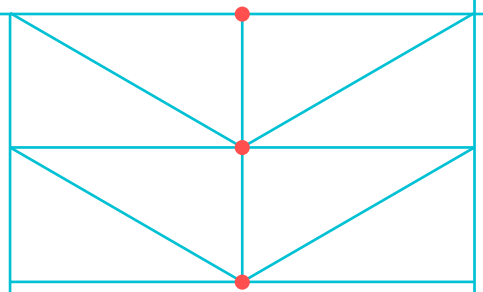
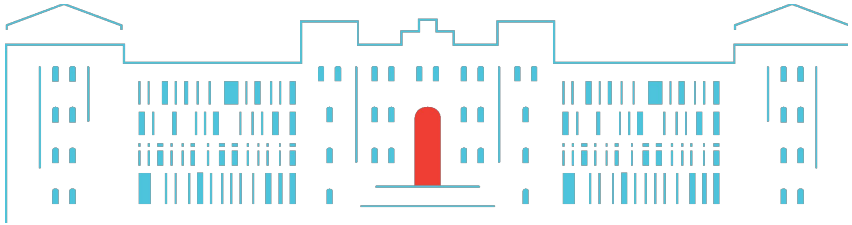
Evaluation of the Cell Allocation Mechanism in 6TiSCH Minimal Scheduling Function for Wireless Sensor Networks - Kickoff

TUHH
Technische Universität Hamburg



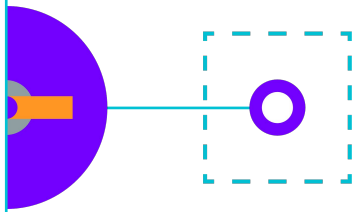
06.01.2025



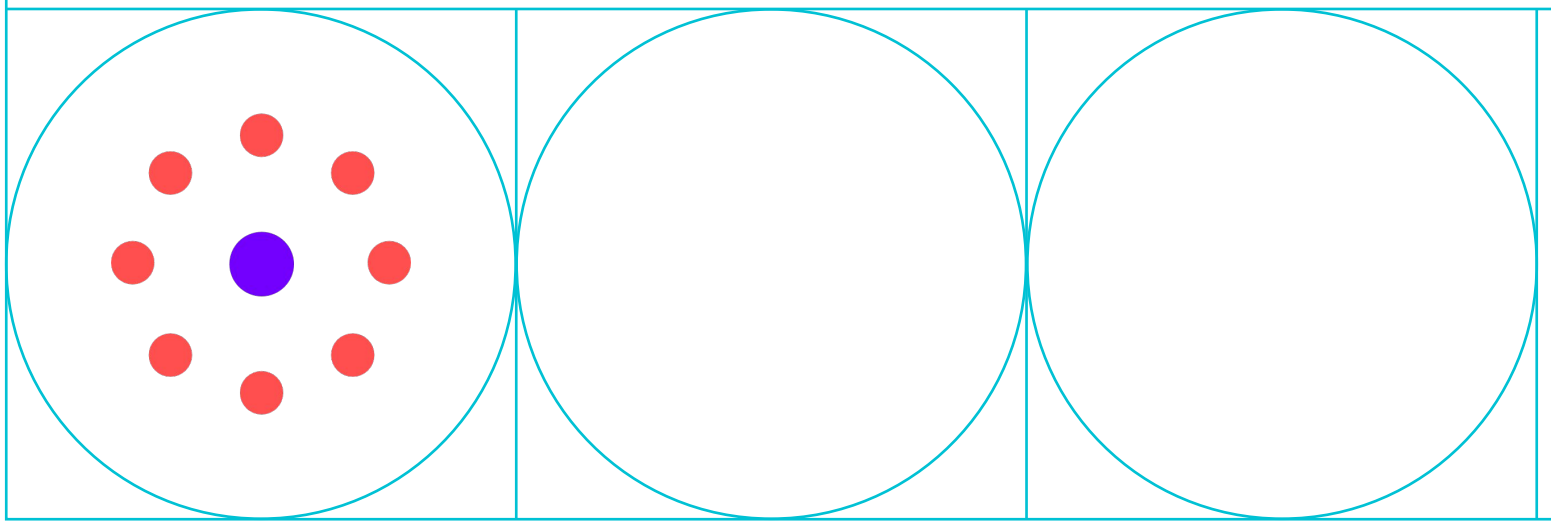
Benjamin Ko
Supervisor: Yevhenii Shudrenko
First Examiner: Prof. Timm-Giel

Agenda:

1. Introduction
2. Motivation
3. Research question
4. Schedule



1. Introduction



1. Introduction – Internet of Things (IoT)

- Effort to digitalize the environment by outfitting objects with digital capability and connecting them
- Gain control and insight into the physical environment
- Many (sensor) nodes that need to be connected

⇒ Wireless networks most suitable for that

Figure 1. IoT network [2]

1. Introduction – Wireless networks for IoT

- Wireless network needed for IoT
  - Cheap
  - Dynamic
  - Scalable
  - Easy to maintain
  - Energy efficient
- Low-power and Lossy Networks (LLN)
- 6TiSCH as a protocol stack for these networks

Figure 1. IoT network [2]

1. Introduction – 6TiSCH

- Enables IPv6 for LLN networks using IEEE 802.15.4
- 6TiSCH stands for IPv6 over TSCH
- Convergence of Operational Technology (OT) and Information Technology (IT)[8]
- Using 6LoWPAN standard for e.g. header compression and neighbour discovery

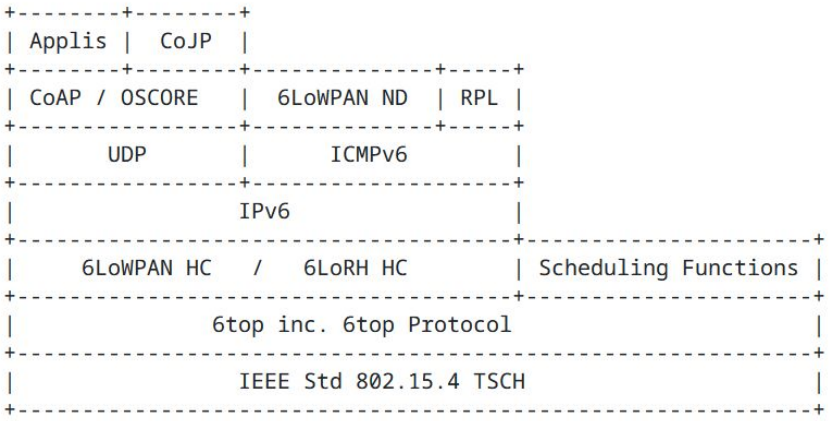


Figure 2. Protocol stack of 6TiSCH [1]

1. Introduction – 6TiSCH

- TSCH used as MAC protocol
  - Mix of TDM/FDM creating a matrix of cells for transmission
  - 6top Protocol (6P) used as communication [3]
- Scheduling function (SF) handles schedule

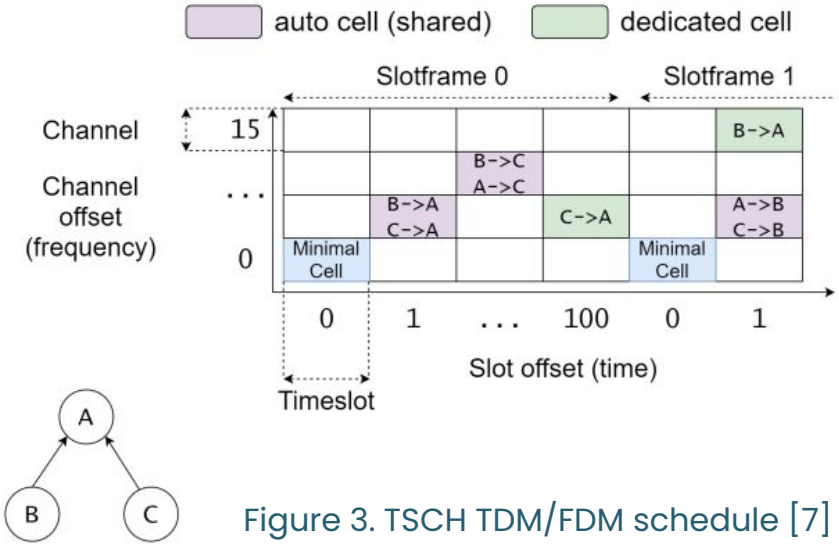
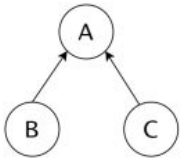


Figure 3. TSCH TDM/FDM schedule [7]

1. Introduction – Scheduling Function

- The scheduling functions tasks for a node are: [1]
  - When and how many to cells add/delete
  - Which cells to include in CellList of the 6P ADD request
- The only scheduling function that has a official RFC by the IETF is the Minimal Scheduling function



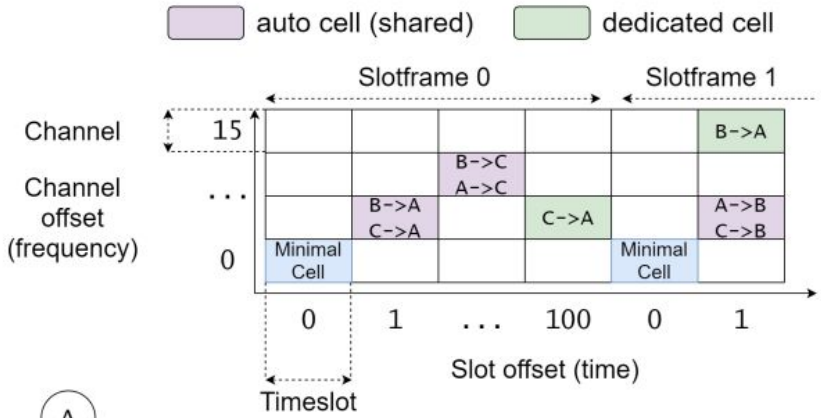


Figure 3. TSCH TDM/FDM schedule [7]

1. Introduction - Minimal Scheduling Function (MSF)

TUHH

- Has mechanisms to decide when to add/delete cells
- CellList is chosen randomly and uniformly
- Example: Relocation of a cell

$$PDR_{cellmax} - PDR_i > RELOCATE\_PDRTHRES$$

⇒ If true MSF will relocate the cell

PDR = Packet delivery ratio

Name	RECOMMENDED value
SLOTFRAME_LENGTH	101 slots
NUM_CH_OFFSET	16
MAX_NUM_CELLS	100
LIM_NUMCELLSUSED_HIGH	75
LIM_NUMCELLSUSED_LOW	25
MAX_NUMTX	256
HOUSEKEEPINGCOLLISION_PERIOD	1 min
RELOCATE_PDRTHRES	50 %
QUARANTINE_DURATION	5 min
WAIT_DURATION_MIN	30 s
WAIT_DURATION_MAX	60 s

Figure 4. MSF recommended values [4]

2. Motivation

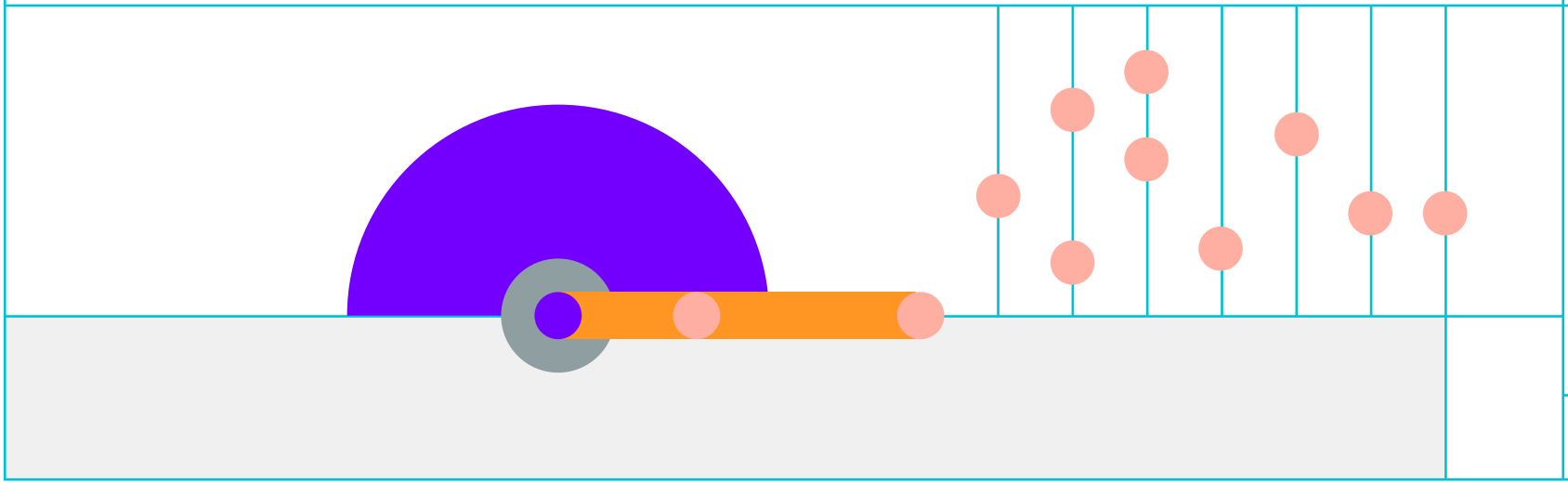
2. Motivation - Pre-existing evaluations of MSF

- Minimal scheduling function has been studied analytically and with simulations in regards to:
  - Convergence in the MSF adaptation period [5]
  - Performance in constant and varying traffic [6]
  - Influence of 6TiSCH MSF parameters on network KPIs, such as PDR, delay, duty cycle and cell utilisation [7]

2. Motivation - Need for study in depth

- 6 TiSCH is an important protocol stack for standardizing the development of IoT
- MSF as the only 6TiSCH SF having an official RFC standard [4]
- More in depth evaluation and understanding valuable
  - Cell allocation mechanism not studied in detail yet
  - Many simulations but little experimental validation

3. Research question



Evaluation of the Cell Allocation Mechanism in 6TiSCH Minimal Scheduling Function for Wireless Sensor Networks

3. Research question – Evaluation

TUHH

- Evaluation of cell allocation duration dependent on:
  - Node density
  - Amount of traffic
  - MSF parameters
  - Cell allocation mechanisms (optional)

3. Research question - Cell allocation mechanisms

TUHH

- Different cell allocation mechanisms to evaluate:
  - Random uniform selection of free cells (default)
  - Keeping a list of candidates in which the node listens and if traffic is detected then it will be exchanged with another cell
    - Stated as possibility in RFC for MSF [4]

3. Research question – How?

1. Analytical modeling

2. Experimental validation

3. Research question - Analytical modeling

- Adapt pre-existing statistical models to the situation

$$T_a = \sum_{i=1}^{\mu_{max}} E[A]\left(E[R]\left(\frac{M}{\mu_i} + \frac{1}{\mu_i + 1} + 0.5\right) + (E[R] - 1)t_o\right), \quad \mu_i = i$$

$$E[R] = \frac{1}{1 - p_I}$$

$$E[A] = \frac{1}{p_{nov}}$$

Figure 5. Pre-existing statistical model for adaptation time

3. Research question - Analytical modeling

$$p_{nov}^{(i)} = \frac{X(X-1)(X-2)\dots(X-n)}{X^n}$$

X = total amount of cells,

n= amount of cells to allocate

Figure 6. Base formula for calculating probability of all cell allocation to be without interference

$$p_{nov}^{(i)} = \frac{(X-n\mu_{i-1})(X-n\mu_{i-1}-1)(X-n\mu_{i-1}-2)\cdots(X-n\mu_{i-1}-n)}{(X-n\mu_{i-1})^n}$$

Figure 7. Further specified formula based on the one above

3. Research question - Analytical modeling

$$T_a = \sum_{i=1}^{\mu_{max}} E[A]\left(E[R]\left(\frac{M}{\mu_i} + \frac{1}{\mu_i + 1} + 0.5\right) + (E[R] - 1)t_o\right), \quad \mu_i = i$$

$$E[R] = \frac{1}{1 - p_l}$$

$$E[A] = \frac{1}{p_{nov}}$$

$$p_{fi} = \frac{nm_i}{(X - m_{i-1})},$$

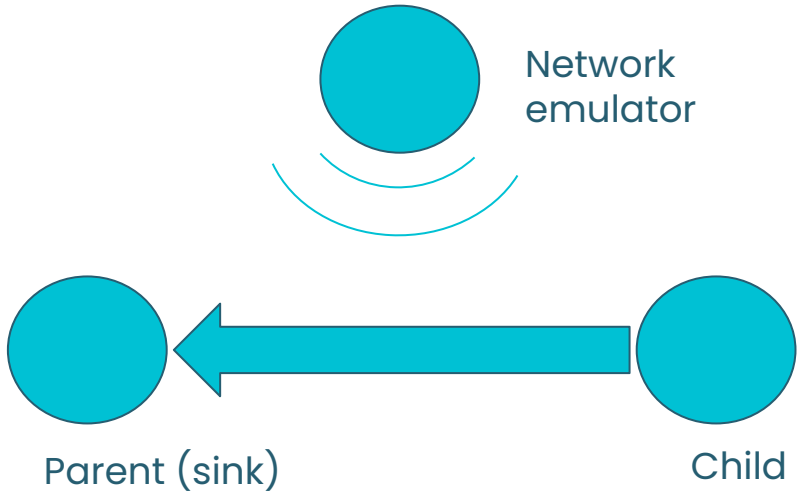
$$p'_{fi} = \frac{nm_i - n_s}{X - m_{i-1} - n_s}, \quad n_s < nm_i$$

$$m_i = i$$

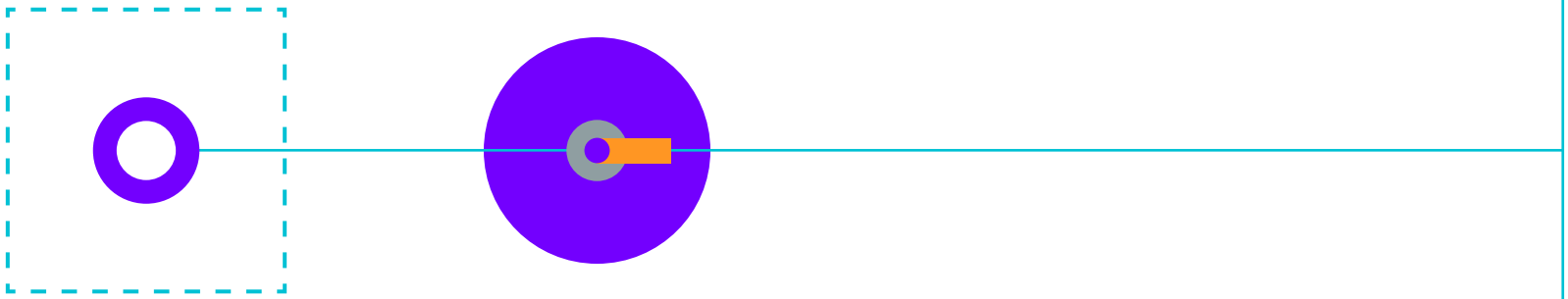
$$X = Sn_{ch}$$

3. Research question - Experimental validation

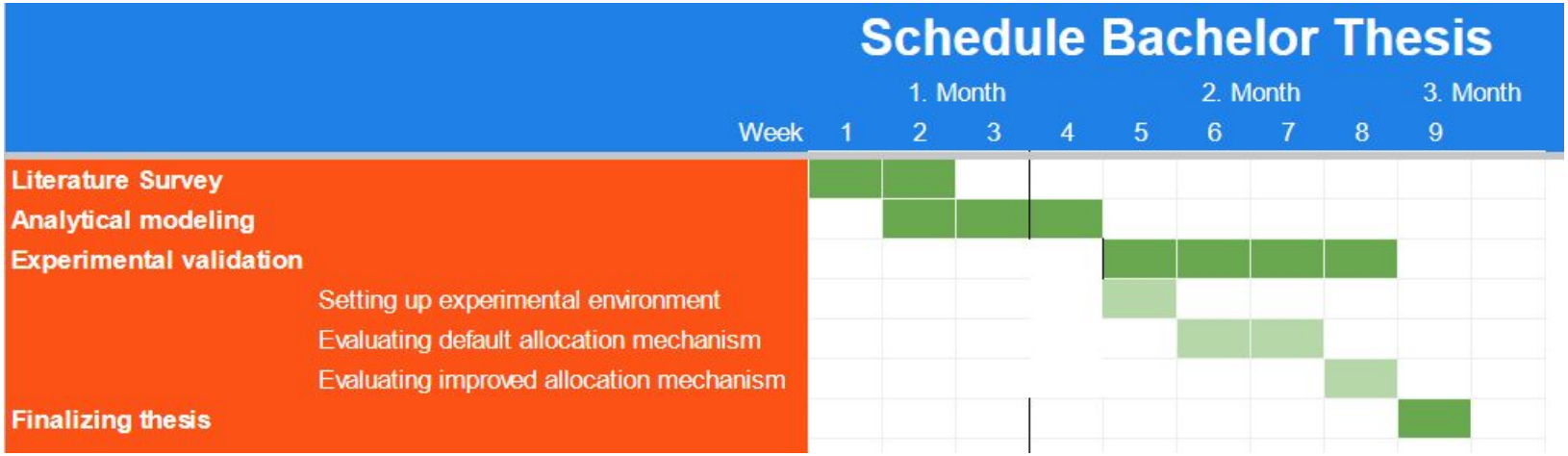
- Using 3 OpenMote B boards running the Contiki-NG operating system
  - Simple 2 node configuration as parent (sink) and child
  - A third board will serve as emulator for different network conditions



4. Schedule



4. Schedule



References

[1] Pascal Thubert . ‘An Architecture for IPv6 over the Time-Slotted Channel Hopping Mode of IEEE 802.15.4 (6TiSCH)’ . RFC 9030 . May 2021 . url: https://datatracker.ietf.org/doc/html/rfc9030.

[2] https://pixabay.com/images/search/iot%20network/ . Pixabay . last visited 27.11.2024

[3]Qin Wang , Xavier Vilajosana , Thomas Watteyne . 6TiSCH Operation Sublayer (6top) Protocol (6P) . RFC 8480 . November 2018 . https://datatracker.ietf.org/doc/rfc8480/ .

[4] T. Chang, Ed., M. Vučinić, Inria, X. Vilajosana, . ‘6TiSCH Minimal Scheduling Function (MSF)’ . RFC 9033. May 2021. doi: 10.17487/RFC9033. url: https://datatracker.ietf.org/doc/rfc9033/ .

[5] David Hauweele, Remous-Aris Koutsiamanis, Bruno Quoitin et al. ‘Pushing 6TiSCH Minimal Scheduling Function (MSF) to the Limits’. In: 2020 IEEE Symposium on Computers and Communications (ISCC). 2020, pp. 1–7. doi: 10.1109/ISCC50000.2020.9219692.

[6] 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 93 (6 June 2021). doi: 10.1007/S11265-021-01668-w.

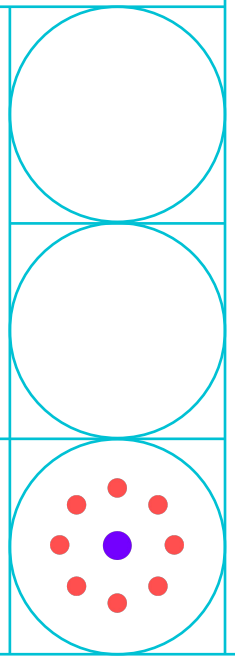
[7] Lukas Borutta. 'Evaluation of the Minimal Scheduling Function for 6TiSCH-based Wireless Sensor Networks' . (16 September 2021)

[8] Pascal Thubert . ‘IPv6 over the TSCH mode of IEEE 802.15.4e’ . https://datatracker.ietf.org/wg/6tisch/about/ . last visited 15.12.2024.

Thank you!

Technische Universität Hamburg (TUHH)
Ko Benjamin

tuhh.de



TUHH
Technische
Universität
Hamburg