RESEARCH ARTICLE · TURKISH JOURNAL OF ELECTRICAL ENGINEERING & COMPUTER SCIENCES · 2019

# Enabling Space Time Division Multiple Access in IETF 6TiSCH Protocol

*Using directional antennas to schedule resources in time, frequency, and space*

**Sedat Görmüş · Sercan Külcü**

Department of Computer Engineering, Faculty of Engineering, Karadeniz Technical University, Trabzon

Turk J Elec Eng & Comp Sci (2019) 27: 4151–4166 · doi:10.3906/elk-1903-127

SUMMARY

# What Problem Does This Study Solve?

## 1 The Problem

6TiSCH networks don't perform as expected when frequency resources are limited and the same band is shared with WiFi, Bluetooth, and other technologies.

## 2 The Approach

A simple, switchable directional antenna system is integrated with the IETF 6TiSCH protocol.

## 3 What's New

Resources are scheduled not only in time and frequency, but also in space (direction) — an algorithm called SF-DA.

## 4 The Finding

In Cooja/Contiki simulations, packet delivery goes up clearly, while delay and energy use drop significantly.

# Why Do We Need Directional Antennas?

## The challenge facing IoT networks

- New applications — smart grids, smart health, smart cities — are quickly increasing the need to connect small devices to the Internet.
- As cell sizes shrink, nodes using the same or nearby frequency channels interfere with each other more often.
- Omnidirectional antennas broadcast in every direction, so they limit how well the wireless space can be reused.
- A solution: low-cost radios with sectorized or directional antennas that enable space division multiple access (SDMA).

**4**
IEEE 802.15.4 channels that don't overlap with WiFi (15, 20, 25, 26)

**2–3**
Directional antennas tested in this study

**25–101**
Different network sizes used in the tests

Source: Soua & Minet (2015); Görmüş & Külcü (2019), Section 1

1.1 · CONCEPT

# Omnidirectional vs. Directional Antennas

## Omnidirectional

- Sends energy equally in all directions
- Low reuse of the wireless space
- Higher risk of co-channel interference and collisions
- Needs more power to reach the same distance

## Directional

- Focuses energy toward one direction
- High reuse of the wireless space
- Fewer collisions and less interference
- Needs less power to reach the same distance

Source: Wong et al. (2015); Dai et al. (2013)

# The IETF 6TiSCH Protocol Stack

| | |
|---|---|
| **Application / CoAP / PCE / Tracking** | |
| **TCP/UDP/IPv6 + RPL** | *Routing* |
| **6LoWPAN** | *IPv6 over the 802.15.4 physical layer* |
| **6Top** | *Distributed scheduler — shares cells between pairs of nodes* |
| **802.15.4e TSCH MAC** | *Collision-free access using time slots and channel hopping* |
| **IEEE 802.15.4 (Physical Layer)** | |

Source: Figure 1b, p.4154 (Görmüş & Külcü 2019)

CONTRIBUTION

# The Main Contribution of This Study

### Direction-aware scheduling

A directional-antenna-aware resource scheduling mechanism (SF-DA) is proposed for 6TiSCH networks.

### A hybrid access scheme

Resources are shared across three dimensions: time, frequency, AND space (direction).

### Cooja / Contiki integration

A switchable directional antenna model was added as a new module to Contiki OS's Cooja simulator.

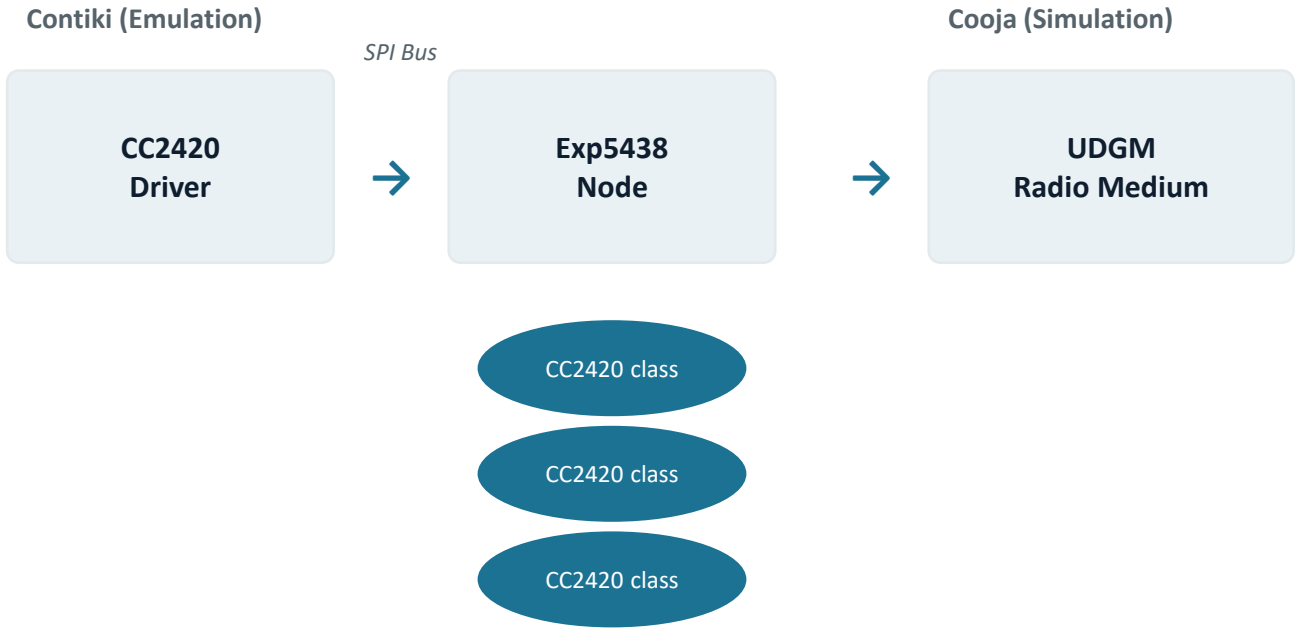
### A fair comparison

The proposed solution is compared against the 6TiSCH Minimal Configuration and Orchestra scheduling mechanisms.

# A Multi-Antenna Architecture for Cooja

## How was it built?

- The TI EXP430F5438 platform was extended with 2–3 CC2420 radio interfaces, each facing a different direction.
- Each interface connects to Cooja through its own SPI port on the Contiki cc2420 driver.
- The UDGM radio medium was updated to also take transmission direction into account.
- The direction of an incoming packet is stored in the MAC layer's neighbour table.




*All 3 directional antenna interfaces are simulated in the same radio medium*

Source: Figure 2, p.4156 (Görmüş & Külcü 2019)

4 · METHOD

# Space-Time Scheduling: A Worked Example

In a 9-node mesh network, every node sends 1 packet to the root node. Compare how many time slots are needed to carry the same traffic:

### Omnidirectional Antenna

**10**

time slots needed

Nodes cannot communicate at the same time; transmissions must happen one after another.

### Directional Antenna (SF-DA)

**8**

time slots are enough

Space-time separation allows more transmissions to happen in parallel.

Source: Figure 3, p.4158 (Görmüş & Külcü 2019)

# Test Environment and Parameters

| MAC Parameters | |
|---|---|
| Min. back-off exponent | **1** |
| Max. back-off exponent | **7** |
| Back-off increment | **2** |
| Retransmission count | **5** |

| Frame / Timing Parameters | |
|---|---|
| Frame size | **127 bytes** |
| Buffer depth | **5** |
| Timeslot duration | **15 ms** |
| Slotframe length | **15** |

| Network Parameters | |
|---|---|
| Transmit range | **50 m** |
| Interference range | **100 m** |
| Node distance | **40 m** |
| Test duration | **2 hours** |

*A 25-node grid topology (200×150 m) was tested with 2 or 3 directional antennas, using 180° / 120° beam widths.*

Source: Table 1, p.4160

# PRR Performance: Minimal Configuration and Orchestra

### Minimal Configuration

Using directional antennas increases the average packet reception ratio (PRR) by 2 to 3 times, depending on the data rate.

### Orchestra Scheduling

A similar improvement is seen here too — directional antennas clearly boost network performance under heavy load.

### Why does this happen?

A narrow antenna beam width gives higher spatial separation, which reduces collisions in shared time slots.

*Test setup: the packet transmission interval was varied between 0.2 and 2 packets/second to create saturated traffic scenarios.*

Source: Figure 4, p.4161 (Sections 5.1–5.2)

6 · RESULTS

# Space-Time Scheduling: Collisions and Channel Count

**↑100%**

The largest PRR improvement seen in the evaluated scenario

**>8**

Above this number of channels, directional antennas add little benefit

**50%**

How much less transmit power a 180° directional antenna needs for the same range

## Key takeaways

- When there are only a few frequency channels, the extra spatial dimension from directional antennas clearly improves PRR.
- In networks with low interference and few nodes, directional antennas may add only a limited benefit.
- SF-DA performance improves as more antennas are added; the benefit becomes even clearer as channel quality gets worse.

Source: Figures 5–6, p.4162 (Section 5.3)

6 · RESULTS

# Delay, Energy Use, and Network Size

As the network gets bigger, PRR drops while delay and energy use go up. Compared to an omnidirectional antenna, using 3 directional antennas gives:

**+5–10%** higher PRR

**–50%** lower average network delay

**↓ Energy** use, clearly reduced

| | 1 directional antenna | | | 2 directional antennas | | | 3 directional antennas | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of Nodes | PRR % | Delay (ms) | Energy (mWh) | PRR % | Delay (ms) | Energy (mWh) | PRR % | Delay (ms) | Energy (mWh) |
| **25** | 94.87 | 1267 | 3.21 | 97.94 | 595 | 1.55 | 100 | 536 | 1.26 |
| **49** | 83.55 | 1560 | 3.65 | 87.61 | 1174 | 1.82 | 88.77 | 1094 | 1.49 |
| **73** | 61.04 | 2254 | 4.09 | 63.49 | 1594 | 1.89 | 66.74 | 1544 | 1.65 |
| **101** | 39.13 | 3145 | 5.08 | 42.17 | 2324 | 2.31 | 44.06 | 1793 | 1.77 |

Source: Table 2, p.4164

CONCLUSION

# Directional Antennas Add a New Degree of Freedom

- Using a simple, RF-switchable smart antenna system improves 6TiSCH network performance and reduces end-to-end delay and energy use.
- 6TiSCH performance improves clearly when scheduling decisions use the direction information gathered by the smart antennas.
- The benefit of directional antennas is greatest in scenarios where the number of frequency channels is limited.
- Future work: validate these results using a testbed with real switchable and steerable antennas, aiming at high-reliability industrial IoT networks.

REFERENCE

# Source and Acknowledgment

**Görmüş, S., Külcü, S. (2019).**
*Enabling space time division multiple access in IETF 6TiSCH protocol.*
Turkish Journal of Electrical Engineering and Computer Sciences, 27(6), 4151–4166. doi:10.3906/elk-1903-127

This research was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK), project number 118E289.

*This presentation is an academic summary of the research paper above. For the full reference list (29 citations), please see the original article.*

# Thank You