Efficient Peer-to-Peer Unicasting for VANET Architectures via Enhanced Monolithic Protocols

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Outline

- Motivation
- Background
- Design & Implementation
- Evaluation
- Conclusion

Motivation

Motivation[1/2] – Introduction

- New communication typologies and next-generation protocols, have enabled new applications to arise - new requirements and standards have emerged.
- Efficient ad hoc networking protocols, in conjunction with novel technologies have enabled a vast spectrum of applications, including cooperative vehicular ad hoc networks.
- We discuss a specific monolithic communication protocol, ESP-NOW, as a means of achieving real-time and next to zero-overhead communications.
- We correlate attributes of the 802.11LR mode with **quality of service** and power draw, and compare it with the nominal 802.11 mode.
- We aim to formulate new methodologies and best practices for real-time vehicular ad hoc communications, considering computational constrains networking requirements.

Motivation[2/2] – Aim of this work

Investigation of the interconnection between bandwidth consumption, end-to-end delay and the power consumption of networked units.

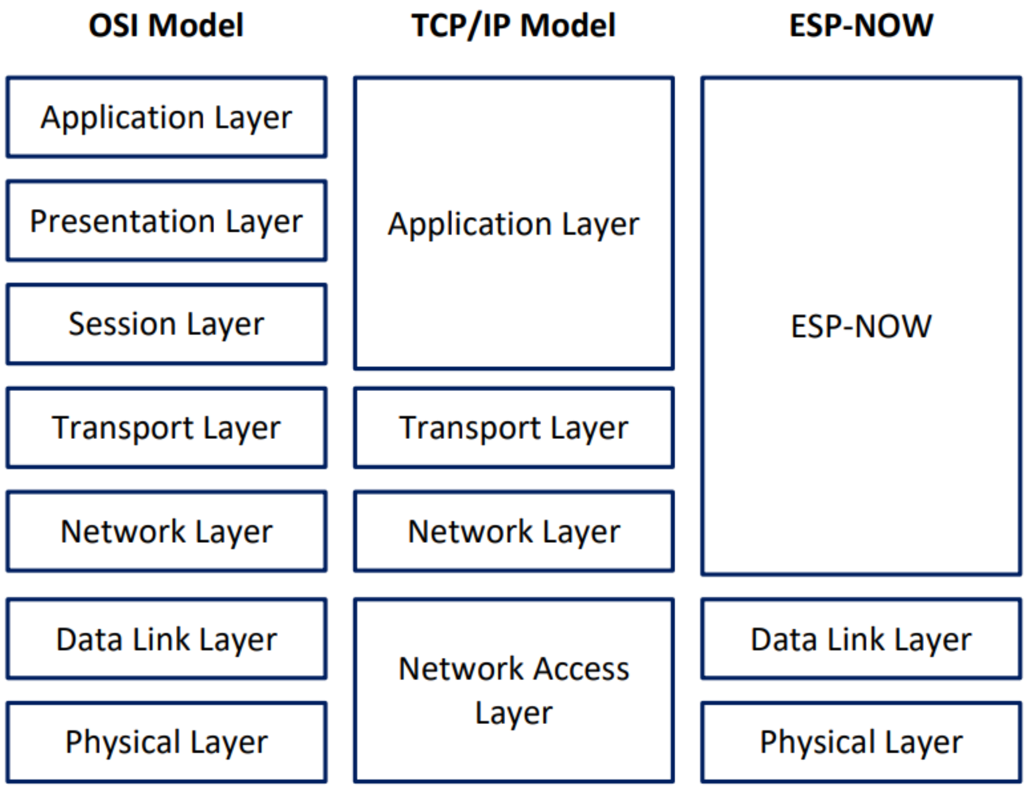
Consideration of ad hoc vehicular deployments and high-velocity, real-time links.

- We explore the proprietary ESP-NOW IoT protocol and its attributes
- We explore different 802.11 modes and their impact in communication quality
- We perform a comparative analysis of the two WiFi modes classes with the same monolithic protocol under two communication scenarios, with increasing distance.

Background

Background[1/3] – ESP-NOW Protocol Attributes

- ESP-NOW is a **connectionless**, **monolithic** communication protocol, occupying the upper three layers of TCP/IP stack, and the upper five layers of the OSI model.
- ESP-NOW does not use acknowledgements (**ACK-less protocol**) and does not perform handshake during the connection establishment. It doesn't supports re-transmission in case of error or packet loss.
- This protocol is (like UDP) unreliable yet **incredibly fast** and **with minimal control overhead**.
- ESP-NOW adopts a **"flat" hierarchy** which allows for easy full duplex communications.
- There is no master-slave relationship between the communicating entities, instead there is a **two-way peer-to-peer relationship**.



Background[2/3] – ESP-NOW Services and Limitations

Services:

1. Encrypted and unencrypted unicast communication
2. Full duplex communication
3. Selective encryption
4. Up to 250 bytes of load per datagram
5. Update the application layer on the sending status (success / failure) via a callback function
6. Connectionless, unreliable peer-to-peer communication

Limitations:

1. No broadcast support
2. Supports max 10 encrypted peers and max 20 unencrypted peers.
3. The payload datagram can not exceed 250 bytes.
4. ESP WiFi connectivity cannot be used at the same time as the 2.4GHz antenna is used for sending / receiving ESP-NOW messages.

Background[3/3] – Initialization and Peer Addition

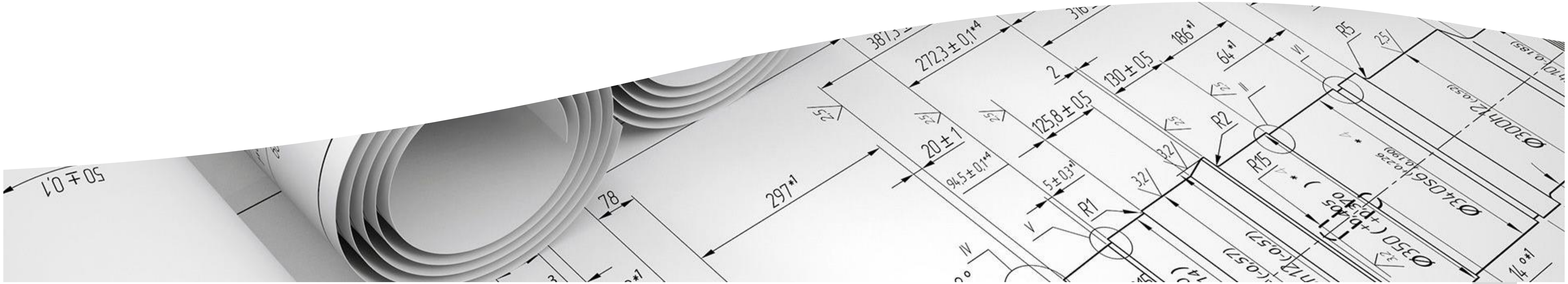
1. For every peer, activate the WiFi antenna and call the `esp_now_init ()` function.

2. Obtain MAC addresses of communicating entities and add them to each peer's address list: `broadcastAddress[] = {0x24 … 0x68}`.

3. Add communicating entitie's MAC address to a "peer array".

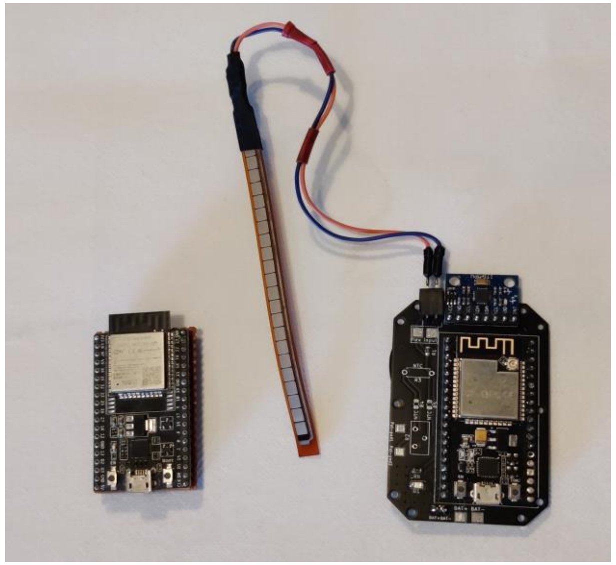
4. Repeat the above process for every participating entity.

Design & Implementation

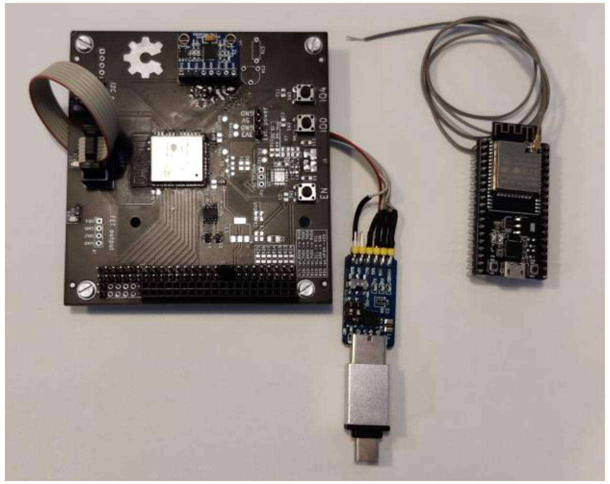


Implementation[1/2] – Testbed Design

- Emulation of the transmission of telemetry and sensor measurements in intra-vehicle links.
- 2xHardware modules developed: one emulating road side units and one inter-vehicle sensory equipment.
- Payload data: Real-time analogue data, as well as angular acceleration and rotation from an accelerometer.
- Common message structure throughout the duration of all tests.
- Emulation of two different vehicular ad hoc communication scenarios.
- Wide spectrum of datatypes utilized.



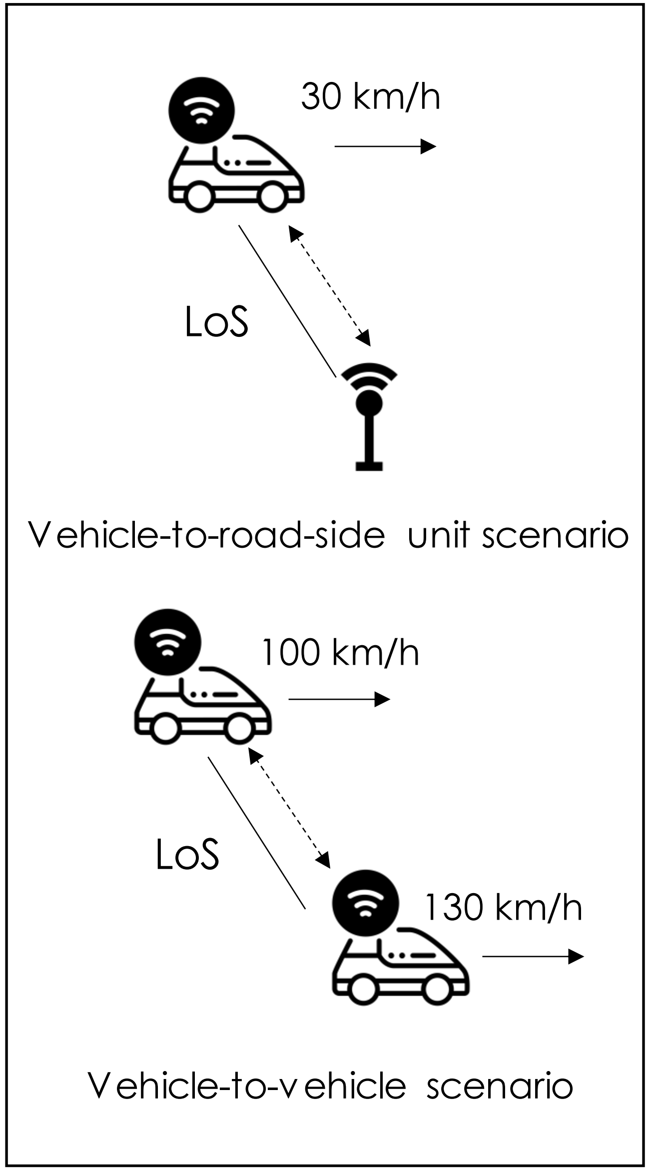
Nominal WiFi modulation testbed



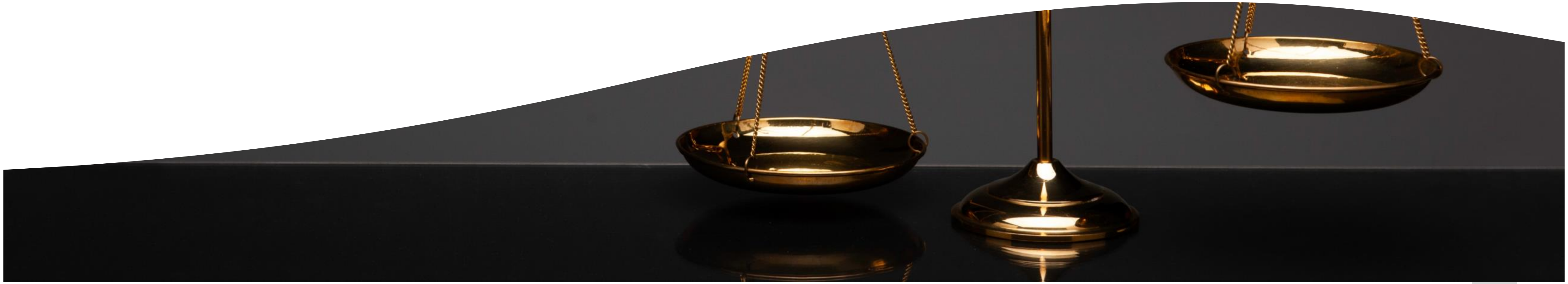
LR WiFi modulation testbed

Implementation[2/2] – Experimental Parameters

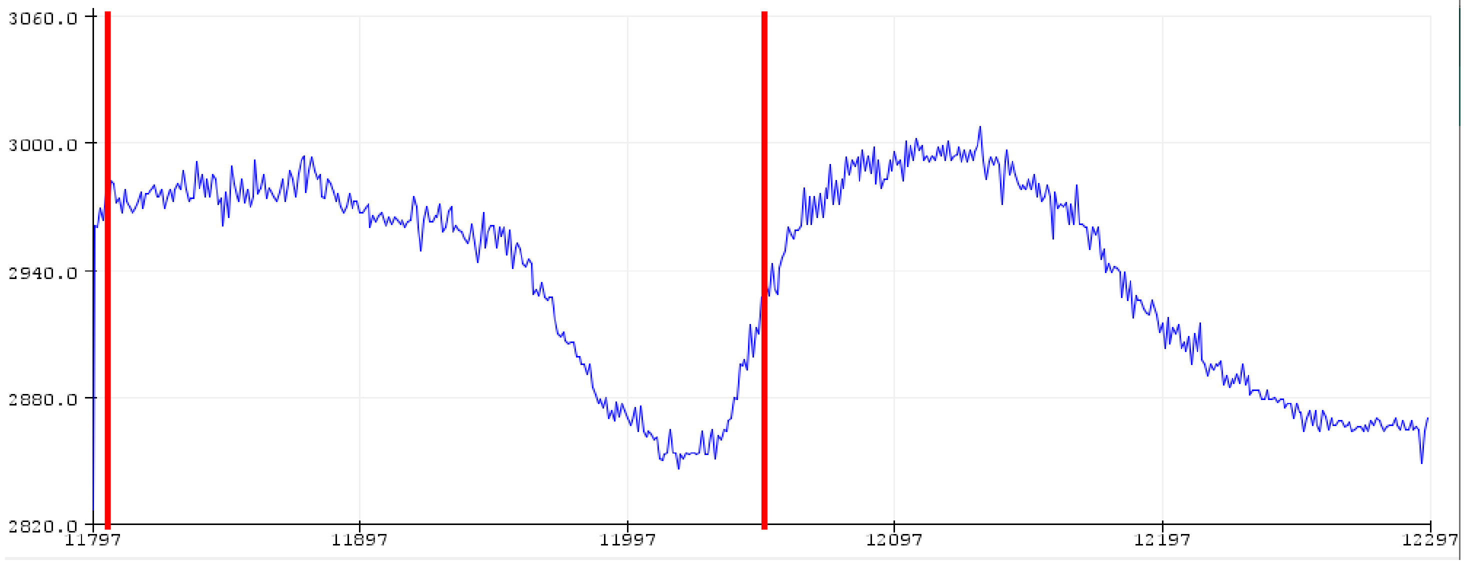
Experimental Parameters	Test #1	Test #2
Relative Node Velocity	8m/s	8m/s
Communication Protocol	ESP-NOW	ESP-NOW
WiFi Standard	802.11b	802.11LR
Frequency	2.4GHz	2.4GHz
Max Datarate	2 Mbps	0.25 Mbps
Max. Tx. Power at 100 meters	2.5 W	2 W
Max. Rx Power at 100 meters	0.28 W	0.2 W



Evaluation

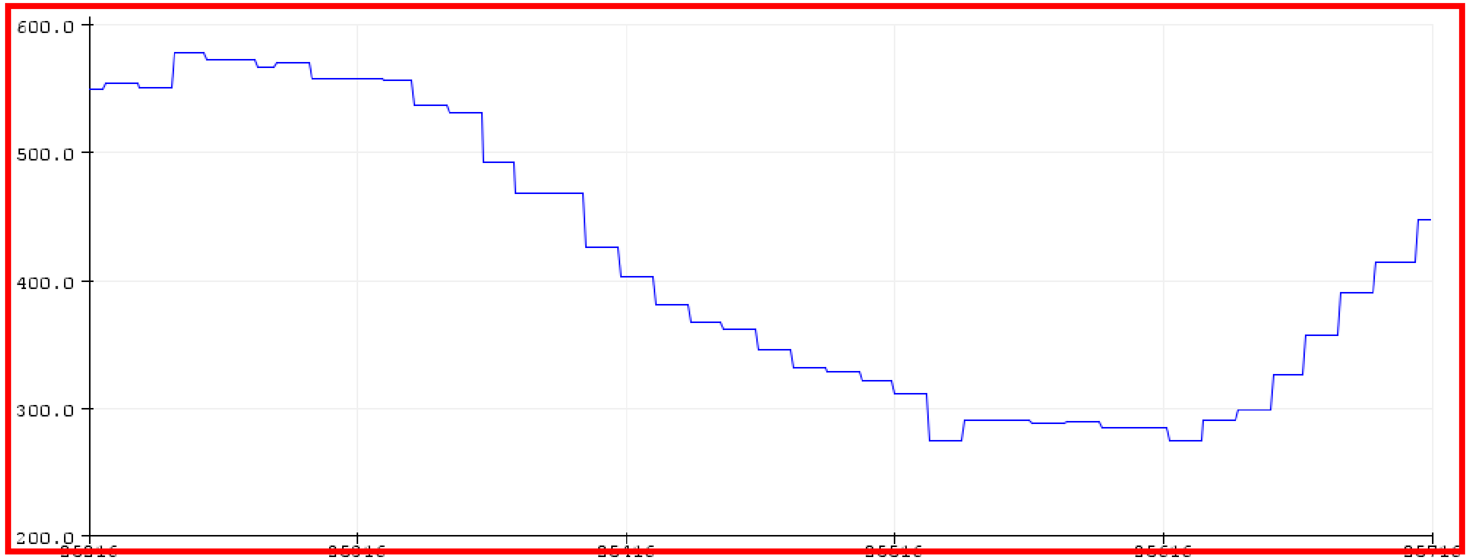


Evaluation[1/3] – Experimental Results

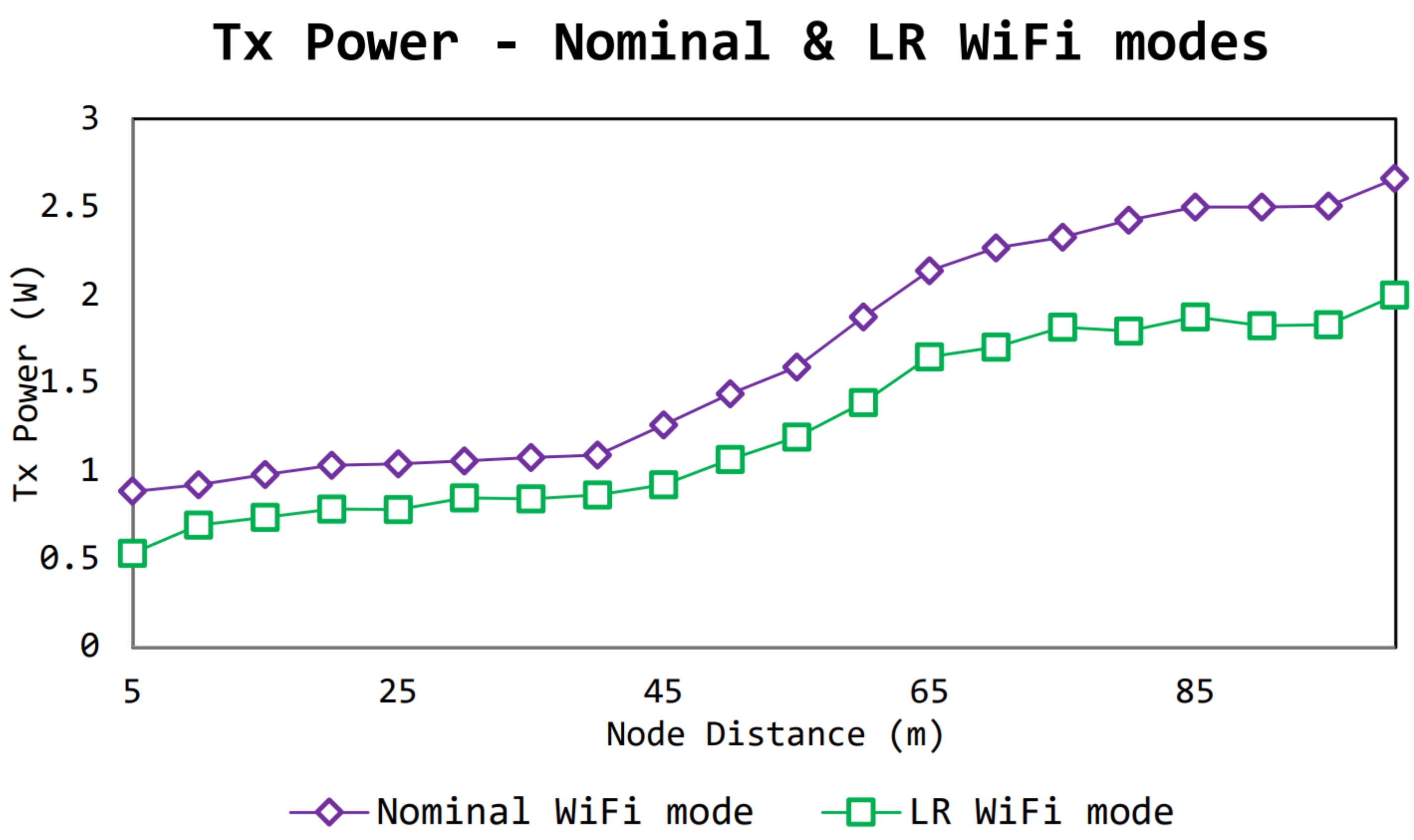


Transmitted test data (analogue values from internal ADC, w/ resolution of 2^{12} steps) using ESP-NOW over 802.11LR.

Received test data using ESP-NOW over 802.11LR.



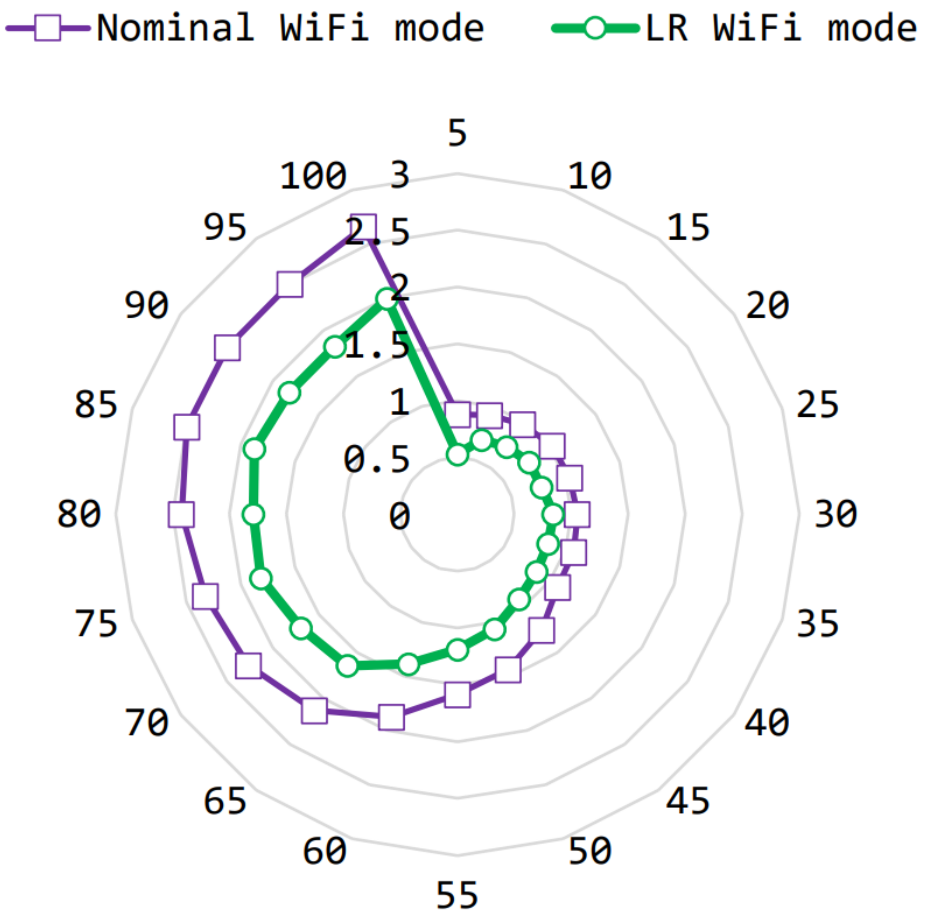
Evaluation[2/3] – Power Consumption 1/2



- Energy consumption follows an almost linear incremental increase with distance.
- Usage of the WiFi LR mode managed to achieve a **25% reduction in energy expenditure.**
- This was achieved by trading off data-rate.
- Interestingly, at the 50 meter mark, we can observe an abrupt increase in both cases.

Evaluation[3/3] – Power Consumption 2/2

WiFi modes - Tx power radar graph

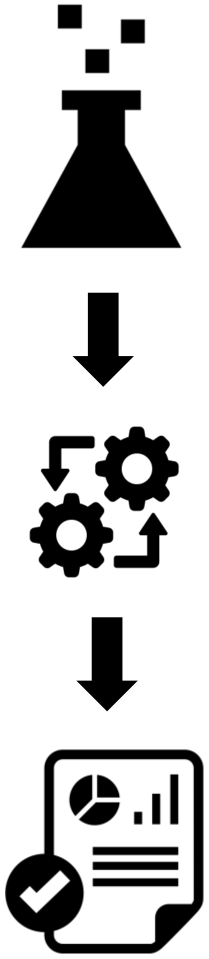


- The experiment conducted validated that dropping the channel bit-rate has tangible effects on energy expenditure, and thus battery lifetime, where applicable.
- It has to be noted however, that while the bit-rate was halved, energy consumption only dropped by 25% (having averaged out all the obtained data from both experiments).
- Power draw decrease peaked at a 28%.

Conclusion

Conclusions

- It is worth mentioning that 802.11 LR alters data rate and uses a different modulation, which is not compatible with any other standard WiFi device.
- 802.11 LR limits the typology of inter-connected devices, and thus achievable network heterogeneity.
- The unique combination of modulation, data-rate and the monolithic nature of the applied ESP-NOW protocol managed to decrease power draw by 25% compared to the nominal 802.11b mode with ESP-NOW.
- It is interesting to note that Espressif's 802.11 LR mode does not apply any Tx power increase. On the contrary, this mode appears to reduce the energy required to transmit the same data over the same distance, effectively maxing out the antenna power draw at a greater distance than in the baseline case.
- This mode-protocol combination would significantly benefit from the use of a backhaul low-proximity connection for the exchange of MAC addresses with local nodes (e.g., vehicles, roadside units, base stations etc.).



Thank you for your attention!

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