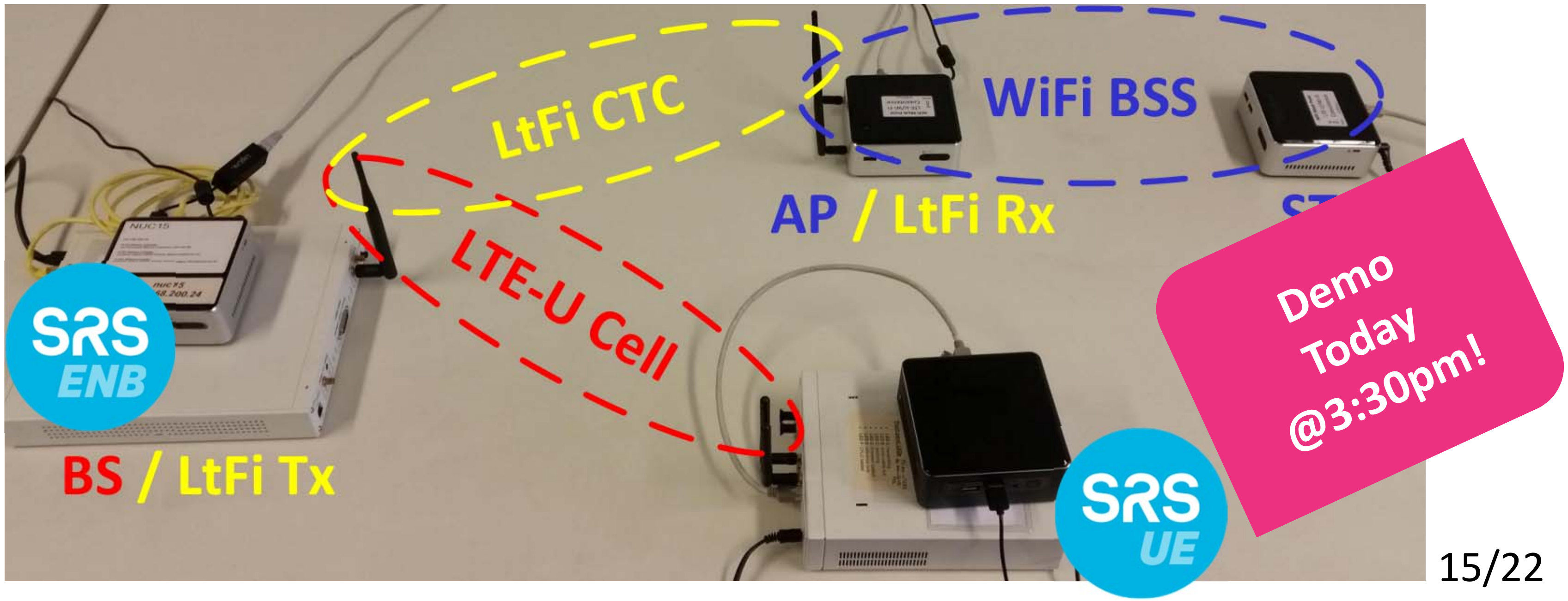
where ***Tcycle*** is LTE-U cycle and ***z*** is number of symbols of 20ms in one cycle



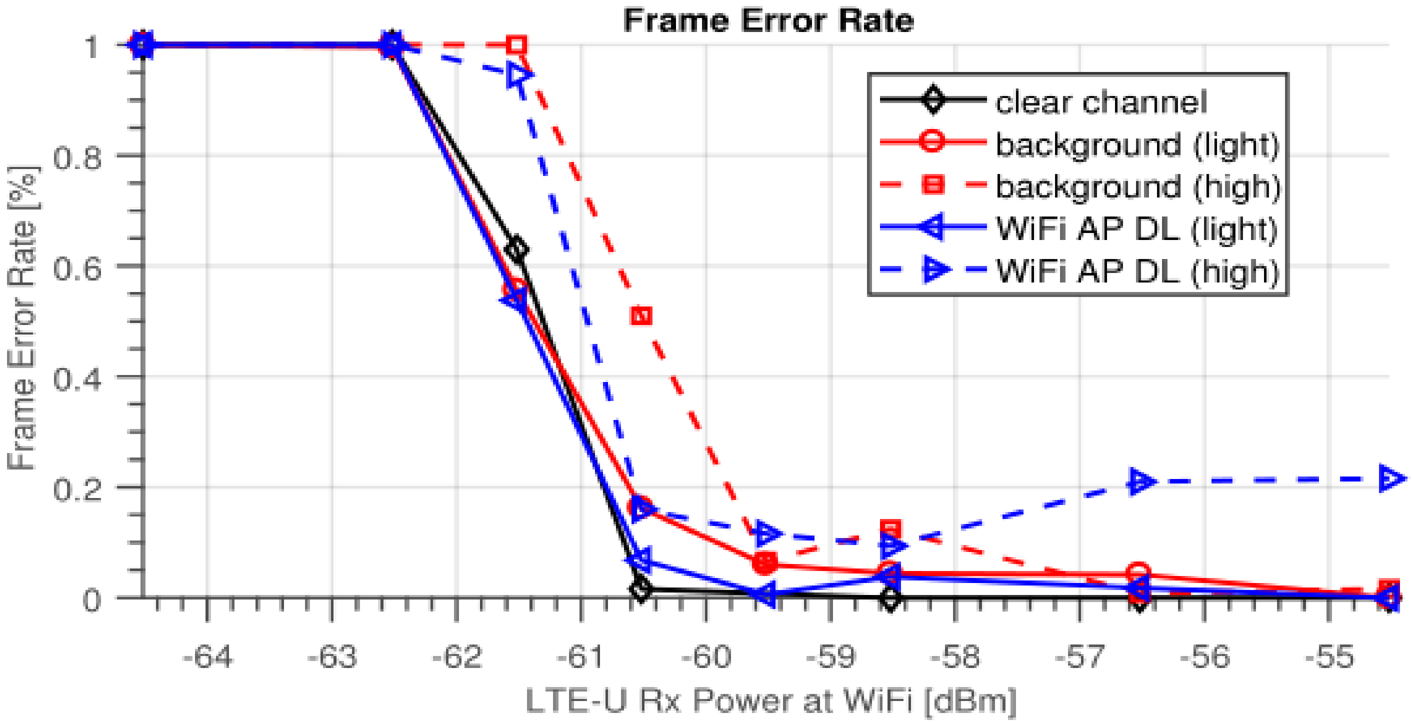
LtFi msg size = 8Bytes
TX time @ 100bps = 0.7s
→ suitable for nomadic/low mobility scenarios

Prototype Implementation

- Is custom **hardware** needed?
  - **No**, prototype based on SDR-USRP (LTE) and COTS (WiFi, Atheros chip)
- Is special **software** required?
  - **No**, only open-source software:
    - **LTE-U side**: srsLTE modified to support duty-cycled operation
    - **WiFi side:** patched ath9k driver, LtFi RX implemented in Python

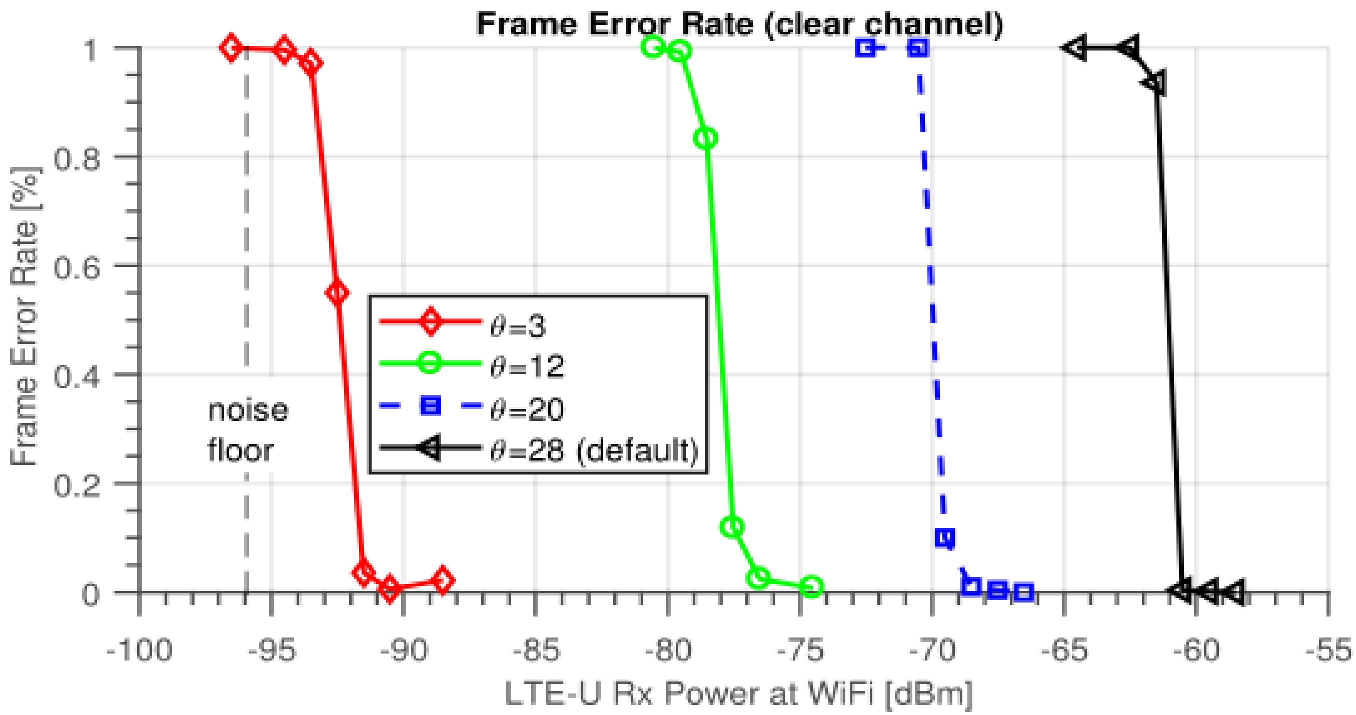


Evaluation: Frame Error Rate



- Works even with ongoing WiFi traffic
- Half-duplex constraint limits performance in case of saturated outbound traffic
- Power of received LTE-U signal must be ≈3 dB above WiFi ED threshold (-62 dBm), but...

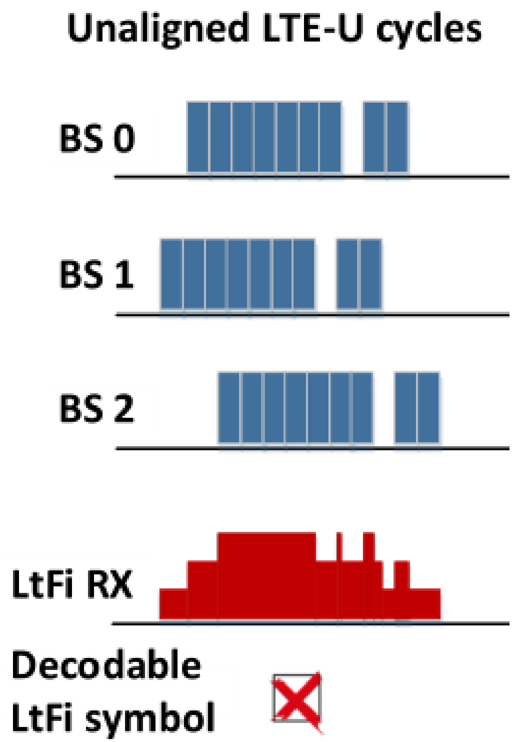
Impact of ED Threshold Adaptation



- ED threshold can be adapted down to -92dBm

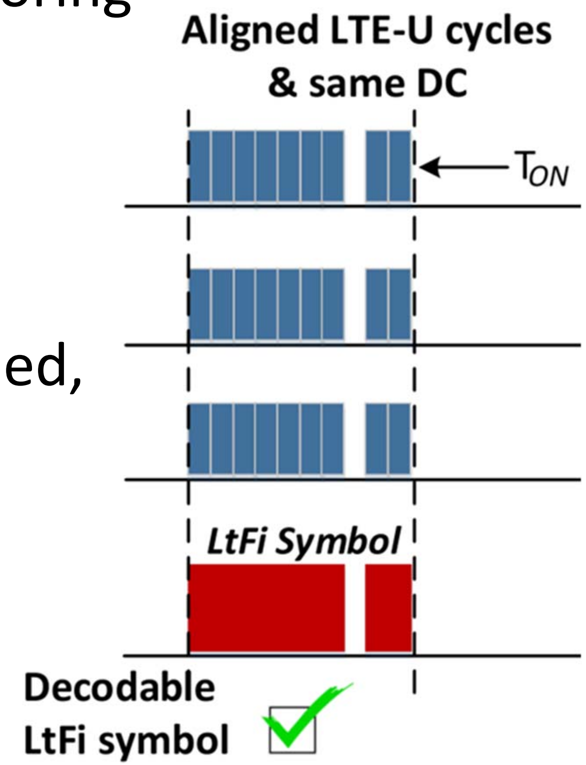
Multi-Cell Operation: Limitations

- In real world a WiFi node is surrounded by multiple LTE-U BSs
  - Transmitting different CTC data
- Results in interference between multiple CTC transmissions
  - Successful decoding highly depends on WiFi node's location
- A coordination between LtFi transmitters is required



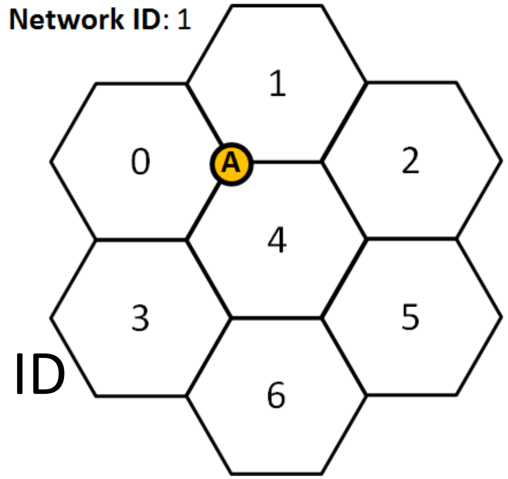
Multi-Cell Operation: Clustering

- To create a decodable LtFi symbol all neighboring LTE-U BSs have to:
  - Time align their on-phase/cycles,
  - Send the same information over the CTC
- Problem: only **LTE-U network** can be identified, but **not individual BSs**
  - Not sufficient for efficient interference/RRM coordination
- **Solution:** group BSs into clusters sending the same information, i.e. cluster ID
  - The same problems appears at cluster edges



Dynamic and Overlaping Clustering

- Members of a given cluster change in each time slot
- In each time slot, depending on its position, a WiFi node may decode different cluster ID



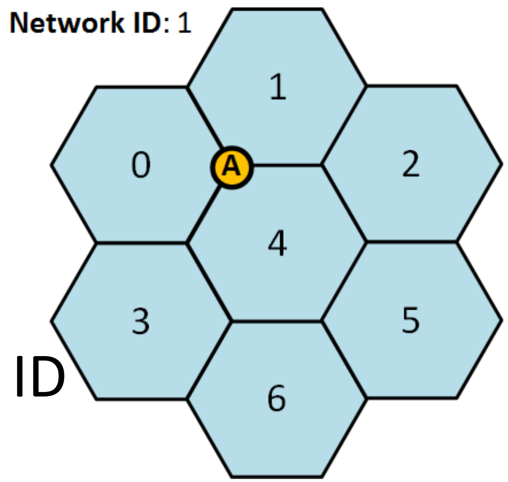
Cluster Membership Table

	slot						
Cell	0	1	2	3	4	5	6
0	0	5	5	2	2	1	1
1	0	5	5	5	5	5	2
2	0	7	7	5	5	4	4
3	0	4	4	1	1	1	1
4	0	5	4	4	5	4	1
5	0	6	6	4	4	4	4
6	0	4	4	4	4	3	0

- {BS_IDs} = **Function(**<time_slot, cluster_ID>**)**

Dynamic and Overlaping Clustering

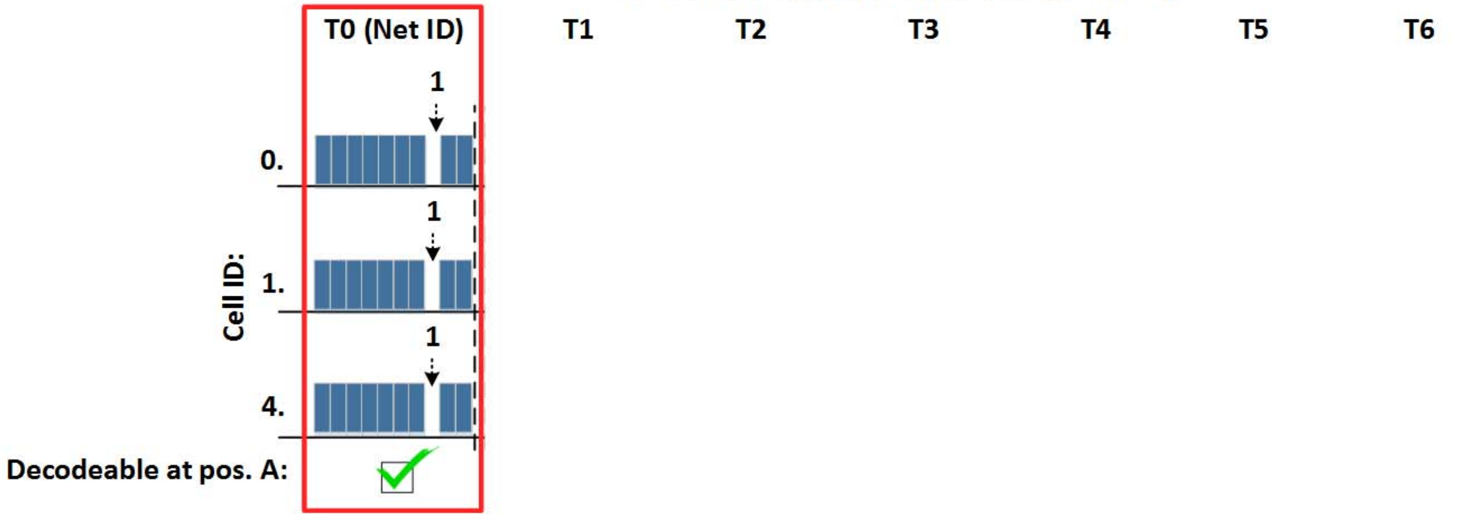
- Members of a given cluster change in each time slot
- In each time slot, depending on its position, a WiFi node may decode different cluster ID



Cluster Membership Table

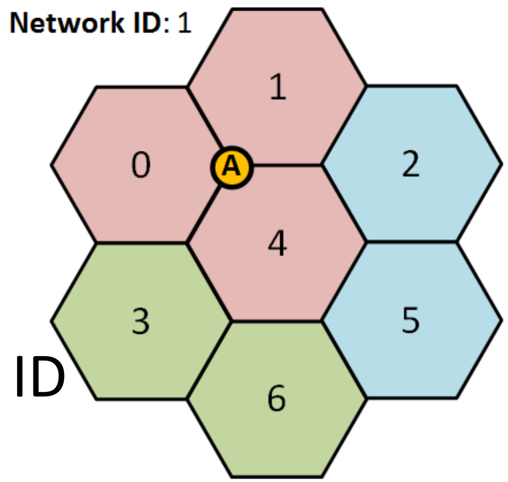
Cell	slot 0	1	2	3	4	5	6
0	0	5	5	2	2	1	1
1	0	5	5	5	5	5	2
2	0	7	7	5	5	4	4
3	0	4	4	1	1	1	1
4	0	5	4	4	5	4	1
5	0	6	6	4	4	4	4
6	0	4	4	4	4	3	0

- {BS_IDs} = **Function(**<time_slot, cluster_ID>**)**



Dynamic and Overlaping Clustering

- Members of a given cluster change in each time slot
- In each time slot, depending on its position, a WiFi node may decode different cluster ID

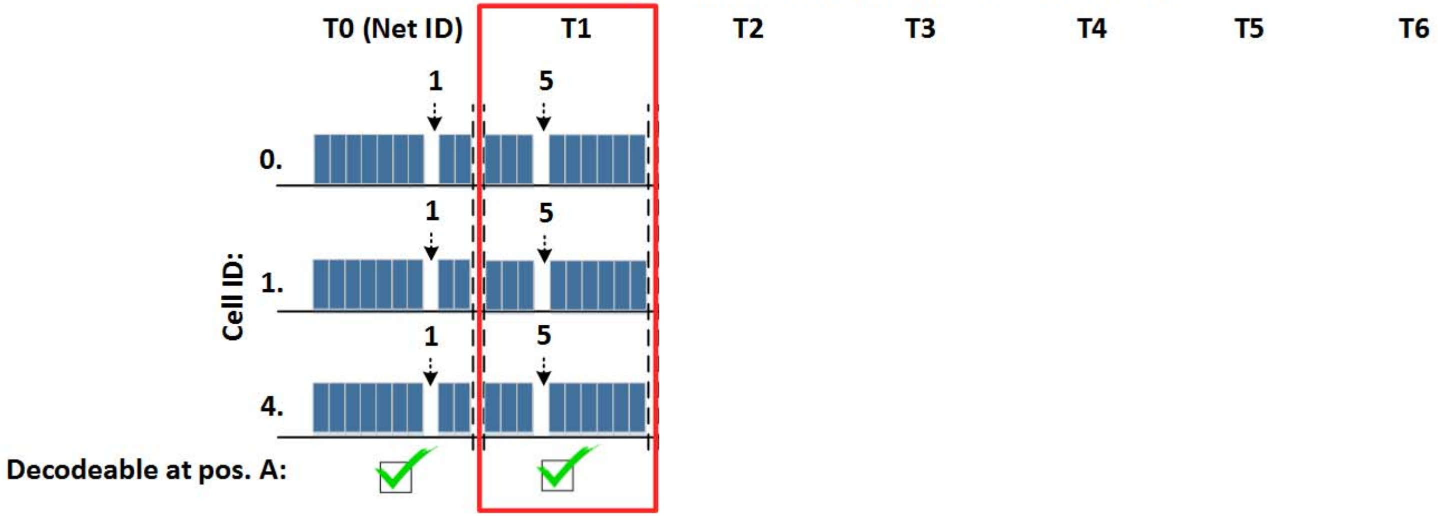


Cluster Membership Table

Cell	slot 0	1	2	3	4	5	6
0	0	5	5	2	2	1	1
1	0	5	5	5	5	5	2
2	0	7	7	5	5	4	4
3	0	4	4	1	1	1	1
4	0	5	4	4	5	4	1
5	0	7	6	4	4	4	4
6	0	4	4	4	4	3	0

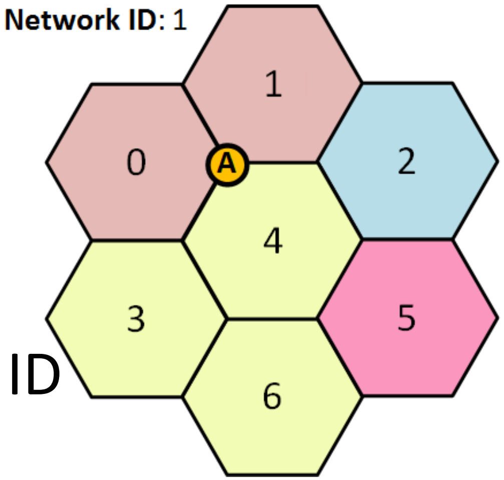
- {BS_IDs} = **Function(**<time_slot, cluster_ID>**)**

Transmitted CTC signal (for cells 0, 1 and 4):



Dynamic and Overlaping Clustering

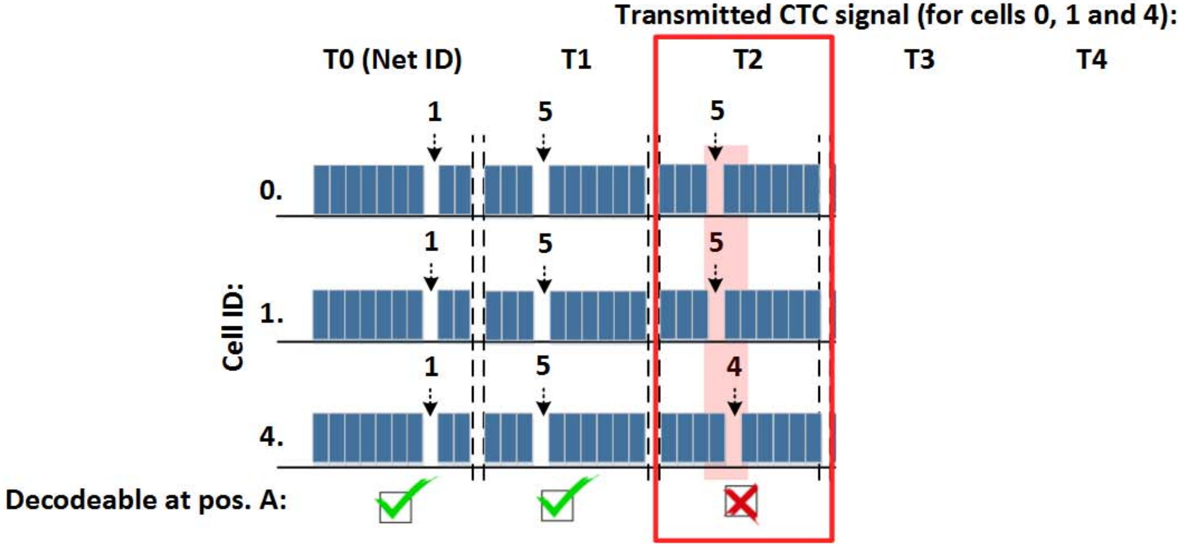
- Members of a given cluster change in each time slot
- In each time slot, depending on its position, a WiFi node may decode different cluster ID



Cluster Membership Table

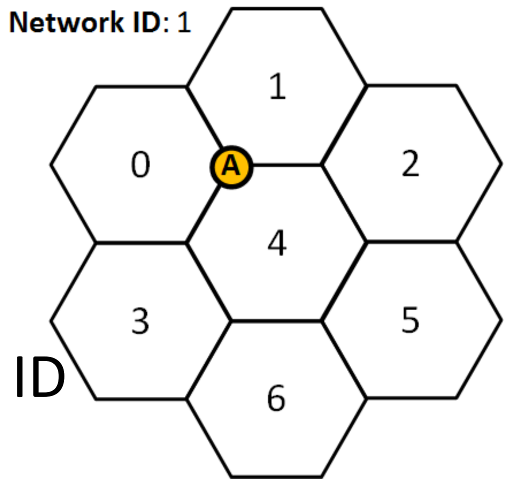
Cell	slot 0	1	2	3	4	5	6
0	0	5	5	2	2	1	1
1	0	5	5	5	5	5	2
2	0	7	7	5	5	4	4
3	0	4	4	1	1	1	1
4	0	5	4	4	5	4	1
5	0	7	6	4	4	4	4
6	0	4	4	4	4	3	0

- {BS_IDs} = **Function(**<time_slot, cluster_ID>**)**



Dynamic and Overlaping Clustering

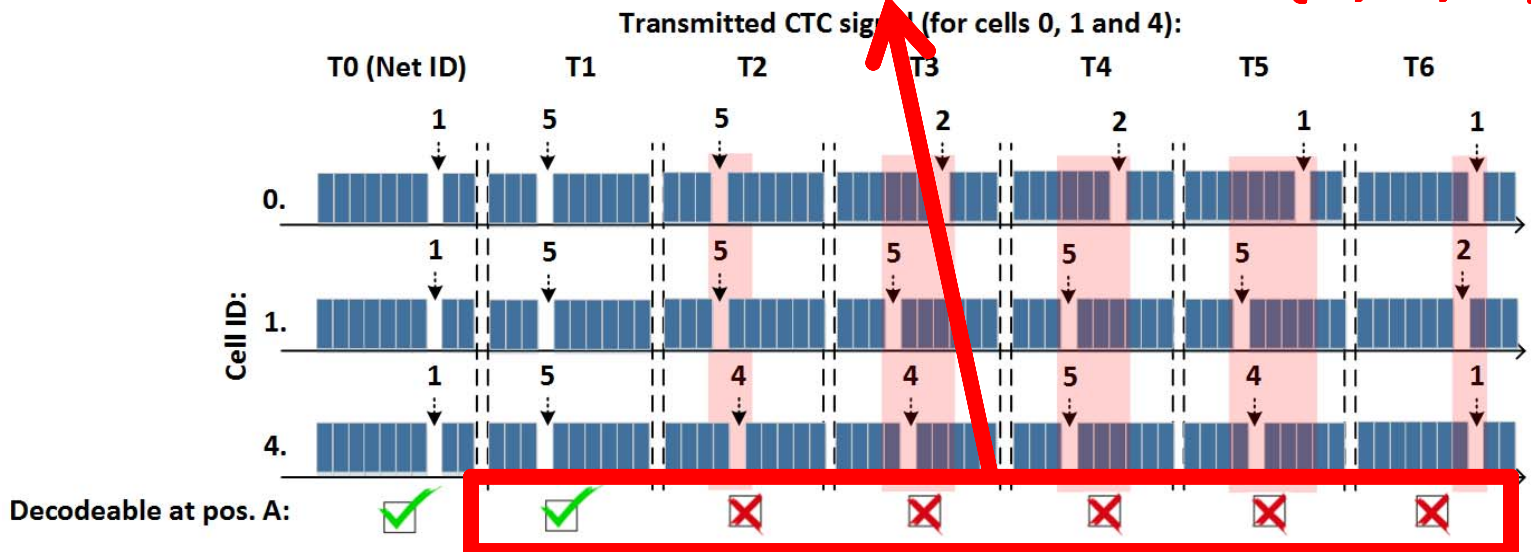
- Members of a given cluster change in each time slot
- In each time slot, depending on its position, a WiFi node may decode different cluster ID



Cluster Membership Table

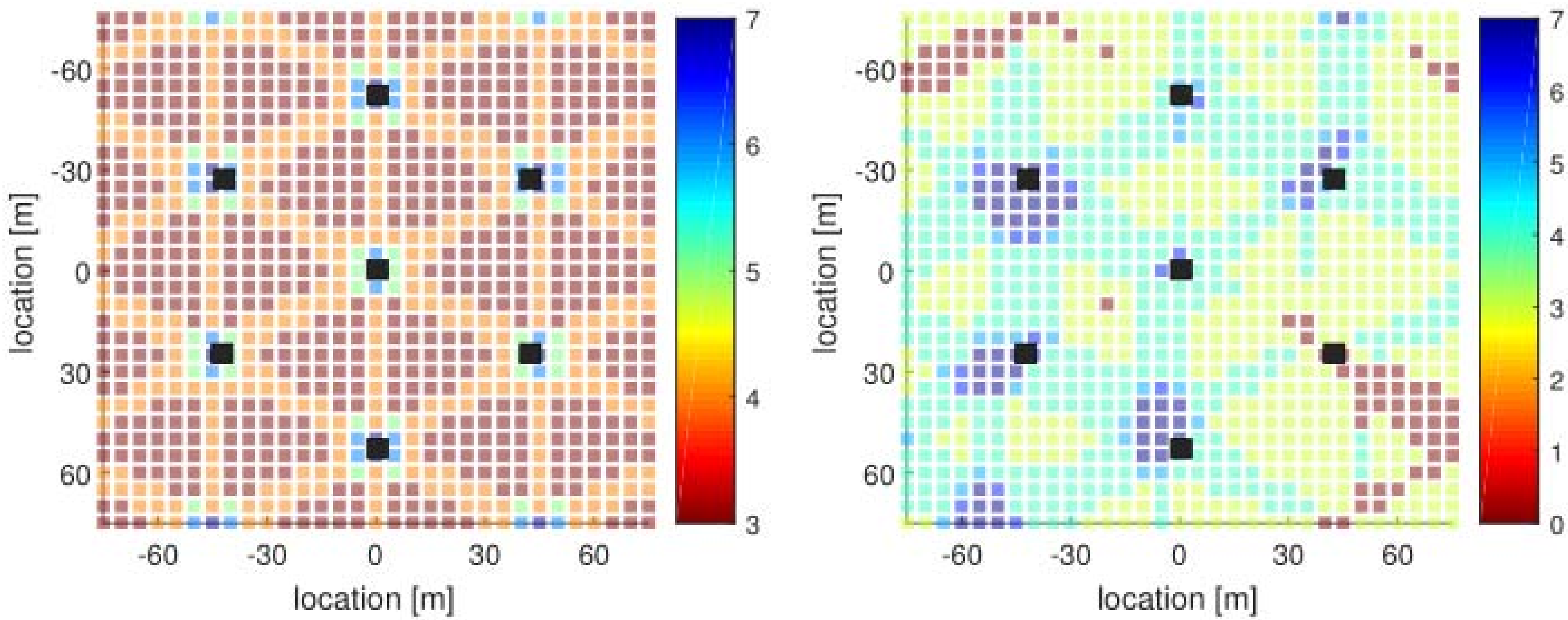
Cell	slot 0	1	2	3	4	5	6
0	0	5	5	2	2	1	1
1	0	5	5	5	5	5	2
2	0	7	7	5	5	4	4
3	0	4	4	1	1	1	1
4	0	5	4	4	5	4	1
5	0	6	6	4	4	4	4
6	0	4	4	4	4	3	0

- {BS_IDs} = **Function(**<time_slot, cluster_ID>**)** **= {0, 1, 4}**



Evaluation

- System level simulation – 100 BSs in hexagonal grid
- Two scenarios: with and without shadowing
- **Observation**: The number of identified LTE-U BSs at each spatial location



(a) Without shadowing (b) With Shadowing

Conclusions

- **LtFi –** the first system enabling CTC between LTE-U and WiFi

- It is a holistic solution allowing for:
  - Cross-technology neighbor discovery and identification
  - Establishment of wired control channel between co-located and interfering LTE-U and WiFi networks

- Enables various cross-technology interference/RRM schemes

- LtFi is fully compliant with LTE-U technology and works with WiFi COTS hardware – proven by our prototype

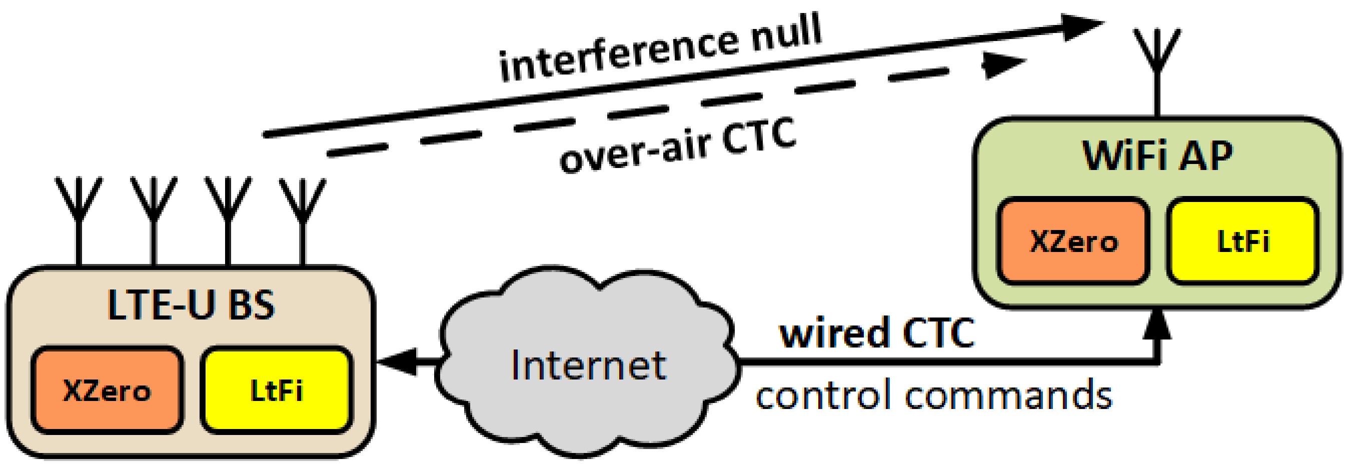
Thank you!

Contact:

gawlowicz@tu-berlin.de

Possible LtFi Application

- Cross-technology interference nulling – **Xzero [1]**:
  - Exploiting MIMO capabilities of modern LTE-U BSs for **steering null** towards WiFi nodes,
  - Favorable as competition for shared time/frequency resources is reduced - **win-win** solution for both LTE & WiFi



[1] Zubow *et al.*, „XZero: On Practical Cross-Technology Interference-Nulling for LTE-U/WiFi Coexistence", arXiv, 2018.