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

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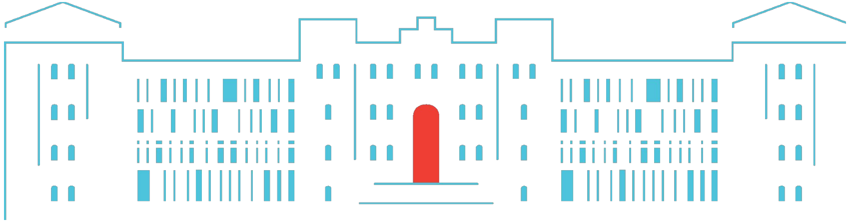

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Agenda:

1. Introduction
2. Motivation
3. Analytical Model
4. Experimental validation
5. Results
6. Conclusion

1. Introduction

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

1. Introduction - Wireless sensor networks

- Wireless sensor networks (WSN) as used in industrial settings
- Enables the collection of environmental data
- Characteristics:
  - Cheap and easy to operate
  - Scalable
  - Energy efficient

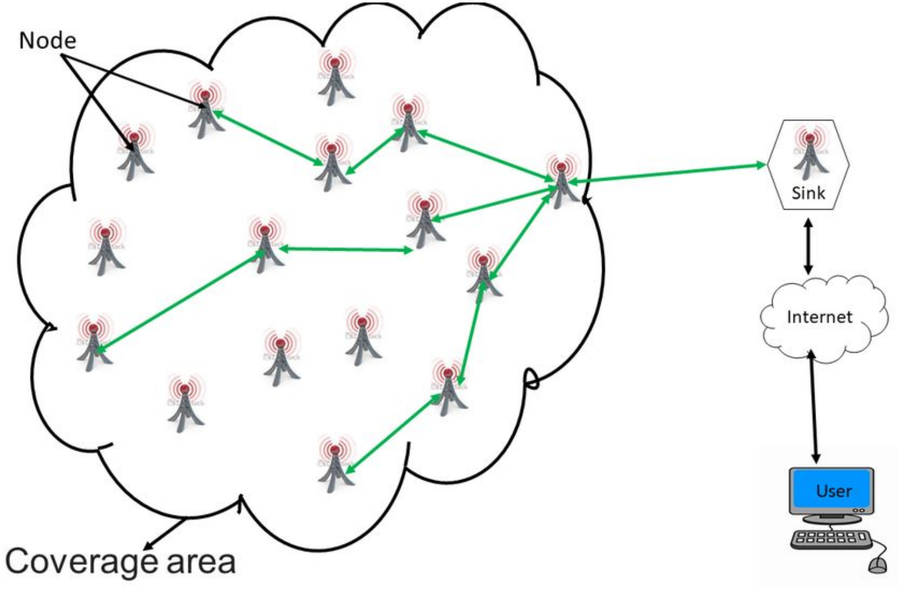


Figure 1. General architecture of a WSN. [1]

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

1. Introduction - 6TiSCH

- IPv6 over the TSCH mode of IEEE 802.15.4
- Utilizes 6LoWPAN for e.g. header compression
- Defines 6top sublayer
- Defines the tasks of scheduling functions

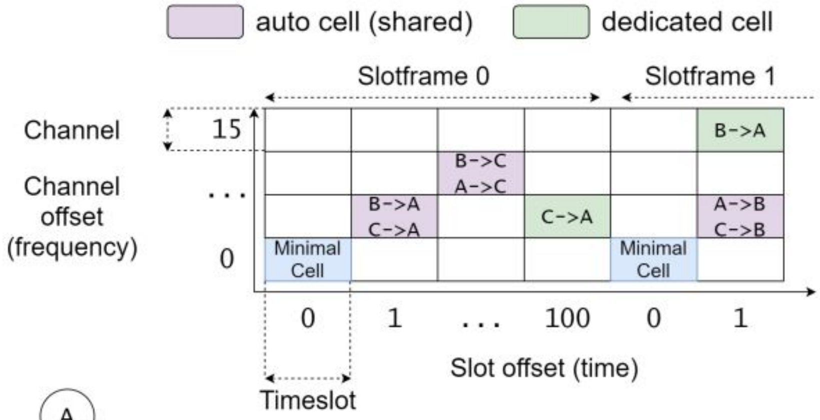
```
+--------+--------+
| Applis |  CoJP  |
+--------+--------+-------------+-----+
| CoAP / OSCORE   |  6LoWPAN ND | RPL |
+-----------------+-------------+-----+
|       UDP       |     ICMPv6        |
+-----------------+-------------------+
|               IPv6                  |
+-------------------------------------+----------------------+
|    6LoWPAN HC   /   6LoRH HC        | Scheduling Functions |
+-------------------------------------+----------------------+
|                 6top inc. 6top Protocol                    |
+------------------------------------------------------------+
|                 IEEE Std 802.15.4 TSCH                     |
+------------------------------------------------------------+
```

Figure 2. Protocol stack of 6TiSCH [2]

1. Introduction - 6TiSCH

- TSCH used as MAC protocol
  - Mix of TDMA/FDMA creating a matrix of cells for communication
  - 6top Protocol (6P) used for cell negotiation[3]

⇒ Scheduling function handles the schedule



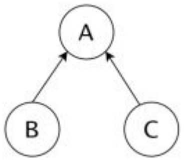


Figure 3. TSCH TDM/FDM schedule [4]

1. Introduction - Scheduling Function

- Tasks of the scheduling function[5]:
    - When and how many cells to add/delete
    - Which cells to include in CellList of the 6P ADD request
- The only scheduling function defined by a RFC is the **Minimal Scheduling Function (MSF)**

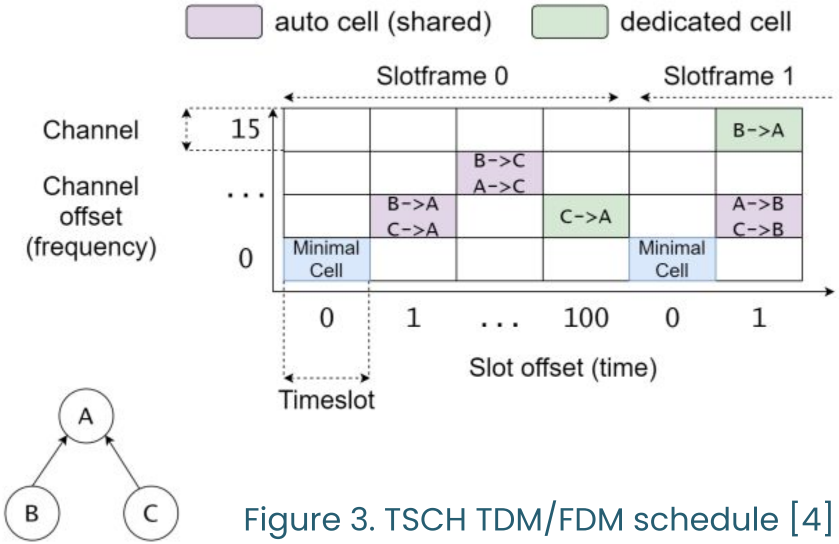
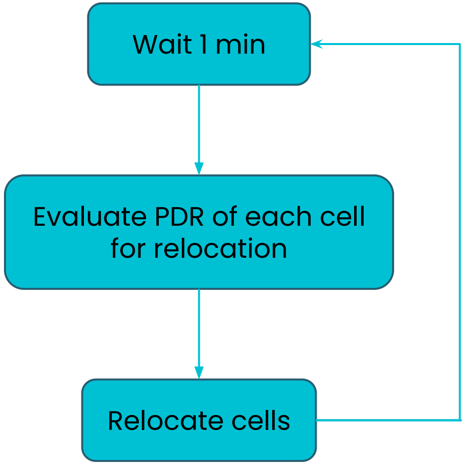


Figure 3. TSCH TDM/FDM schedule [4]

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

1. Introduction - Minimal Scheduling Function (MSF)

- Has mechanisms to decide when to add/delete/relocate cells
- Example: Relocation of a cell



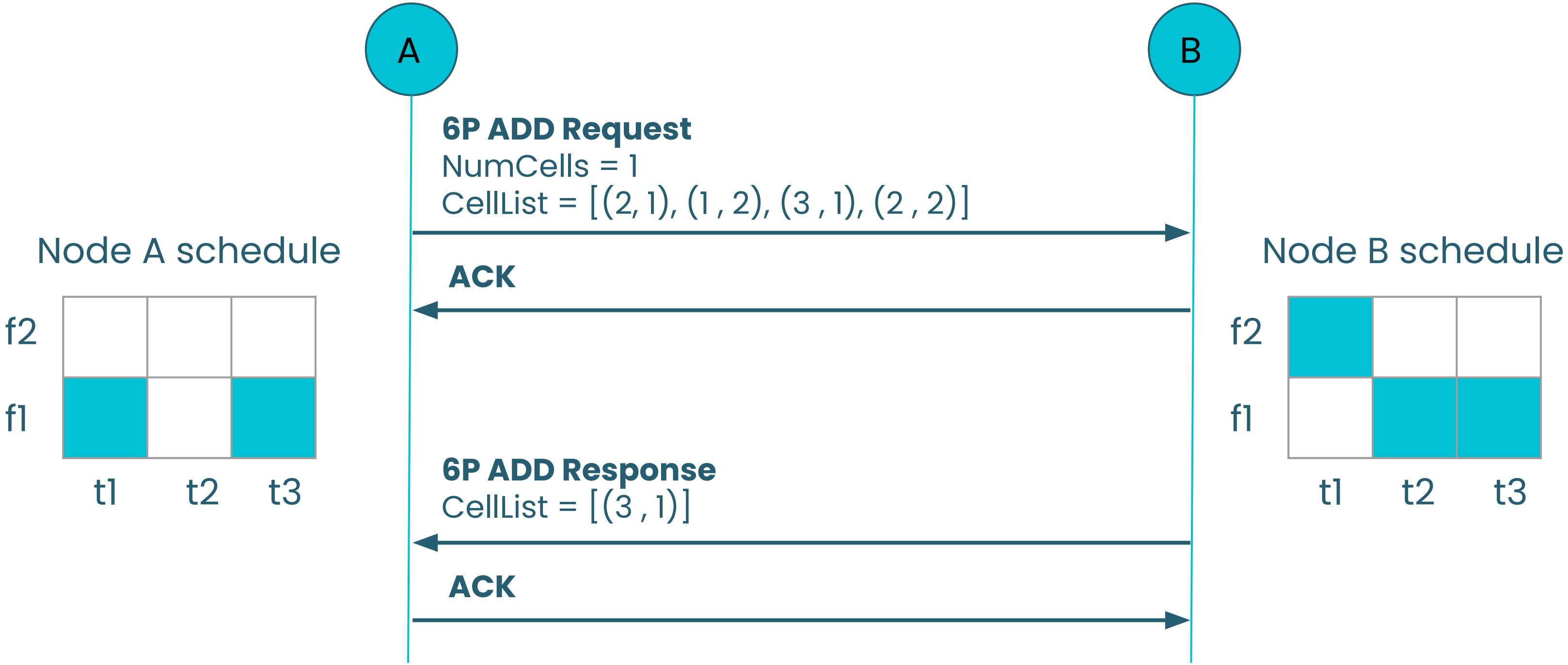
PDR = Packet delivery ratio

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 [2]

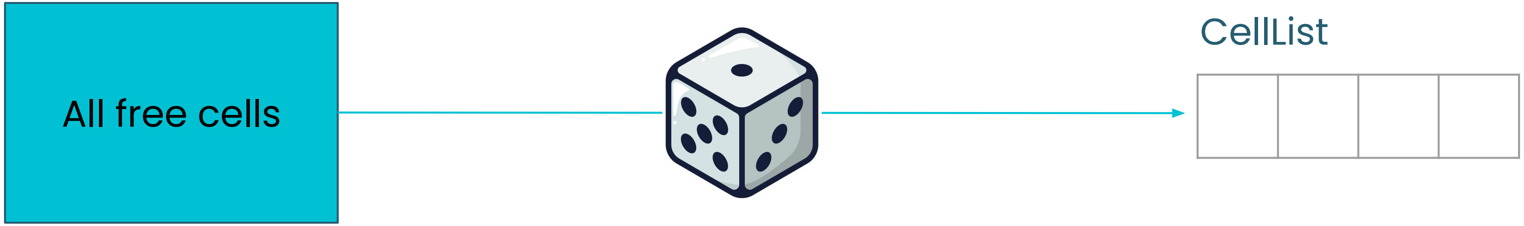
Evaluation of the Cell Allocation Mechanism in 6TiSCH Minimal Scheduling Function for Wireless Sensor Networks

1. Introduction - Cell allocation mechanism



1. Introduction - Cell allocation mechanism

1. Default cell allocation mechanism
   - MSF randomly uniformly selects cells



1. Introduction - Cell allocation mechanism

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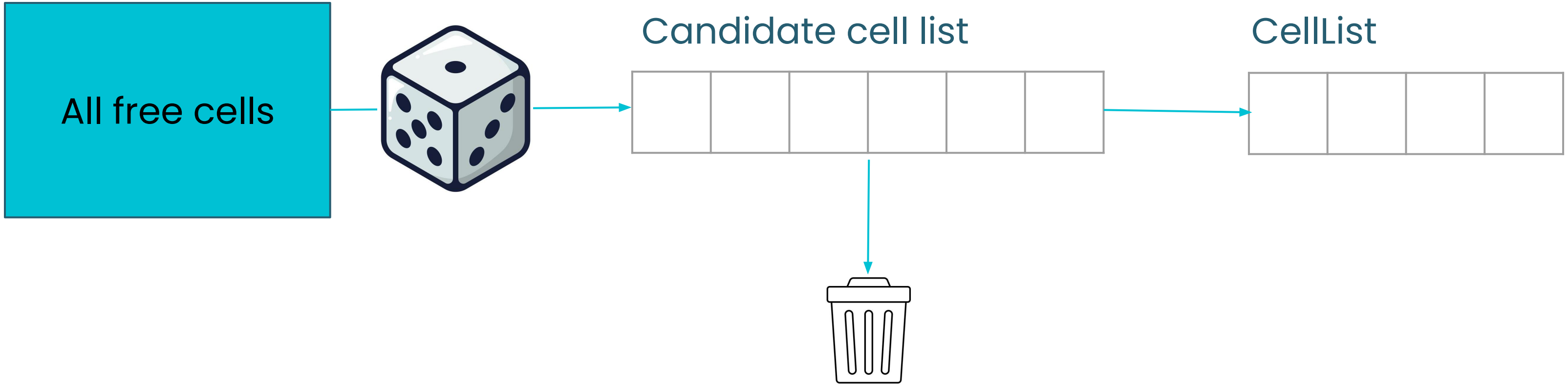
2. Sensing cell allocation mechanism as proposed by RFC 9033 [4]
   - A candidate cell list is maintained where MSF senses for traffic
   - When traffic detected cell is dropped



2. Motivation

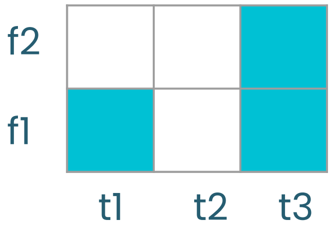
2. Motivation - Previous work

- Previous work on MSF has focused on:
  - Analytical and Simulation based evaluation of MSF parameters by Tangfei Chang et al. [6] and David Hauweele et al. [7] [8]
  - Proposing improved version of MSF by for instance varying the number of cells allocated Tangfei Chang et al [6] and Manas Khatua Karnish et al. [9]
  - Experimental evaluation of 6P and MSF by Francesca Righetti et al. [10]

⇒ Lacking research of cell allocation mechanism and experimental validation

2. Motivation - This work

- Evaluate the default and sensing cell allocation mechanism for MSF
- Using the KPI:
  - $\mathbf{T_s}$: Time it takes to allocate μ_{max} cells and the network to stabilize
    - Stabilize: No more relocations necessary
  - $\mathbf{p_{ov}}$: Probability of overlap



⇒ Using an analytical model and experimental validation

3. Analytical Model

3. Analytical model

- Calculate the T_s for μ_{max} cells to be allocated:

$$T_s = T_a + T_r$$

T_a = allocation time,

T_r = relocation time

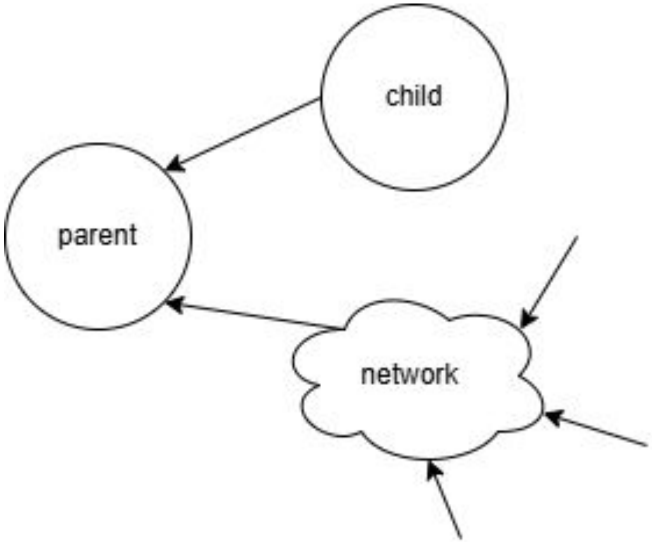


Figure 5. Network topology of analytical model

3. Analytical model - Cell allocation time

$$T_a = \sum_{i=2}^{\mu_{\max}} \left(\frac{M}{i-1} + \frac{1}{i} + 0.5 \right)$$

Time to next cell allocation

6P ADD request

6P ADD response

$\mu_{\max}$ = target service rate, $M = MAX\_NUM\_CELLS$

3. Analytical model - Relocation time

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$$T_r = t_h \min(\lfloor E_\Sigma[O] \rfloor, 1) + \left(\frac{1}{\mu_i} + 0.5\right) \left\lceil \frac{\lfloor E_\Sigma[O] \rfloor}{r_l} \right\rceil$$

Time until all cells are evaluated

$$E_\Sigma[O] = \sum_{i=1}^{\mu_{\max}} \frac{p_{ov}(\mu_i)}{1 - p_{ov}}$$

Maximum cells per relocation

Example: $E_\Sigma[O] < 1 \longrightarrow T_r = 0$

3. Analytical model - Probability of overlap

1. Default cell allocation mechanism:

$$p_{ov}(\mu_i) = \frac{N}{X - \mu_{i-1}}, \quad X = n_{ch} n_{sf},$$

2. Sensing cell allocation mechanism:

$$p_{ov}^{(C)} = 1 - (1 - \frac{N}{X'})^C, \quad X' = X - n_{min} - \mu_i - n_{auto}$$

- The time it takes for allocating a cell allows for the candidate cell list to become non overlapped (its relatively fast)

$N =$ Cells with interference, $X =$ Total number of cells, $C =$ Candidate cells

4. Experimental validation

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4. Experimental validation

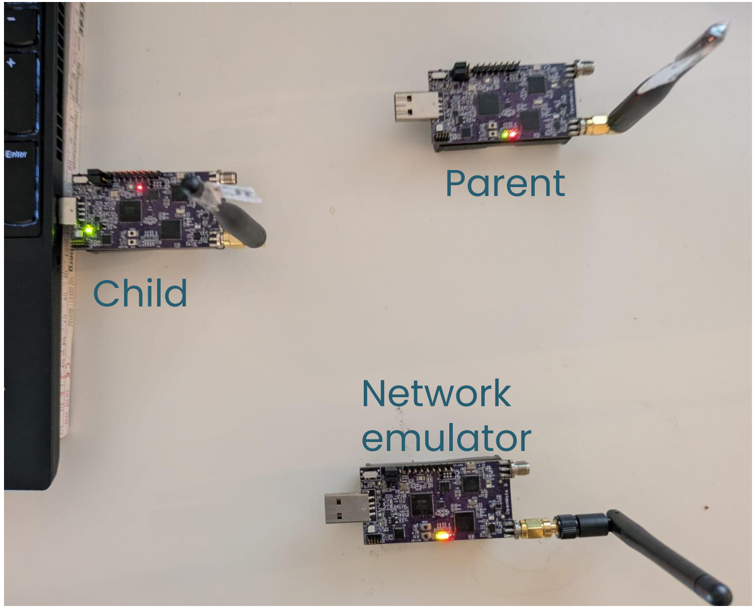

Figure 6. Experimental setup

- Testbed consisting of Openmote-B boards running Contiki-NG

- 3 Openmote-B nodes:
  - Parent (TSCH-coordinator, RPL-root)
  - Network emulator
  - Child

4. Experimental validation

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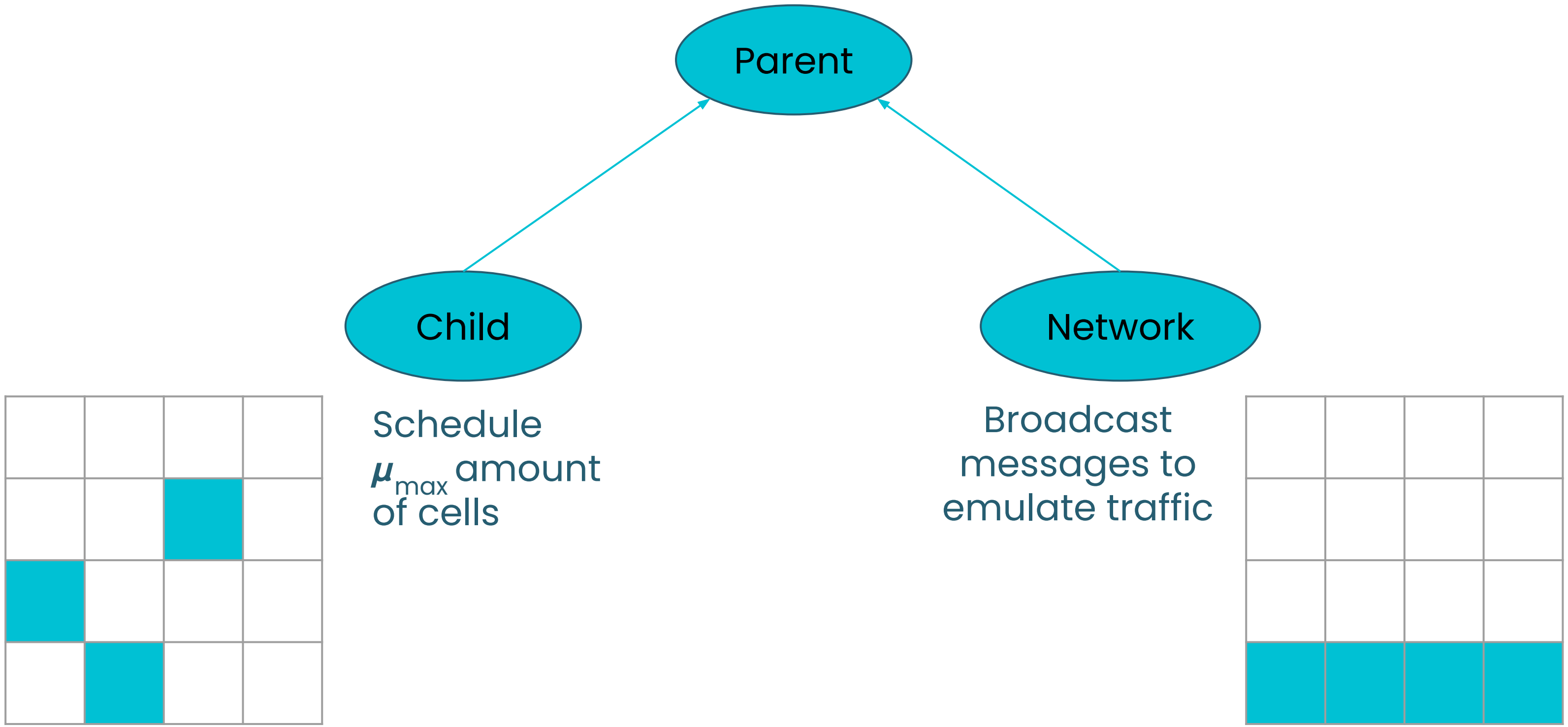

4. Experimental validation

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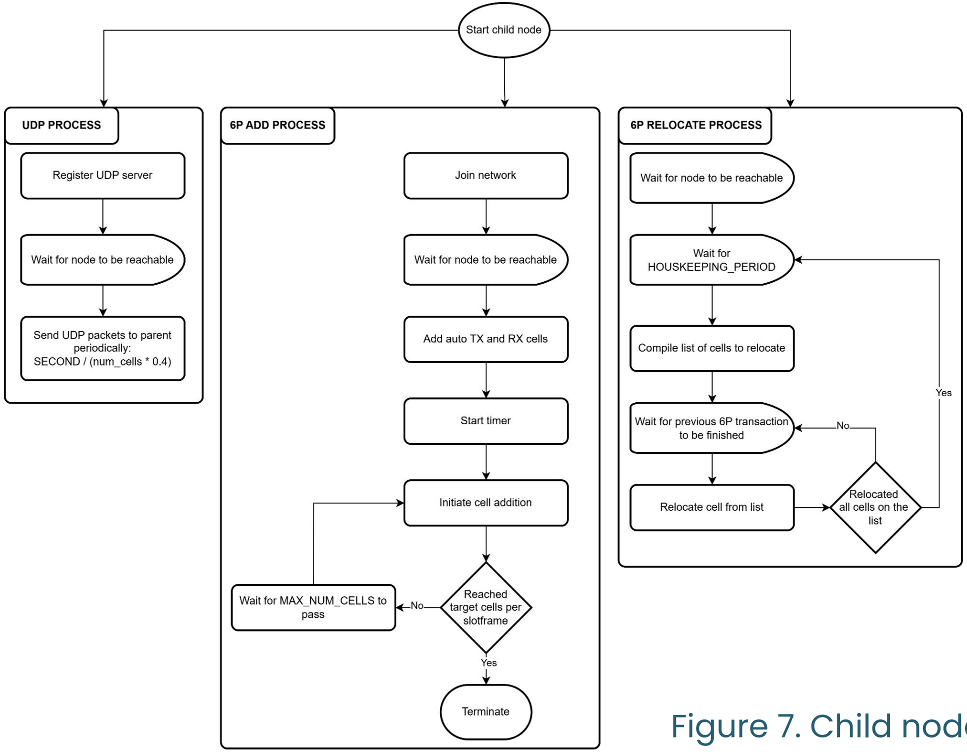

Figure 7. Child node implementation.

4. Experimental validation - Parameters

Parameters	Values
Test runs per setup	10
MAX_NUM_CELLS	100 , 50
Network interference	20% , 10%
HOUSEKEEPINGCOLLISION_PERIOD	60s
Channels	4
MAX_NUMTX	32
Slotframe length	100

5. Results

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5. Results - Scheduling time

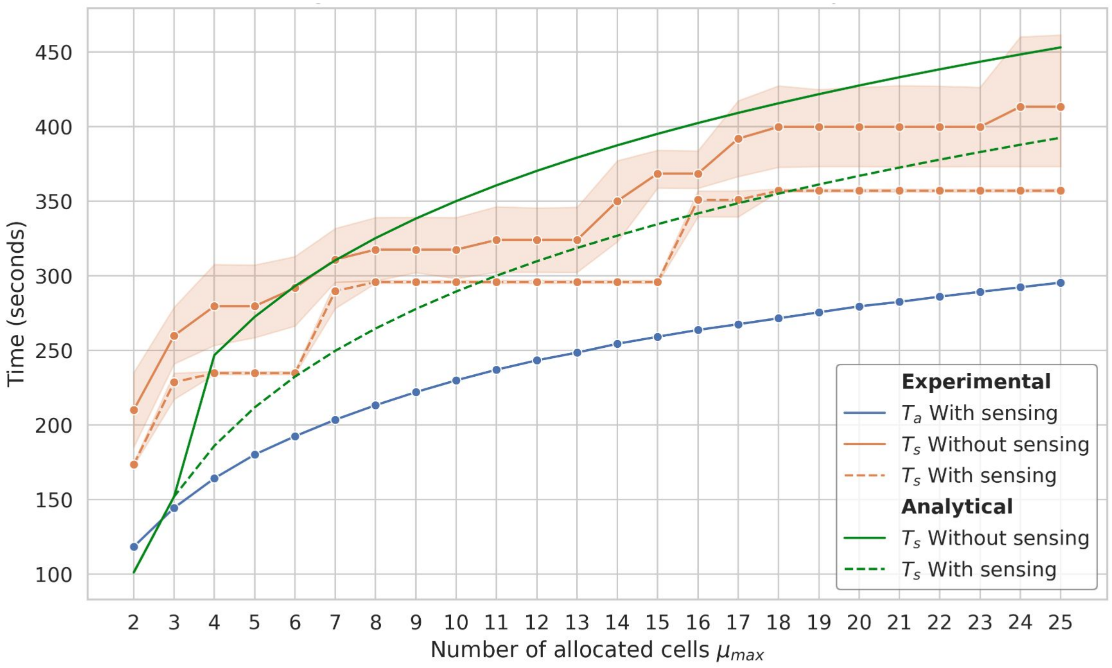

Figure 8. Experimental and analytical results with 20% interference.

5. Results - Scheduling time

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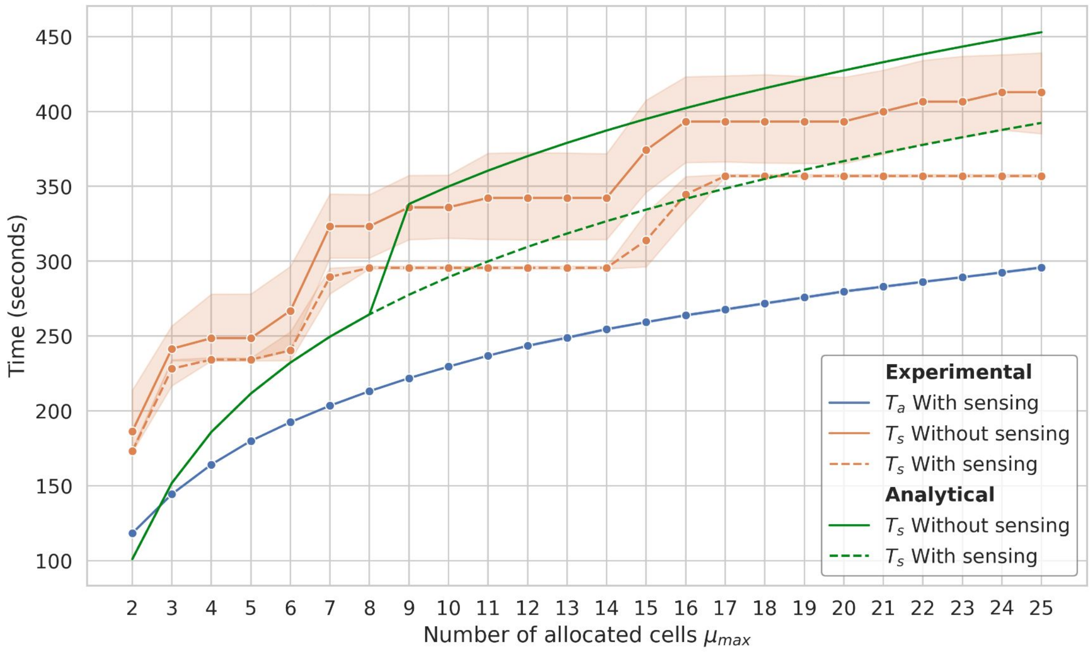

Figure 9. Experimental and analytical results with 10% interference.

5. Results - Probability of overlap

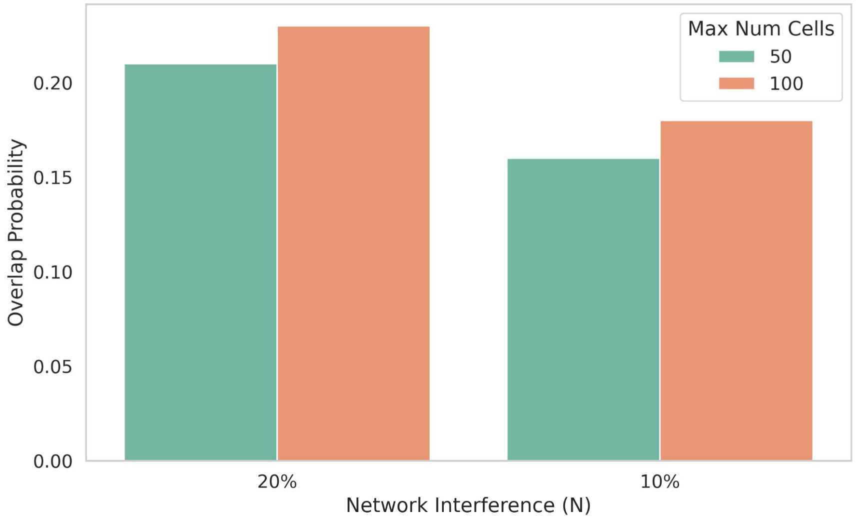

Figure 10. Probability of overlap without sensing.

- Probability of overlap higher with higher network interference
- Probability of overlap for sensing mechanism is 0
- Experimental data confirms analytical predictions

6. Conclusion

6. Conclusion

- ➔ Sensing mechanism reduces cell overlaps and allocation time, avoiding relocations
- ➔ Network interference impacts allocation time across all mechanisms
- ➔ Lower MAX_NUM_CELLS reduces the allocation time but has insignificant effect on probability of overlap
- ➔ Experimental results confirm the model’s accuracy
- ➔ Future work: Full experimental implementation of sensing mechanism & refined model considering multiple relocations and 6P timeouts

References

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Thank you!

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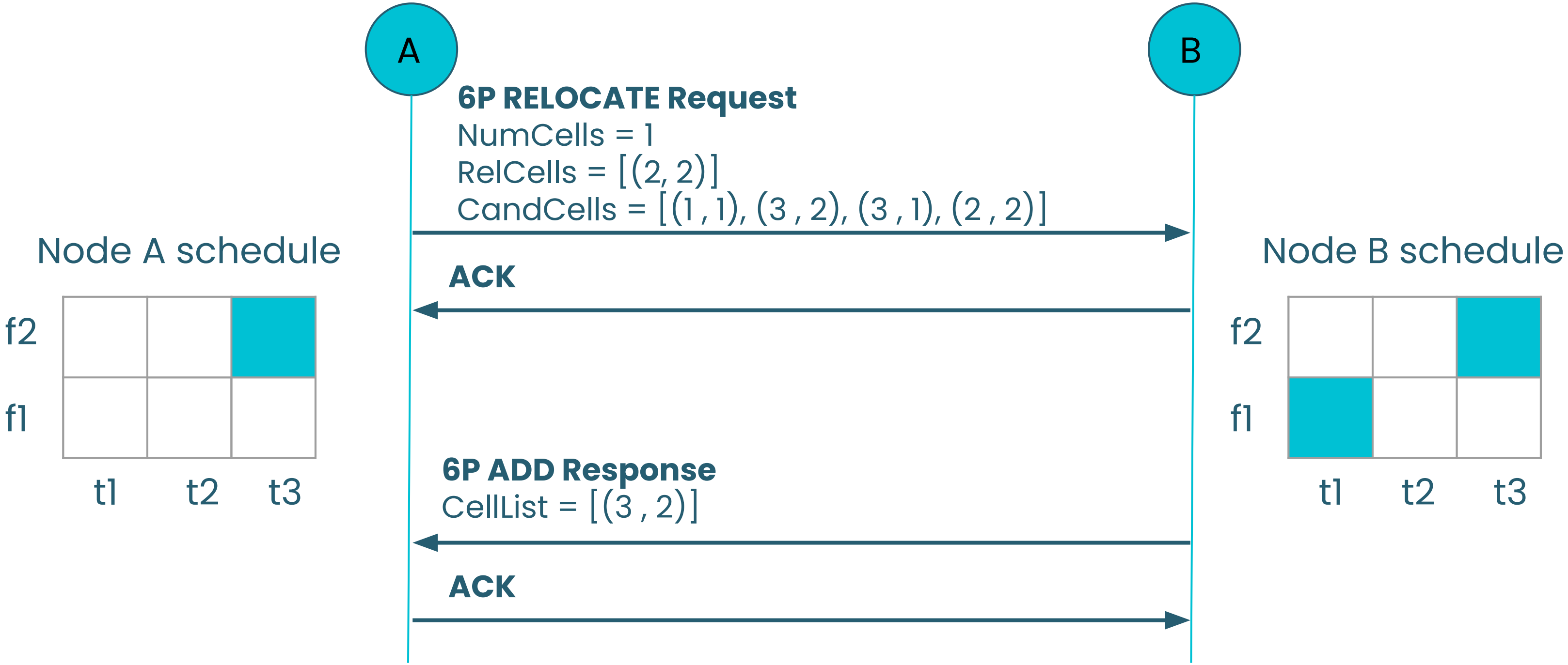
1. Introduction - Cell relocation



3. Analytical model

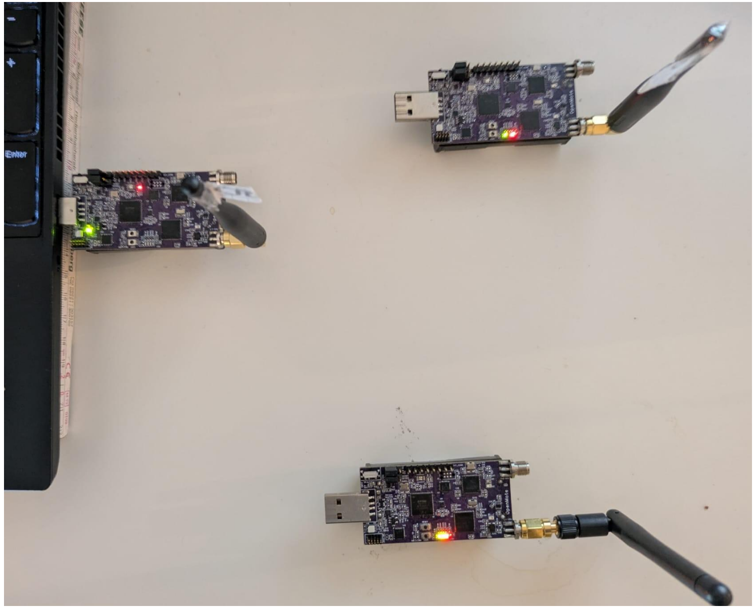
$$T_r = t_h \min(\lfloor E_\Sigma[O] \rfloor, 1) + \left(\frac{1}{\mu_i} + 0.5\right) \left\lceil \frac{\lfloor E_\Sigma[O] \rfloor}{r_l} \right\rceil$$

$$t_h = \left\lceil \frac{MAX\_NUMTX t_{slotframe}}{t_{housekeeping}} \right\rceil t_{housekeeping}$$

$$E_\Sigma[O] = \sum_{i=1}^{\mu_{\max}} \frac{p_{ov}(\mu_i)}{1 - p_{ov}}$$

$$r_l = \left\lfloor \frac{P_{\max}}{(\eta + 1)c} \right\rfloor, \quad \eta \geq 1$$

4. Experimental validation



3 Openmote-B nodes:
- Parent (TSCH-coordinator, RPL-root)
- Network emulator
- Child

Additional implementation added in Contiki-NG code:
- Setting up of autonomous cells
- Relocation mechanism
- Interferer mechanism of broadcasting
- Sensing approach

3. Analytical model - Sensing approach

- Initially upon selection of the cells the probability of overlap is

$$p_{ov}^{(C)} = 1 - (1 - \frac{N}{X'})^C, \quad X' = X - n_{min} - \mu_i - n_{auto}$$

Probability of no overlap at all

- The time it takes for allocating a cell allows for the candidate cell list to become non overlapped (its relatively fast)