TUHH
Hamburg University of Technology

ComNets
Institute of Communication Networks

Bachelor Thesis Outline

Evaluation and Improvement of the Collision Handling Mechanism in 6TiSCH Minimal Scheduling Function for Wireless Sensor Networks

1 Project Description

1.1 Background

Going wireless is one of the global trends affecting almost every branch which involves human-to-machine or machine-to-machine interaction. In the context of Internet of Things (IoT) the focus is on interconnecting many small sensors in a reliable and latency-, energy-efficient way. While wireless communication offers unparalleled benefits in terms of cost-efficiency, coverage and flexibility, it brings a number of challenges, in particular involving medium access. On a radio medium, signal degradation is due to reflections, path loss and multipath fading with inter-user interference further exacerbating the problem.

Reliability and low latency are among the key Key Performance Indicators (KPIs) for many applications in the industry and healthcare. To address these challenges imposed on a communication network, IEEE 802.15.4 for Low Power and Lossy Networks (LLNs) defines the Medium Access Control (MAC) and physical (PHY) layers, see Figure 1.1, serving as a basis for modern IoT protocol stacks such as ZigBee, 6TiSCH, Thread, etc. The standard specifies a number of MAC schemes for scheduled—Timeslotted Channel Hopping (TSCH), as well as randomizde—Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) medium access. The goal of a deterministic medium access like TSCH is to improve reliability and reduce energy consumption through restrictive, but predictable behavior of each node, following Time-Division Multiple Access (TDMA) principle.

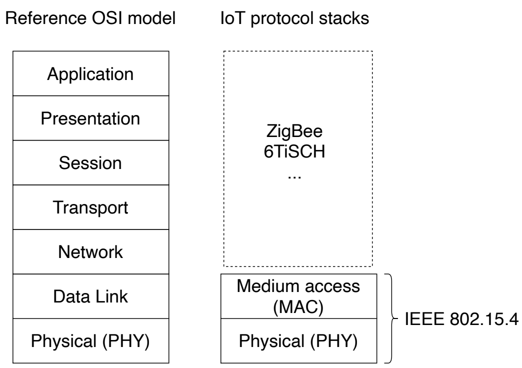

Figure 1.1: IEEE 802.15.4 and the OSI model.

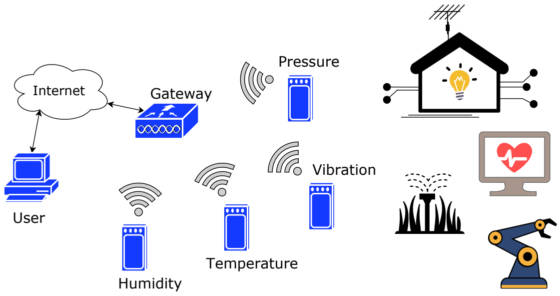

Figure 1.2: Wireless Sensor Network (WSN) example.

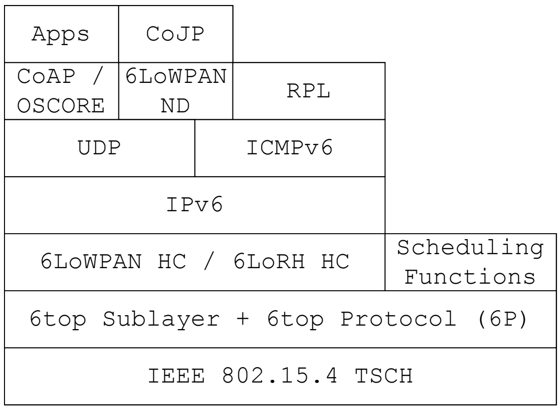

Figure 1.3: IPv6 over the TSCH mode of IEEE 802.15.4 (6TiSCH) protocol stack.

Among IEEE 802.15.4-based protocol stacks, 6TiSCH, shown in Figure 1.3, is an open standardization effort by Internet Engineering Task Force (IETF), which brings IPv6 features to the IoT. Medium access in TSCH is scheduled, where each pair of nodes is assigned a certain portion of time—*slot offset* and frequency—*channel offset* for communication. A tuple [*slotOffset*, *channelOffset*] is commonly referred to as a *cell*. Multiple cells are organized into *slotframes*, which repeat over time, making the schedule periodic, as shown in Figure 1.4.

The cells are managed by the *scheduling function* defined in 6TiSCH to bridge application requirements to the MAC layer resources. With non-overlapping cells scheduled between all neighbors a collision-free communication is possible. However, building such a schedule in a dynamic manner is an NP-hard problem, and many heuristic solutions were proposed to date. Among those, IETF Minimal Scheduling Function (MSF) [1] is a widely used solution which employs randomized scheduling approach. MSF is robust, reacts to traffic changes and can mitigate external interference by relocating communication cells.

TSCH offers channel hopping to mitigate external interference by changing the frequency of every transmission. However, if a cell is being used by several pairs of nodes within the interference range, a cell collision occurs.

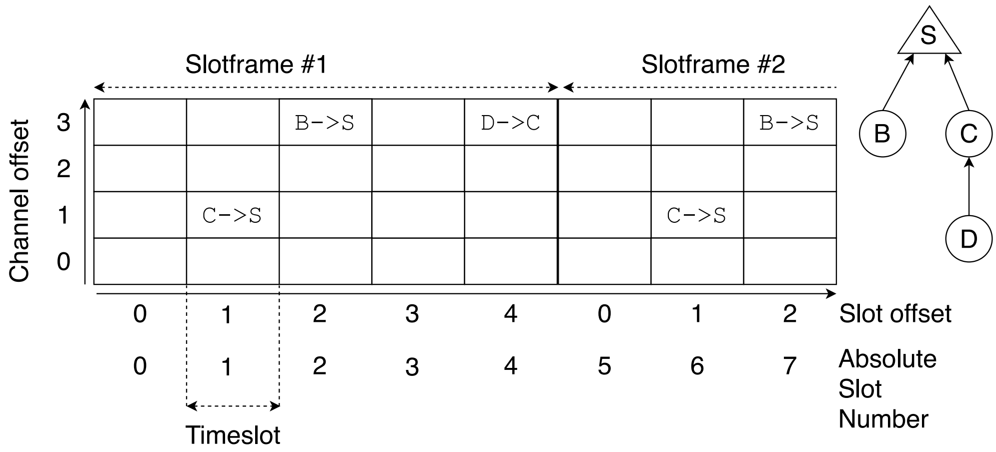

Figure 1.4: TSCH schedule example for slotframe with 5 time slots and 4 frequency channels.

MSF provides a mechanism to resolve cell collisions by monitoring cell performance in terms of Packet Delivery Ratio (PDR). In case there is an underperforming cell with PDR significantly lower than that of other scheduled cells, the interfered cell will be relocated by MSF as shown in Fig. 1.5.

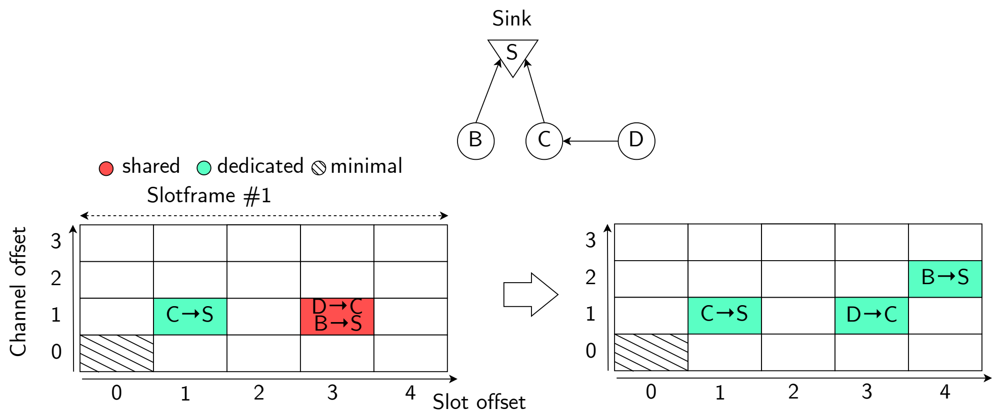

Figure 1.5: Internal interference resolution by MSF.

1.1.1 Problem Statement

Despite being a widely used and studied scheduling function, some features of MSF were not evaluated in detail. In particular, the duration of cell relocation procedure depending was not considered. This duration depends on a number of factors including node density, amount of traffic and MSF parameters. While some existing work [2] provides an in-depth analysis of MSF, the cell relocation time for networks of variable density is not covered. It is therefore necessary to clearly understand the impact of abovementioned parameters on the cell relocation time and derive mitigation techniques.

1.1.2 Research Question

To evaluate the impact of network density, traffic load and MSF parameters on the duration of cell relocation process, an analytical model should be used and, if necessary, adapted, based on existing stochastical and combinatorial methods [3]. Furthermore, to improve the cell relocation mechanism a random sensing approach is to be developed and evaluated. The approach involves listening to the medium in the otherwise unused cells in order to detect which cells are already being used by the neighbors.

To validate theoretical expectations and the proposed improvement, an experimental evaluation should be carried out using OpenMote B boards running Contiki-NG operating system. As additional KPIs, control traffic overhead and energy consumption may be considered.

1.2 General Tasks

1.2.1 Disclaimer

Please note that this document provides
merely a starting point
for your research.

This is just a description of the initial idea of your research effort. We cannot foresee whether the approach will work well, and we cannot foresee all of the problems that arise as you progress. The topics and tasks may change, new ones may be added, or they may be replaced completely. You can use this as a baseline, to know where to start. Likewise the tasks given in this outline are *not* the structure of your thesis; you are responsible for a sensible content structure which you should discuss with your supervisor. So please be aware that this is not a "binding contract", and that simply working through the tasks given here does not guarantee a good thesis.

1.2.2 Literature Study

A good starting point is always to have a look at recent literature on the topic. Your thesis should have a "Related Work" section that gives a brief history of the problem at hand (if applicable), and then describes the *state-of-the-art* solution to your problem.

1.2.3 Conceptualize

With the state-of-the-art as a baseline, motivate how the current approach is lacking in some area, and how your approach may change that. Give a thorough description of what you are aiming to do *and why solving this problem is a worthwhile research effort.*

1.2.4 Implement

Implement your idea with a suitable tool, such as OMNeT++, Python, MATLAB, ...
Test your implementation as you go! Define simple scenarios that are verifiable by hand and make sure that your implementation does what it should.
(*You may even consider test-driven development with automated tests that ensure that a new feature does not break an old one.*)

1.2.5 Evaluate and Validate

Design scenarios that describe an interesting application of your problem. Be thorough with this design: motivate *why* you picked n users, *why* they are positioned as they are, *why* their data generation requirements are as you specify and think about *what you expect* as an outcome. Once obtained, analyze the results with suitable scientific methods. Can you trust your results? Do you need more than one simulation run since things change randomly? How *reliable* are your results, and how can you show this? Once representative and reliable results are obtained, what can you deduce from these? Is your approach working as you had hoped? Why, or why not?

1.2.6 Conclude

Draw a conclusion from the work you have done. A short wrap-up of your approach and of the evaluation should motivate why your thesis contributed to your specific problem. Then highlight what you were not able to do: what are sensible next steps, what is future work?

2 Administrative

2.1 Supervisor Agreement

To have an agreement on what is expected of me as the supervisor and you as the author of this thesis:

Regular Updates We agree that you update me on your progress at least once every two weeks or as discussed with your supervisor. If regular student meetings take place, I expect you to come to these. If a face-to-face update is not possible, then at least a short update via email should be done.

Questions As your supervisor I am glad to answer any and all questions that you have. Feel free to contact me via email anytime. If you require a face-to-face question round, either wait for the next meeting, or set up a date with me via email.

Feedback on text As your supervisor I would like to read your full thesis at least once. As it is hard to find time and focus to read an entire thesis in one go, I encourage you to send me chapters of your thesis when you deem them ready to be reviewed. What is deemed “ready” constitutes both content and form – if you struggle with English, it makes sense to have a good English-speaker proofread your text.

Do not hand in text for feedback too late. Try to hand in the first chunk of text after half of the time *at the latest*, and expect a reading time of at least one week.

Do not plagiarize We agree that you do not copy full or parts of text or code from other sources. If you quote something, then *always* reference the source. If you put in a figure that you have not made yourself, *always* reference the source. Your thesis will be digitally analyzed by a plagiarism detection service. Improper citation and source handling may result in a fail.

Scientific Work Ethic We agree that you work in a scientific way. This means that you take notes and keep a list of your tasks and your questions. This means that you give reason to *all* of your statements. If you make statements that you do not prove (mathematically or through argumentation) yourself, then *reference* where this proof can be found. If you do prove it yourself, then reference to that point in your work. When you add figures, *always* reference to them in the text.

Autonomy We agree that as your supervisor I comment and recommend directions of research. We also agree that *you* are the author of your thesis, and *you* make the last call of what to look at. As your supervisor I do not direct every step you take. Instead it is *your job* to find sensible next steps and research directions. With your ideas you can always come to me and I will give you feedback on these.

2.2 Good Scientific Practice

We value a Good Scientific Practice, as e.g. defined by the Deutsche Forschungsgemeinschaft in [4]. An excerpt of **misconduct** of good scientific practice is:

- Picking ideas from others without citing (plagiarism).
- Selective presentation of data (rejection of unwanted results).
- Giving wrong information (e.g. in the Related Work section).
- Improper citation or authorship without permission.

Any severe misconduct regarding the above stated criteria may result in a fail.

According to the 2013 Proposal for Safeguarding Good Scientific Practice (also from DFG), **basic values and norms in science** are:

- Honesty
- Fairness
- Openness
- Confidentiality

For more details please refer to [4].

2.3 Guidelines at ComNets

An overview of your thesis milestones and important presentations is given in Table 2.1. For your kickoff presentation, you should replicate the Gantt chart in Figure 2.1 with tasks specific to your thesis. The general evaluation criteria of our institute is then presented in Table 2.2.

Presentation	Time	Purpose
Kickoff	Once the student has understood what to do.	Official starting point of the project. The student shall present the problem statement, the technical and scientific approach, and the time schedule. When supervisor(s) and Professor agree that the student has understood the problem and has set up a feasible schedule, the thesis can begin.
Seminar *(only Research Project)*	2 – 4 weeks after Kickoff	Present the *state of the art survey.*
Intermediate	1st 6 – 8 weeks after Kickoff *only Master's Thesis:* 2nd 6 – 8 weeks after first	Discuss intermediate results and adapted time schedules with both the Professor (or a PostDoc) and supervisor(s).
Final	0 – 2 weeks after the submission date	Official final presentation and defense of the entire thesis. All institute members are invited, the Professor and Second Examiner and supervisors will be present.

Table 2.1: Your thesis milestones (the big picture).

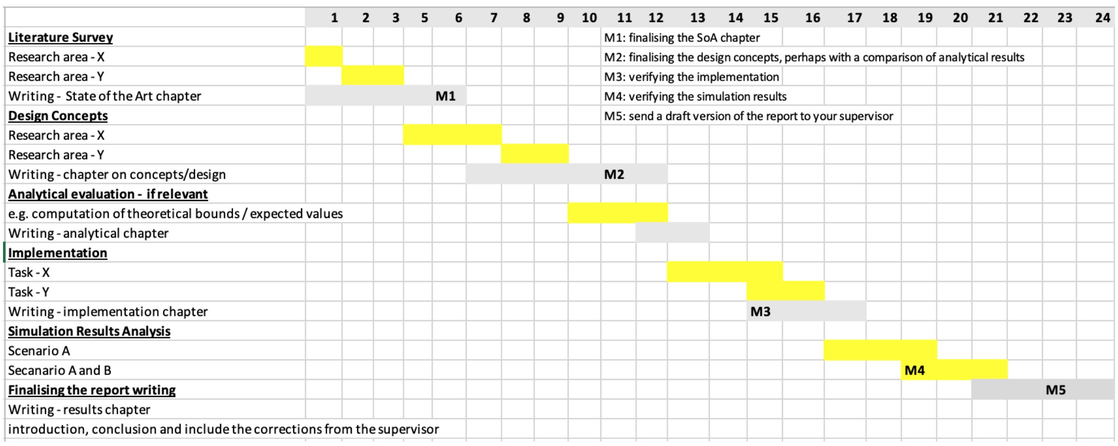

Figure 2.1: Example Gantt chart, which you should replicate for your kickoff presentation (the small picture).

2.3.1 Evaluation Criteria

40 % – **Engineering**	– Programmatic implementation; Execution of experiments (quality and quantity) – Structured approach for experiments, simulations and implementation – Understanding of methods and tools used – Structured approach to parameter and scenario selection, and with obtaining results – Complexity of the used simulator, and of the implementation – Independent problem solving and adequate discussion with the supervisor – Report and presentation structure, ...
40 % – **Scientific Analysis**	– Result analysis: validated, explained, reasoned, critically questioned – Justification of used parameters and models – Adequate choice of scientific methods; quality of solution and its investigation – Complexity of mathematical models – Independent problem solving and adequate discussion with the supervisor – Quality of report content, discussion after final presentation, references, use of scientific language
10 % – **Presentation**	– Well-formatted slides – Presentation style – Presentation structure: Motivation, problem statement, contribution, discussion, ...
10 % – **Discussion**	– Quality of scientific discussion after final presentation: are questions answered clearly, how are the explanations?

Table 2.2: Evaluation criteria at ComNets.

Bibliography

[1] Tengfei Chang, Mališa Vučinić, Xavier Vilajosana et al. *6TiSCH Minimal Scheduling Function (MSF)*. RFC 9033. May 2021. DOI: 10.17487/RFC9033. URL: https://rfc-editor.org/rfc/rfc9033.txt.

[2] David Hauweele, Remous-Aris Koutsiamanis, Bruno Quoitin et al. 'Thorough performance evaluation & analysis of the 6TiSCH minimal scheduling function (MSF)'. In: *Journal of Signal Processing Systems* 94.1 (2022), pp. 3–25.

[3] Yevhenii Shudrenko, Daniel Plöger, Koojana Kuladinithi et al. 'A novel approach to enhance the end-to-end quality of service for avionic wireless sensor networks'. In: *ACM Transactions on Internet Technology* 22.4 (2022), pp. 1–29.

[4] Deutsche Forschungsgemeinschaft DFG. *Good Scientific Practice*. URL: https://www.dfg.de/en/research_funding/principles_dfg_funding/good_scientific_practice/index.html (visited on 18th November 2019).