WiSHFUL

Wireless Software and Hardware platforms for Flexible and Unified radio and network controL

Year 3 Demonstration of Showcases

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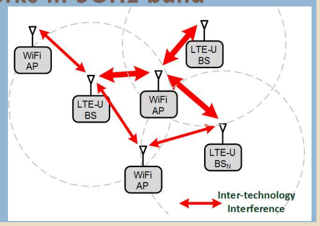
LTFI – COLLABORATION BETWEEN LTE-U AND WIFI

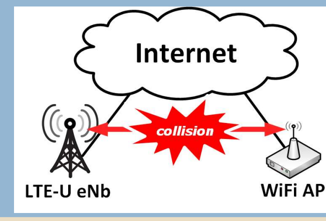
GOALS

- Enable collaboration between co-located LTE-Unlicensed and WiFi networks in 5GHz band
- Improve their performance using cross-technology interference & radio resource management schemes



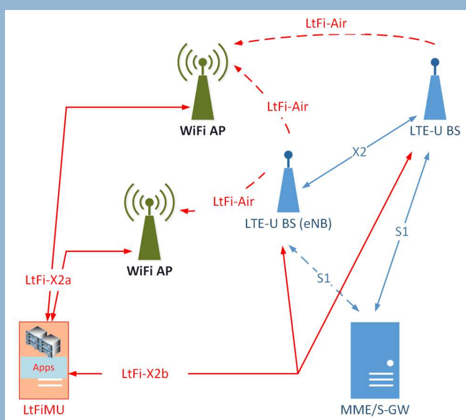
CHALLENGES

- LTE & WiFi have incompatible PHY layers – they cannot communicate nor discover over the air
- How to identify interfering networks and establish collaboration channel between them?



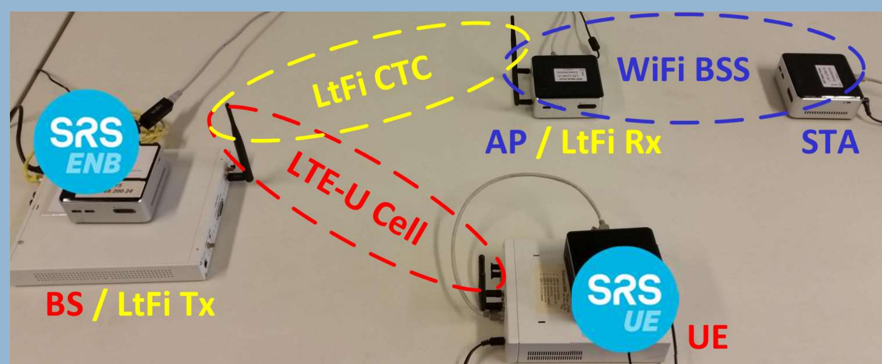
DEMO SETUP

Architecture of LtFi and its integration into an LTE network



Demonstrator setup consisting of an LTE-U and a WiFi network:

- Hardware: SDR-USRP (LTE) and COTS devices (WiFi)
- Software: WiSHFUL Control Framework, srsLTE, ath9k driver



DEMO SCENARIOS

I. Baseline

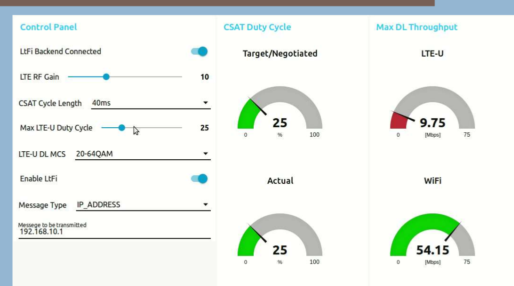
- Demonstration of uncoordinated coexistence of LTE-U and WiFi.
- Both networks are interfering with each other
- Multiple parameters can be configured at runtime

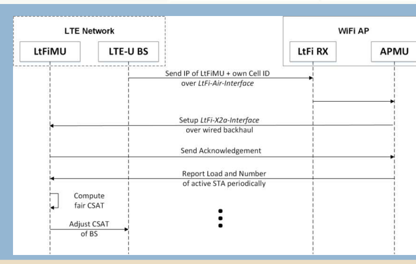
II. Cross-technology neighbor discovery using CTC channel

- Sending data (e.g. IP address) over CTC channel from LTE-U BS to WiFi AP

III. Cross-technology Collaboration

- A collaboration scheme between the LTE-U cell and WiFi BSS that allows them to negotiate the fair share of radio resources, i.e. per-client air-time fairness





CONCLUSIONS

- Performance of co-located LTE-U and WiFi networks can be improved via collaboration
- We managed to setup cross-technology communication channel between LTE-U and WiFi nodes using COTS devices

INNOVATION & IMPACT

- Cross-technology neighbor discovery mechanism on top of CTC
- Enabling cooperation between co-located heterogeneous wireless networks

TOWARDS EFFICIENT COEXISTENCE OF IEEE 802.15.4E TSCH AND IEEE 802.11

GOALS

- Intended sharing of 2.4GHz ISM spectrum
- Mutual cross-technology interference
- IEEE 802.11 Wi-Fi
    - High throughput
    - Best effort
- IEEE 802.15.4e TSCH Time-Slotted Channel Hopping
    - Low throughput, high energy efficiency
    - High reliability

CHALLENGES

- Wi-Fi CCA overlooks low-power TSCH nodes
- Wi-Fi can over-power TSCH nodes

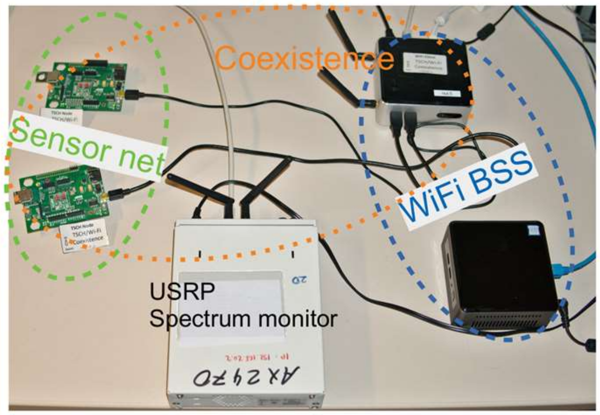
SOLUTION IDEA

- TSCH will occupy a small share of time
- Wi-Fi can avoid transmitting in the „collision periods"

DEMO SETUP

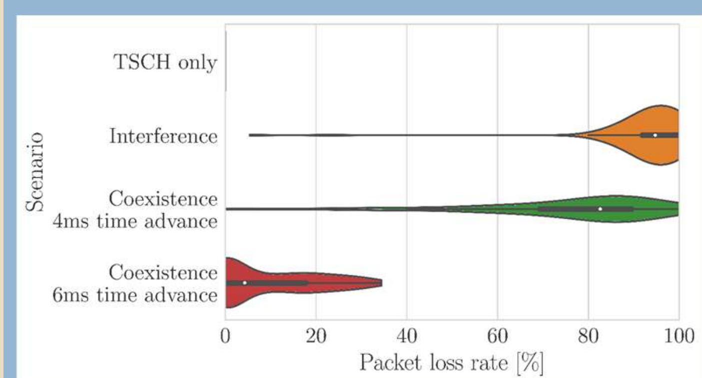
- From known schedule
- Generate TSCH spectral model
- Correlate with Wi-Fi Spectrum sensing
- Acquire TSCH timing at Wi-Fi network
- Enforce silence periods in Wi-Fi

- Scenarios
    - Baseline
        - Sole operation of each technology
    - Uncontrolled interference
        - Both networks are interfering with each other
    - Coexistence of both technologies
        - Wi-Fi is recovering TSCH timing and avoids transmission in overlapping periods

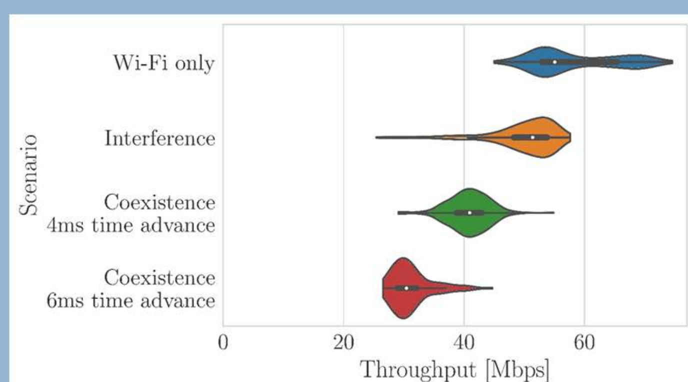


RESULTS

TSCH Packet loss rate



Wi-Fi throughput



CONCLUSIONS

- Cross-technology synchronization algorithm
- Keep the channel free for the time of TSCH transmissions
- No overhead on the TSCH network
- Possible to use COTS devices

INNOVATION & IMPACT

- Interference is a key problem in current wireless networks
- Particularly for incompatible technologies
- Cooperation between networks

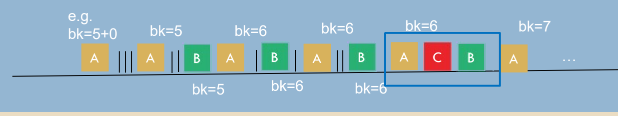
DETERMINISTIC BACKOFF

GOALS

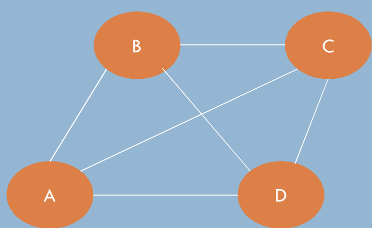
- Validating in real experiments an innovative backoff mechanisms proposed for standardization by Qualcomm.
  - Is it possible to reducing the delay jitters of stations in contention-based protocols?
- Making the protocol robust
  - Adjusting backoff for keeping fixed 'time-distances' from previous transmitting station.

CHALLENGES

- How to reduce access jitters?
  - Random access mechanisms are very effective for sharing a wireless channel, but suffer of performance fluctuations because of exponential backoff.
- Basic idea:
  - After a random contention phase and successful transmission, keep a fixed backoff equal to a flat number of slots + the number of backoff freezes



DEMO SETUP

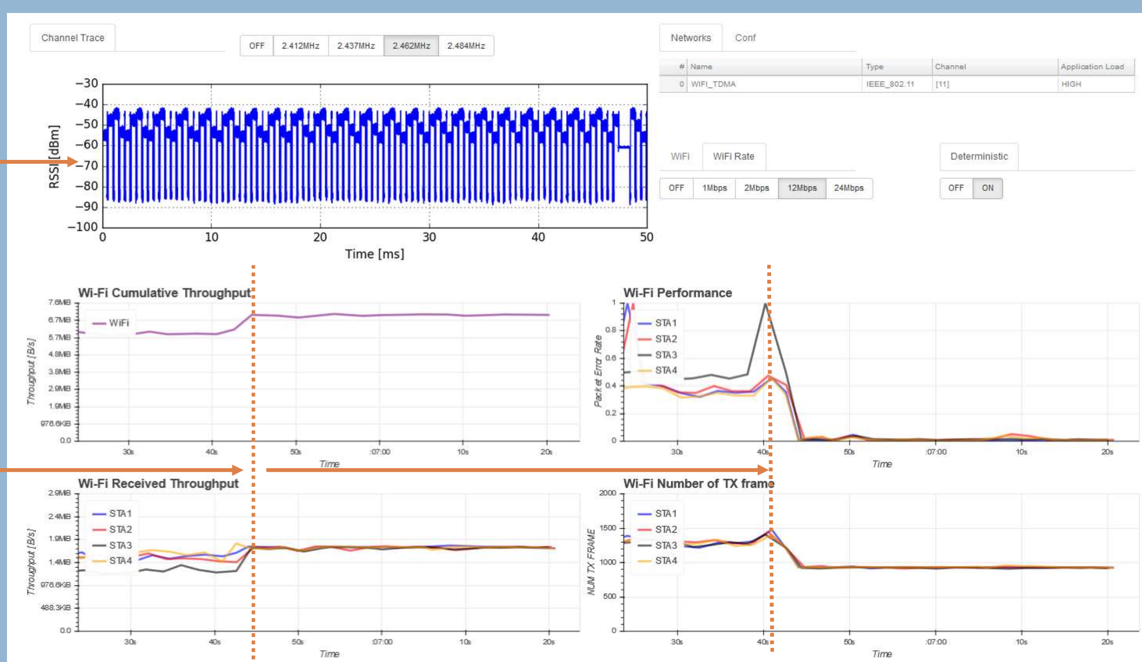


- Scenario: 4 stations with greedy traffic sources are simultaneously active
- Phase 1 : comparison between legacy DCF and deterministic backoff in terms of throughput stability and fairness
- Phase 2 : Some stations are activated/de-activated dynamically Channel access schedules automatically adjusted

RESULTS

Precise schedule for all nodes

Deterministic algorithm forcing



- Legacy DCF is improved in terms of fairness and throughput stability
- Alternative backoff mechanisms can be executed even on commerical cards

CONCLUSIONS

- Innovative MAC protocols can be easily prototyped thanks to WISHFUL
  - Exploiting WP3 functionalities for composing a new radio protocol.
  - Exploiting WP4 functionalities for activating the innovative protocol on all the network nodes.

INNOVATION & IMPACT

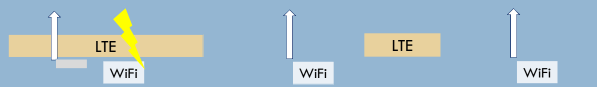
- Bringing experimental validation in the design-phase of low-level MAC protocols!
- Demonstrate that simulation-based design can completely neglect some problems/phenomena.

A WIN-WIN COEXISTENCE MECHANISM FOR WIFI/LTE

GOALS

Define and validate a best response strategy for interfering WiFi and LTE stations leading to a win-win coexistence solution

- From LTE unilateral adaptations to reciprocal impairments or cooperation



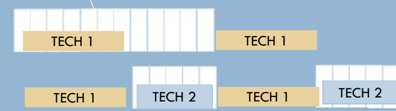
1) LTE can esploit WiFi white spaces as long as WiFi networks keeps unsaturated
2) WiFi can aggregate white spaces by means of Contention-Free periodic periods

CHALLENGES

How can WiFi and LTE stations independently decide about:

- LTE duty-cycle?
- WiFi contention-free length?

How can the two technologies act in a synchronized manner?

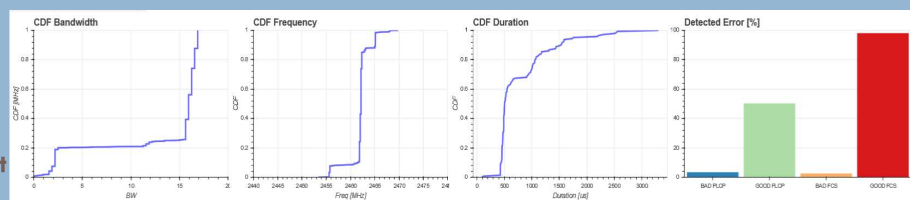


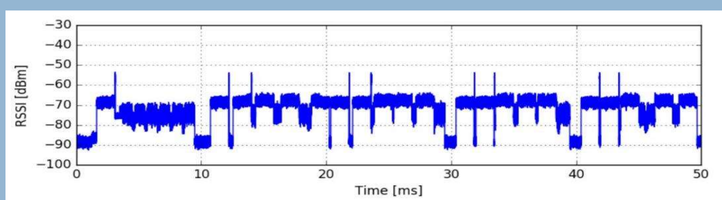
DEMO SETUP

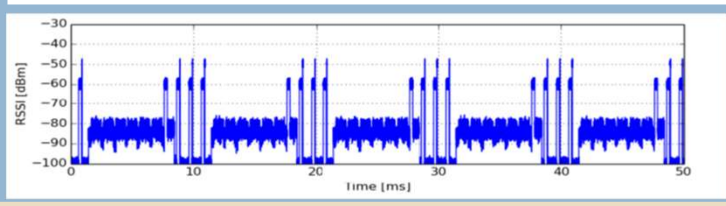
Storyline 1 (Phase1) :

Identifying interference on WiFi network, by aggregating different solutions

using commercial cards by different vendors in a non-intrusive way



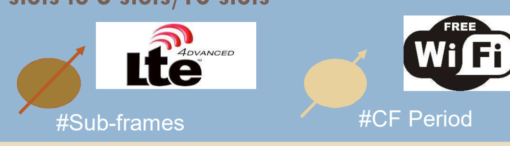




Storyline2 (Phase2) :

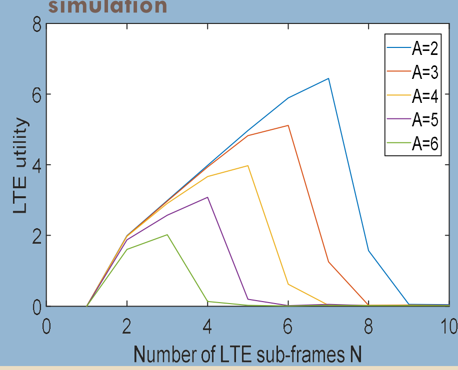
Monitor throughput and PER performance with/without cooperation between the two technologies

Visualize scheme adaptability as the WiFi offered load in gradually increased from 2 slots /10 slots to 6 slots/10 slots

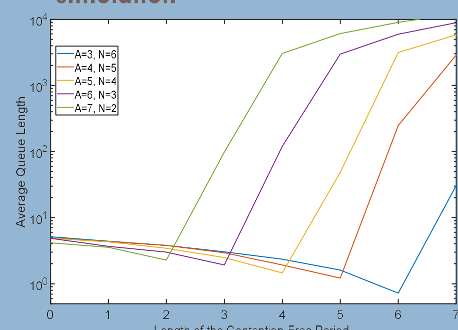


RESULTS

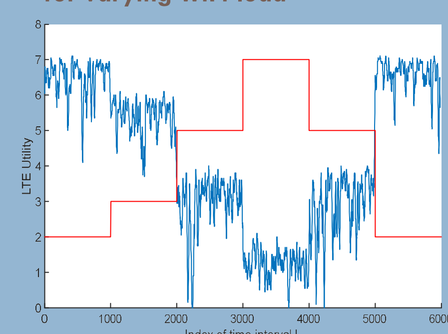
LTE Best-Response found in simulation



WiFi Best-Response found in simulation



LTE utility in case of cooperation for varying WiFi load



UPI USAGE

UPI_HC	UPI_R
Start local control programs on both LTE and WiFi nodes implementing best-response strategies **start_local_control_program();**	To activate a custom radio program **activate_radio_program**('radio_program_name')
	To set protocol parameters: **set_parameters**(interface, UPI_R.CSMA_CF_PERIOD) **set_parameters**(interface, UPI_R.LTE_SUBFRAMES)
	To get nodes and medium statistics: **get_measurements_periodic**(params) **Packet queue, Transmitted, Transmitted Success, Transmit Other, Bad Reception, Busy slot**

POST MORTEM

What we demonstrate to other experimenters?

- How to build network intelligence and complex inter-technology coexistence mechanisms
- How to use UPI for gathering low-level channel traces and configure protocol parameters
  - Sub-frames@LTE, CF periods@WiFi
- How to opportunistically combine simulation and experimental validation for protocol design.

OVER THE AIR UPDATING OF MAC PROTOCOLS

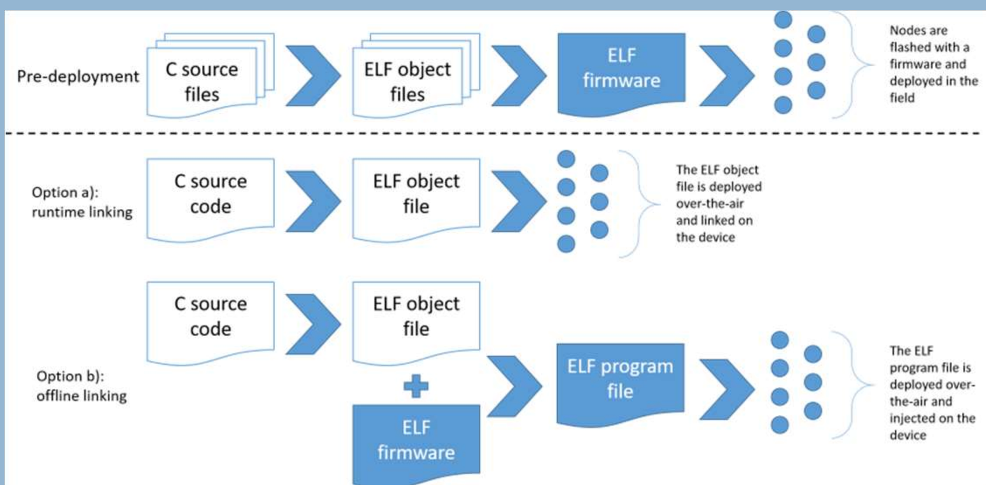
GOALS

- **Enable partial protocol (MAC) updates on constrained devices in order to avoid full firmware updates.**
- **Provide a robust and efficient algorithm to transfer, install and activate software modules.**
- **Minimize the number of message exchanges.**

CHALLENGES

- **Constrained devices do not have any operating system support for linking or loading.**
- **Software running on constrained devices was not designed for partial updates at run-time.**
- **The nodes are battery powered and sometimes have restricted access to the medium (i.e. sub-GhZ spectrum).**

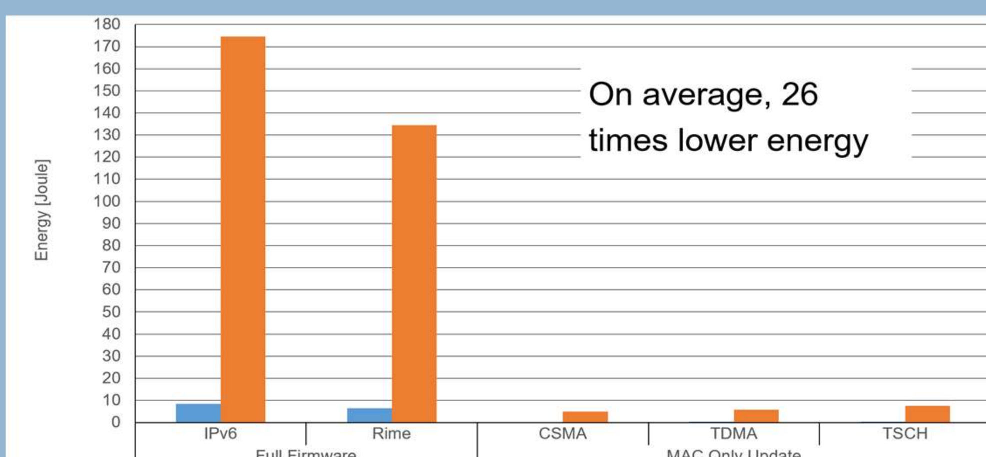
DEMO SETUP



- **Demo steps:**

1. **Allocate memory on each device.**
2. **Link the new ELF object files offline using the allocated memory and the ELF firmware installed on each device.**
3. **Transfer the resulting ELF program to each node. This step uses block acknowledgements.**
4. **Install and activate the ELF program file.**

RESULTS



	IPv6	Rime	CSMA	TDMA	TSCH
LoRa SF7	8.377411461	6.449915658	0.23936127	0.27804119	0.355600097
LoRa SF12	174.552314	134.405507	5.029417452	5.833064448	7.453098639

- **Energy required to update a MAC protocol in a LoRa network for two different modulation settings:**

1. **SF7 (long range, blue)**
2. **SF12 (ultra long range, orange)**

A full firmware update requires much more energy compared to a single MAC update.

CONCLUSIONS

- **Update size and medium access is minimized:**
  - **Partial updates instead of full firmware update.**
  - **Offline linking instead of linking on the node.**
  - **Broadcast multi-message transaction algorithm with bitmap-based block acknowledgements.**

INNOVATION & IMPACT

- **Energy and spectrum efficient partial software updates.**
- **Minimal network down-time and bootstrapping because a device reboot is not required.**
- **Presented solution is extremely suitable for enabling software updates in duty-cycle restriced low power wide area sub GhZ networks.**

RADIO AND FINE-GRAINED BBU VIRTUALIZATION: PUSHING THE BOUNDARIES OF FUTURE MOBILE NETWORKS

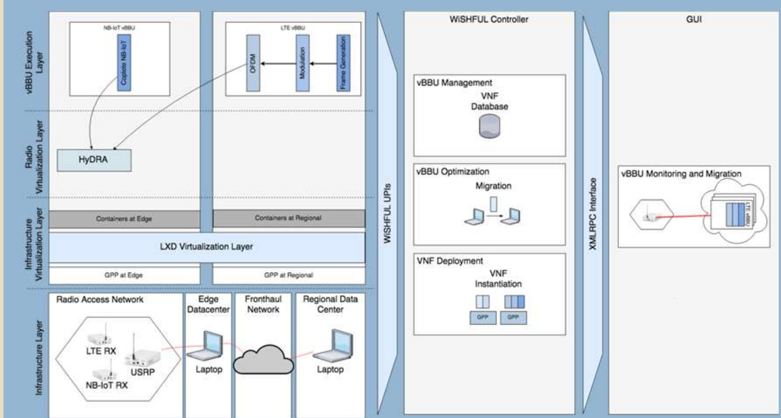
GOAL

To enhance the centralized baseband architecture with scalability, multi-RAT capabilities, and programmability

DEMO CHALLENGES

- Current centralized baseband architecture present the following limitations:
  - One-size-fits-all air interface
  - Huge fronthaul network requirements
  - BBUs are inflexible and not scalable

DEMO SETUP



- Regional and edge data center for distributed fine-grained execution
- LAN to connect edge and regional data centers
- LXD to virtualize the physical infrastructure resources
- HyDRA+LXD to abstract the radio resources
- LTE vBBU splitted in three containers
- NB-IoT atomic vBBU
- GUI to monitor and manage all virtual resources

RESULTS

	CPU %		Fronthaul	Memory	
	Regional	Edge		Regional	Edge
All at Regional	3 %	14%	47 Mbps	3.5 GB	1.3 GB
LTE at Edge, NB-IoT at Regional	18%	30%	12 Mbps	2 GB	2.4 GB
All at Edge	2.9%	38%	0 Mbps	1.7 GB	3 GB

- **All at Regional:** : All four VNFs are executed in the regional data center. The CPU and memory usage is the highest at the regional and the lowest in the edge data center.IQ samples of both vBBUs are transferred over the fronthaul, resulting in the highest fronthaul usage.
- **LTE@Edge, NB-IoT@Regional:** Edge data center with the highest CPU and memory usage because of all LTE VNFs. Fronthaul usage is reduced as only raw IQ samples from the NB-IoT vBBU are transported over the network.
- **All@Edge:** Edge data center presents the highest CPU and memory usage. The fronthaul is not used, as it is not used to transport any information.

CONCLUSIONS

- We demonstrate fine-grained BBU virtualization as a solution to enhance centralized baseband architectures with scalability, multi-RAT capabilities, and programmability
- To this end, we designed an architecture and implemented a prototype

INNOVATION & IMPACT

- Enhancing future centralized baseband architectures with scalability, multi-RAT capabilities, and programmability
- Use of WiSHFUL UPIs to enable fine-grained vBBU management and configuration
- Design and implementation of a prototype
- Aligned with current research topics in 5G

MAC SELECTION BASED ON MAC PERFORMANCE PREDICTION

GOALS

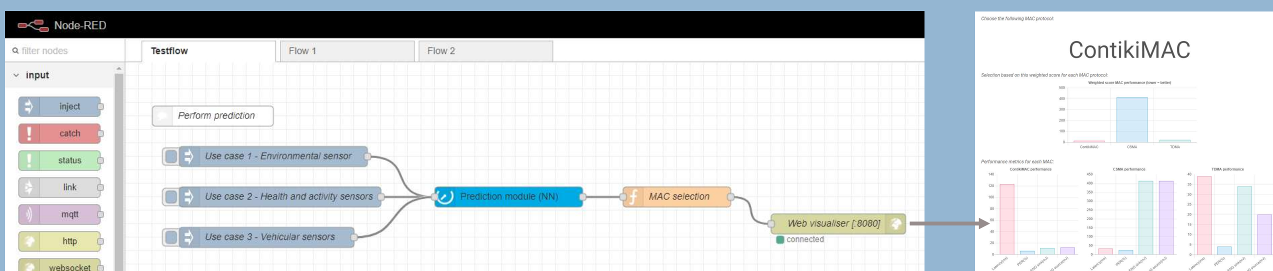
- Detect MAC performance for a given environment
- Select optimal MAC protocol based on the performance
- Support multiple use-cases for MAC selection
    - Environmental sensors
    - Health and activity sensors
    - Vehicular sensors
    - …

CHALLENGES

- Characterize environments
- Train prediction models for MAC performance
- Allow flexible decision making depending on performance needs

DEMO SETUP

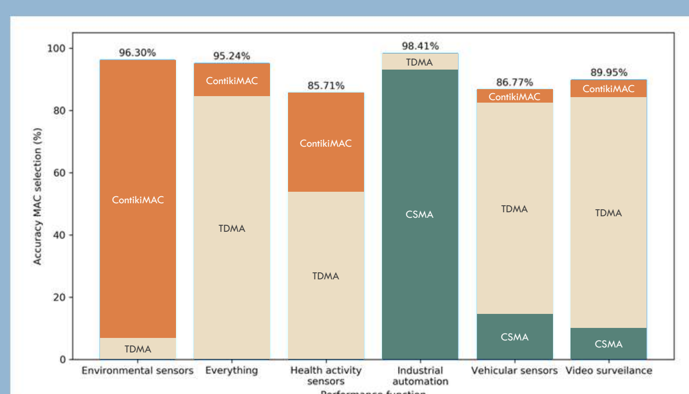
- In Node-RED, the prediction module is implemented
- Various use-cases demonstrate MAC performance in different environments
- MAC selection is demonstrated using different levels of importance for each performance metric
- A web application is designed to visualize MAC selection and performance results



RESULTS

- The trained model is able to accurately predict performance metrics
- MAC selection is feasible using prediction performance metrics with an average accuracy of 93%

$$Accuracy = \frac{\#\ selected\ MACs\ using\ predicted\ data}{\#\ selected\ MACs\ using\ groundtruth\ data}$$



CONCLUSIONS

- Neural networks play an important role in accurate performance prediction.
- Predicting performance enables flexible decision making for MAC selection

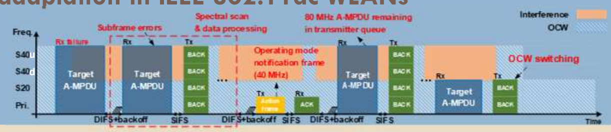
INNOVATION & IMPACT

- Black-box model can be used to predict MAC performance given environmental parameters, without requiring machine learning expertise
- The proposed prediction model architecture can be re-used in real life scenarios.

IEEE 802.11AC BANDWIDTH CONTROL USING WISHFUL

GOALS

- IEEE 802.11ac wide bandwidth operation
  - ✓ Very high throughput achievement
  - ✓ Vulnerable to interference
- RECONN: receiver-driven operating channel width adaptation in IEEE 802.11ac WLANs

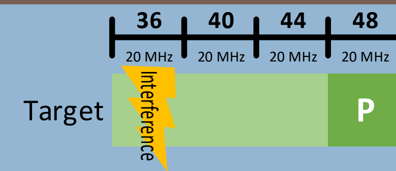


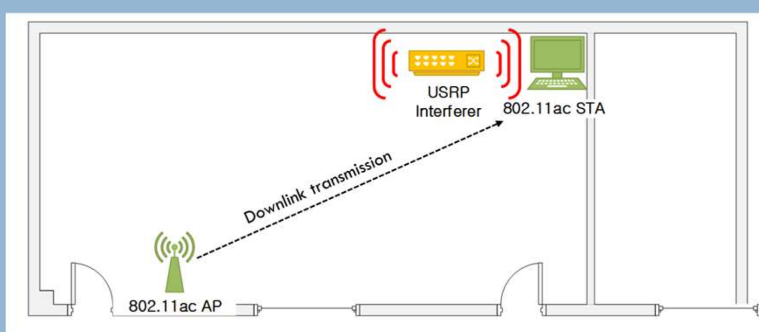
CHALLENGES

- To implement RECONN on WiSHFUL Framework
  - ✓ init_spec(phy_dev): spectral scan initialization
  - ✓ reconn(phy_dev, wlan_dev, run_time, wait_counter): RECONN operation, including spectral scan triggering and operating channel width changing
  - ✓ Ath10k_module

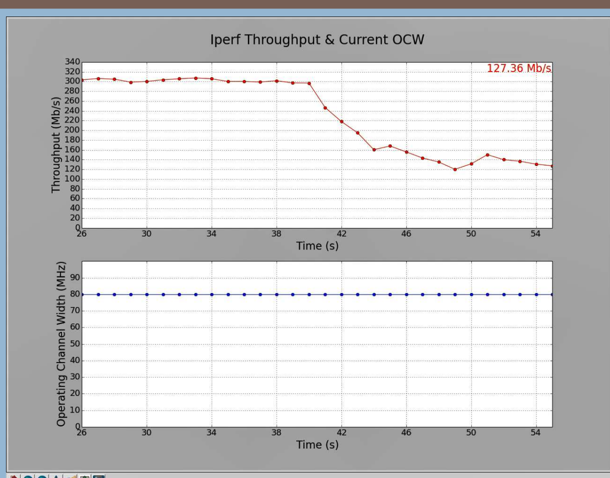
DEMO SETUP

- Demo environment
  - ✓ Transmitter: ath10k-based QCA9880 NIC (AP)
  - ✓ Receiver: ath10k-based QCA9880 NIC (STA)
  - ✓ Interferer: NI USRP

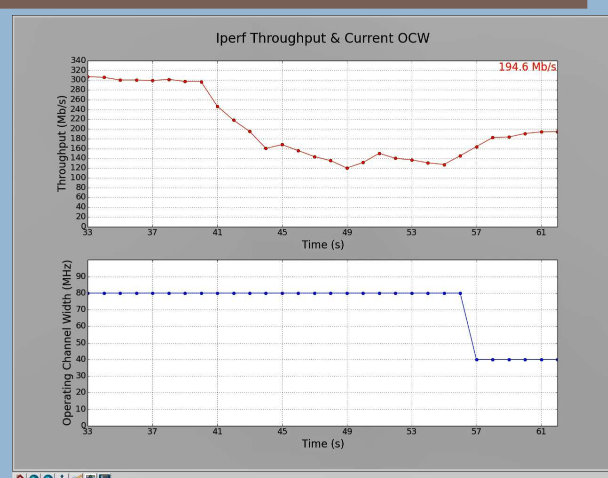




RESULTS



Interference on, RECONN off
Throughput: 127.36 Mb/s



Interference on, RECONN on
Throughput: 194.6 Mb/s (52.8% gain)

CONCLUSIONS

- RECONN implementation on WiSHFUL Framework
- Newly define ath10k module on WiSHFUL Framework
  - ✓ Applying to 802.11ac related implementation

INNOVATION & IMPACT

- Run-time WiFi performance enhancement in wide bandwidth operation
- Successful implementation of RECONN on WiSHFUL framework
  - ✓ Modification of device/control module in local controller
  - ✓ Verification of easy prototype

PROJECT DATA

Start Date: 01/01/2015; Duration: 40 M

EU Funding: 5.171 M€

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