Introduction to IEEE 802.15.4

ComNets

TUHH
Institute of Communication Networks

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31st of March 2025

Course Contents

Online lectures

- ~~Lecture 1 - Introduction~~
- ~~Lecture 2 – IEEE 802.15.4~~
- Lecture 3 – IETF 6TiSCH

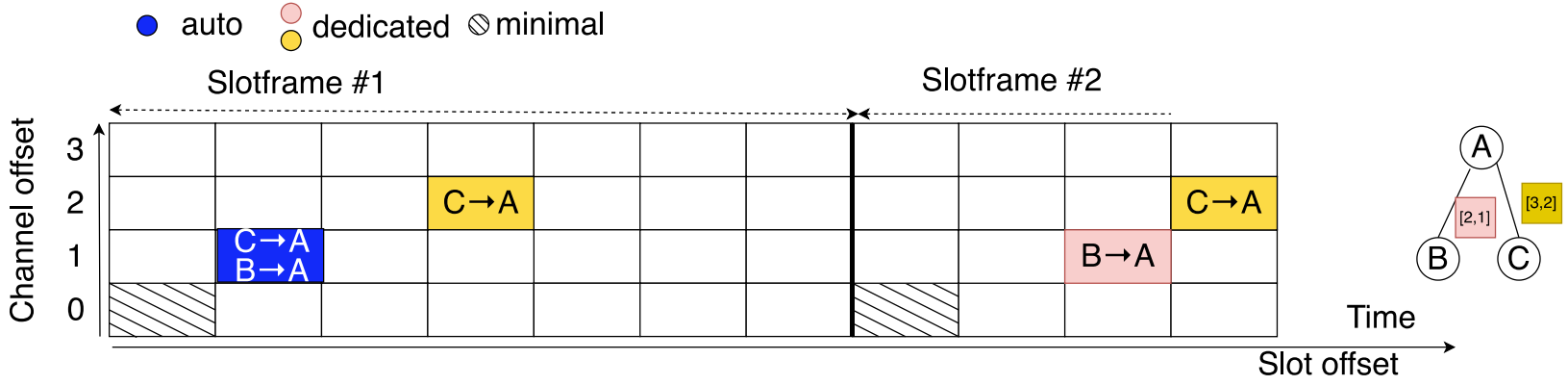
Physical Meeting 13th to 17th of April

- Lecture 4 – Theoretical Analysis
- Cooja Simulations and Experiments
- Industrial visit and a talk
- Team Presentations on self learned material
- Lecture 5 – Research Project Results

More details on our padlet,
https://tuhh.padlet.org/c00zll01/enabling-industry-4-0-j88rkh1i3j7rzmv3

TSCH Open Issues

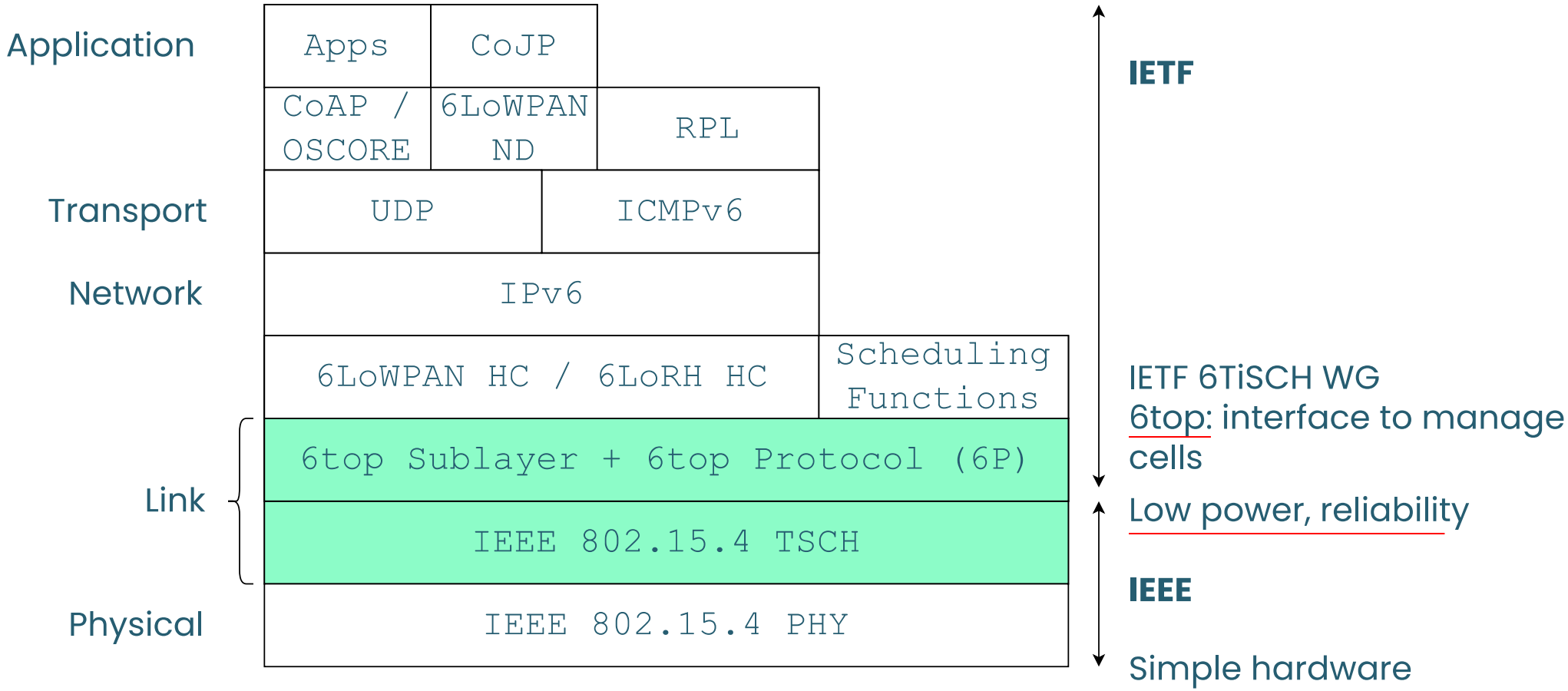
- Scheduling: trade off between throughput, delay and power consumption
  - Centralized vs. distributed
  - Time slot length, slotframe size
  - Spectrum sensing and blacklisting of channels
  - Number of cells per link
    - Avoiding internal collisions
    - Adaptive cell allocation (traffic monitoring)
- Synchronization
- Scalability
- Deployment
- …



6TiSCH Protocol Stack

These slides were prepared using the following references.
[1] RFC 8480 - 6TiSCH Operation Sublayer (6top) Protocol (6P)
[2] RFC 9033 - 6TiSCH Minimal Scheduling Function (MSF)

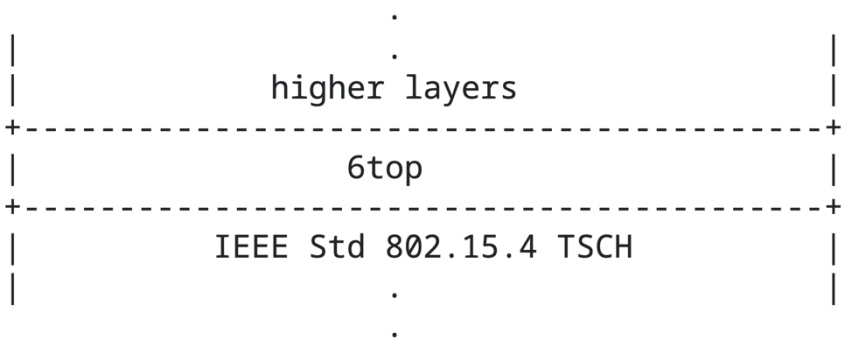
6TiSCH Overview



IETF – Internet Engineering Task Force
IEEE – Institute of Electrical and Electronics Engineers

6top Protocol (6P)

- Allows neighbors to add/delete/relocate cells
- 6P allocates cells in Slotframe 1



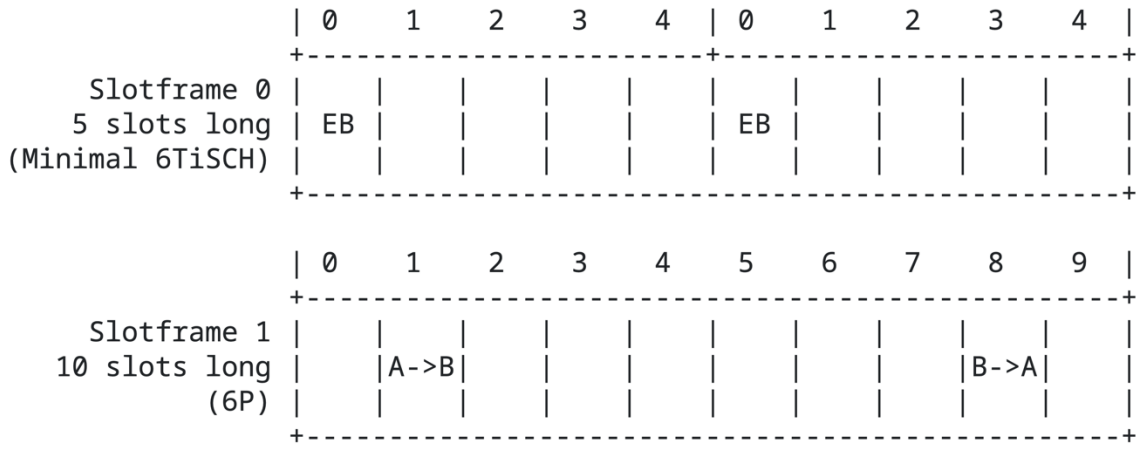


Figure 2. 2 Slotframe Structure when using 6P alongside the Minimal 6TiSCH Configuration

6P Transactions

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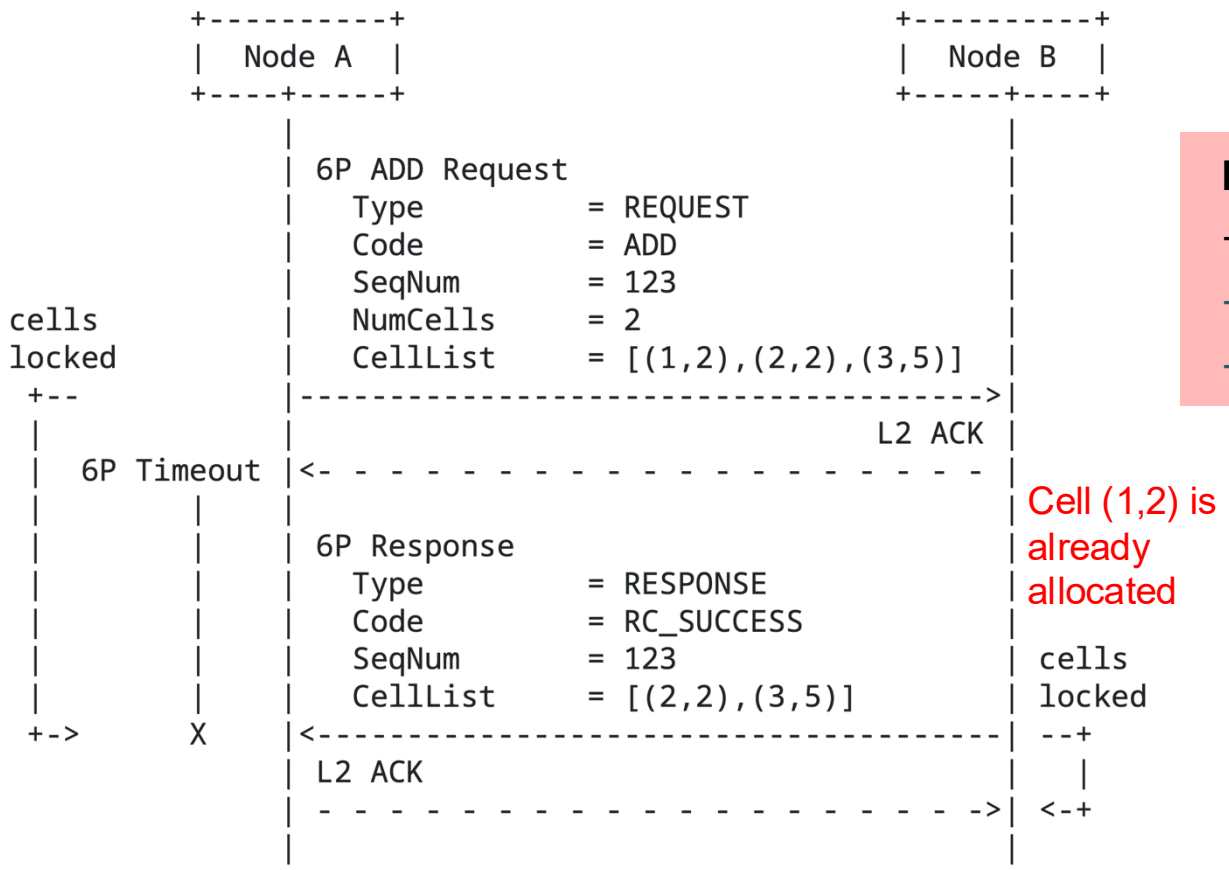
- 6P messages for allocating (add/delete/relocate) cells among neighbors
- 2- or 3-step
- Use auto cells for the initial transaction

2-Step 6P Transaction



Discuss the protocol behavior for these cases:

- **A sends ADD request with only [1,2] in cell list**
- **6P Add Request to B is lost**
- **6P Response from B is lost**

6P Return Code – Status & Error Handling

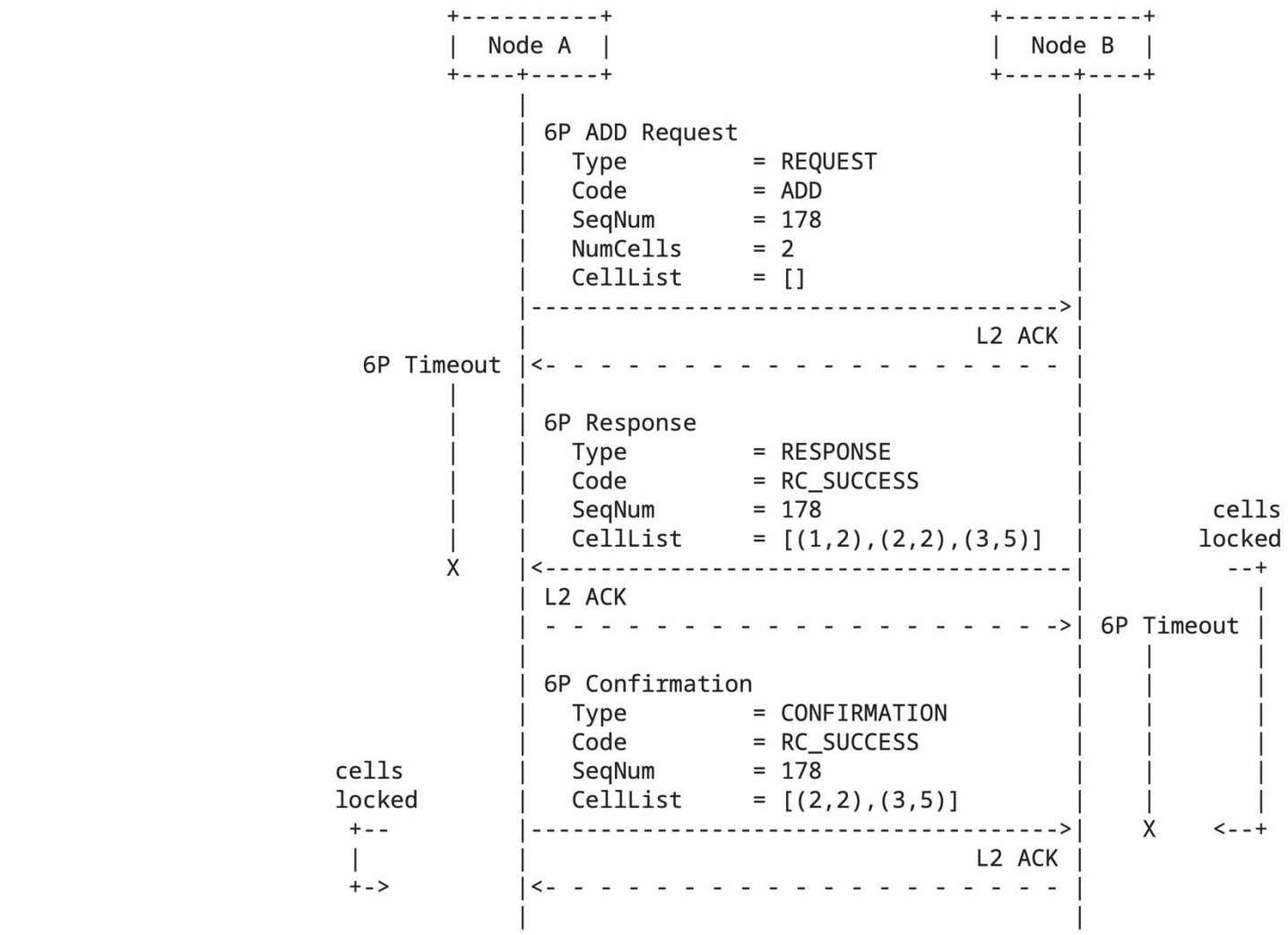
- Return code indicates the status
- Timeout at the originator handles Req/Res losses

Table 1. 6P return codes

Code	Name	Description	Is Error?
0	RC_SUCCESS	operation succeeded	No
1	RC_EOL	end of list	No
2	RC_ERR	generic error	Yes
3	RC_RESET	critical error, reset	Yes
4	RC_ERR_VERSION	unsupported 6P version	Yes
5	RC_ERR_SFID	unsupported SFID	Yes
6	RC_ERR_SEQNUM	schedule inconsistency	Yes
7	RC_ERR_CELLLIST	cellList error	Yes
8	RC_ERR_BUSY	busy	Yes
9	RC_ERR_LOCKED	cells are locked	Yes

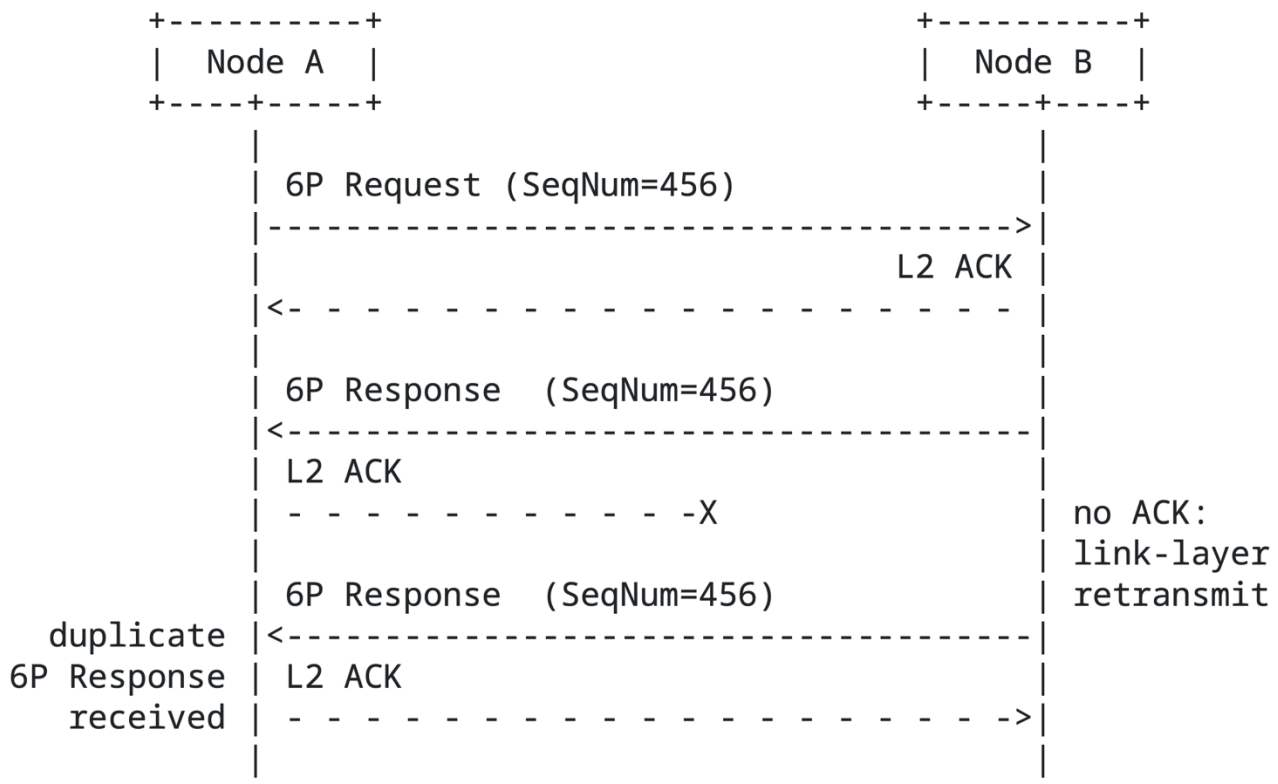
Why is L2 ACK used here?

3-step 6P Transaction



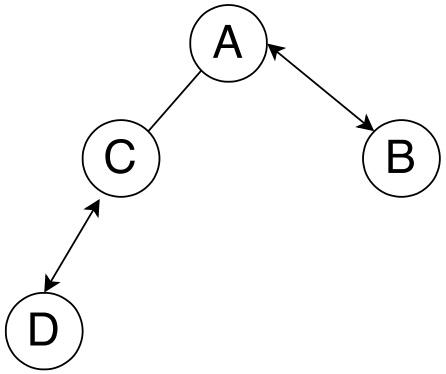
Why do we need SEQ numbers?

Duplicate 6P Messages



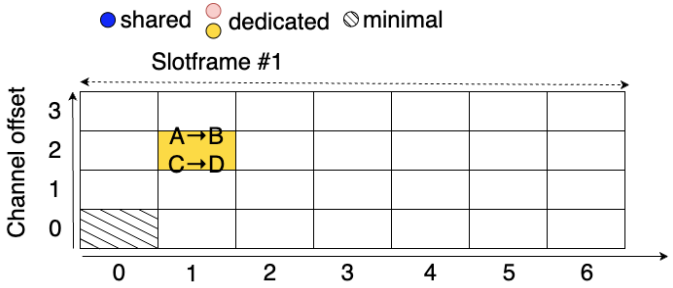
Cell Collision

- If two pairs of neighbours use the same cell
  - A & B use Cell [1,2]
  - C & D also use Cell [1,2]



- Cell collision does not always result in packet collisions ☺

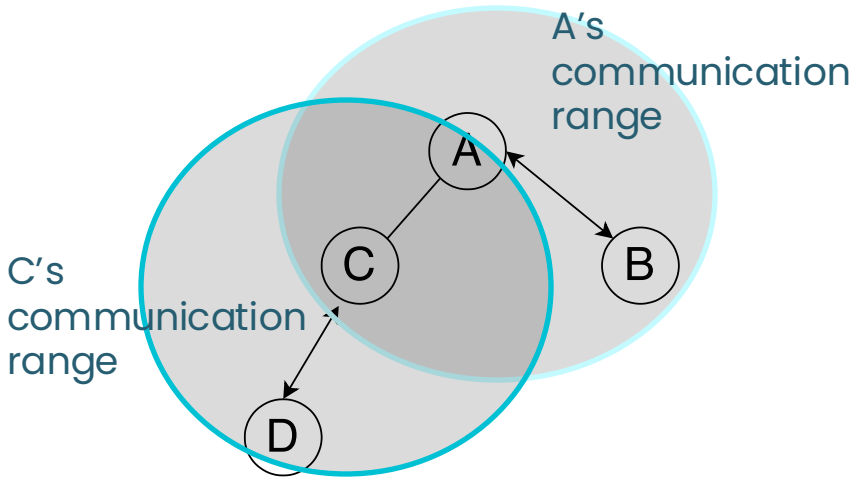
Discuss the probability of cell collision in the given topology. Consider the case where A & B as well as C & D use bidirectional communications.



Cell Collision contd.

- A -> B and C -> D use the cell at [1, 2]
  - They transmit at the same time with the same channel offset.

- A & C are neighbours
  - A TX & C RX (☹)
  - A RX & C TX (☹)
  - A TX & C TX (☹)
    - Is this possible with TSCH based MAC?
  - A RX & C RX (☺)



How do we identify the cell collision in a distributed manner?

6TiSCH Minimal Scheduling Function (MSF) – RFC 9033

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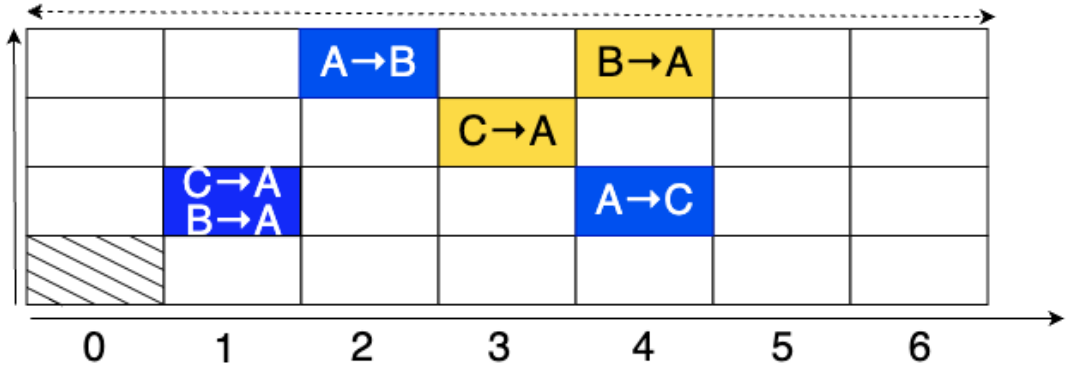
- MSF is built upon the 6p protocol
  - describes the behavior of a node when joining the network
  - describes how the scheduling is managed in a distributed manner

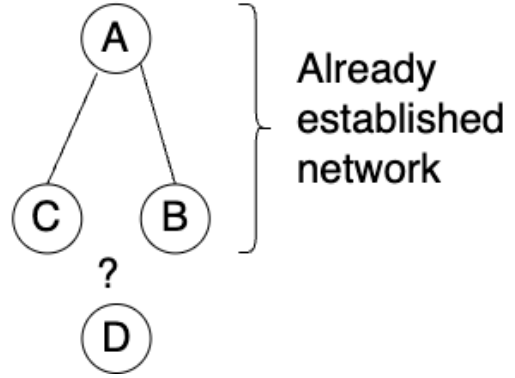
MSF - Joining the Network

1. Randomly choose a frequency from the channels through which the network cycles and starts listening for EBs on that frequency.
2. Receive EBs, learn the number of neighbors and select a routing parent.
3. Set up auto cells.

End of the joining phase:

- Is synchronized to the network
- has selected one neighbor as its routing parent
- has one AutoRxCell
- has one negotiated Tx cell to the selected parent
- starts to send DIOs
- starts to send EBs





MSF – Distributed scheduling

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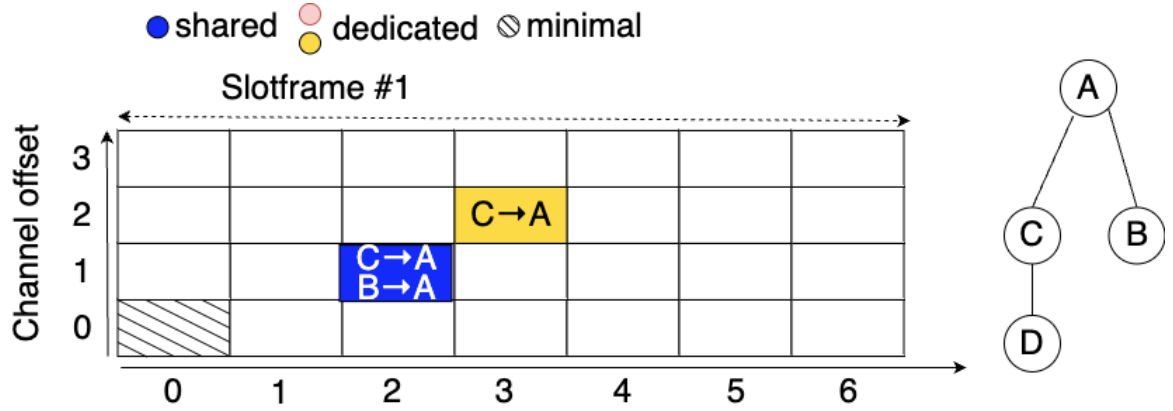
- 2 types of cells for control messages
  - Minimal: EB, routing info, etc..
  - Auto: 6P messages
- Dedicated cells between a node and its routing parent
  - Selected randomly
- Dedicated cells: monitoring cell usage
  - Cell collisions
  - Packet drops due to queue overflows
  - Cells overprovisioning

MSF – Monitoring the Cell Utilization

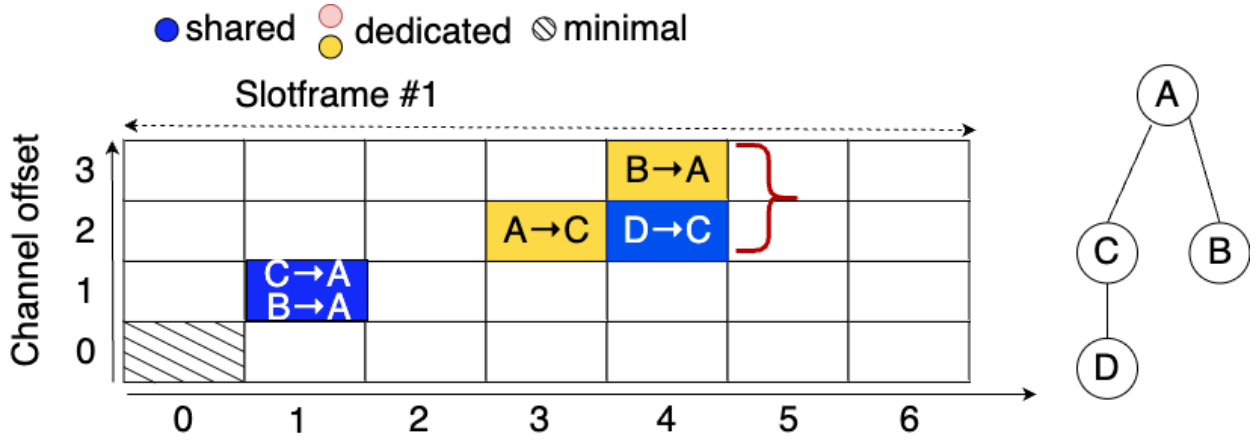
- Monitors cell utilization
  - A cell is added/deleted if utilization threshold is crossed
- Monitors cell performance
  - Packet Delivery Ratio (PDR) is low compared to other cells => relocate



What are the pros/cons of a randomized scheduling?

MSF – Schedule Collisions

- **To avoid cell collisions**
  - Monitor PDR per cell - Section 5.3[2] of RFC 9033
  - If the difference to other cells' PDR > threshold => reallocate cell



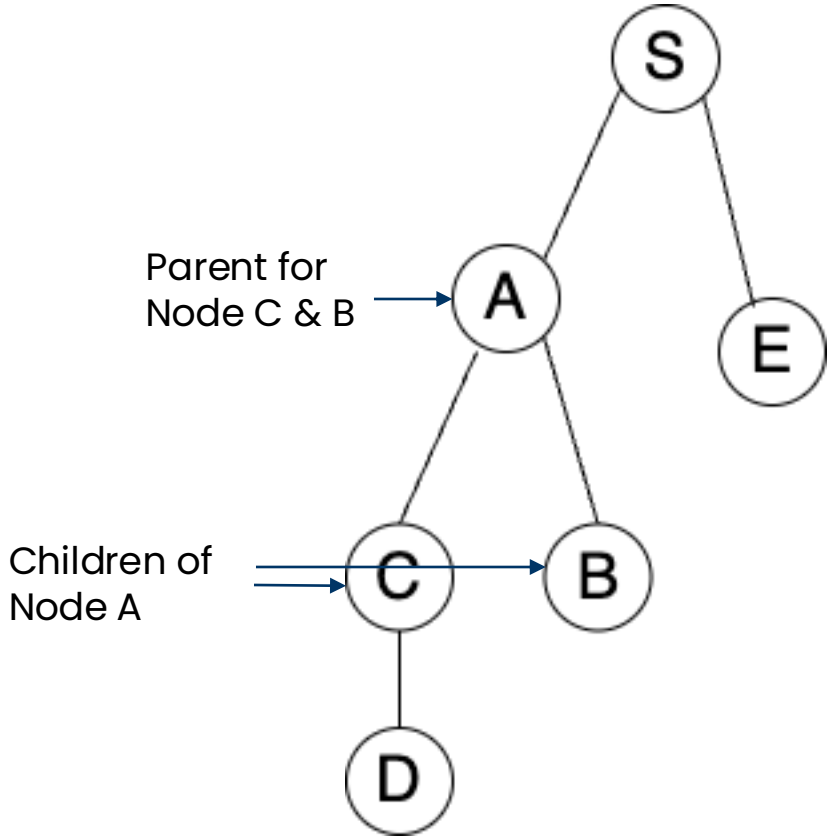
Monitoring Cell Usage and Adapting to Traffic

- Reading break
  - Section 5.1[2] of RFC 9033

- **Adaptation to traffic**
  - Based on cell utilization:

$$\rho = \frac{cells\_used}{cells\_elapsed}$$

  - Add/remove cells if respective upper/lower thresholds are crossed



Distributed/centralized?
How to avoid the ping pong effect?

2. https://datatracker.ietf.org/doc/html/rfc9033#name-adapting-to-traffic

Performance Evaluation of 6TiSCH

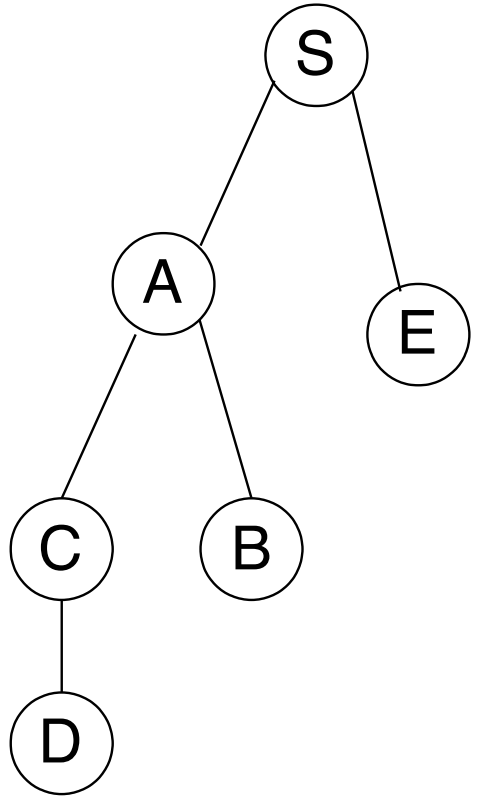
These slides were prepared using the following reference.

[1] Shudrenko, Yevhenii, and Andreas Timm-Giel. "Modeling end-to-end delays in TSCH wireless sensor networks using queuing theory and combinatorics." Computing (2024): 1-25.

End-to-End Delay

Discuss the following:

- **What kind of delays are involved when A sends data to S?**
- **When C sends data to S?**
- **What is definition of end-to-end delay?**



End-to-End Delay contd.

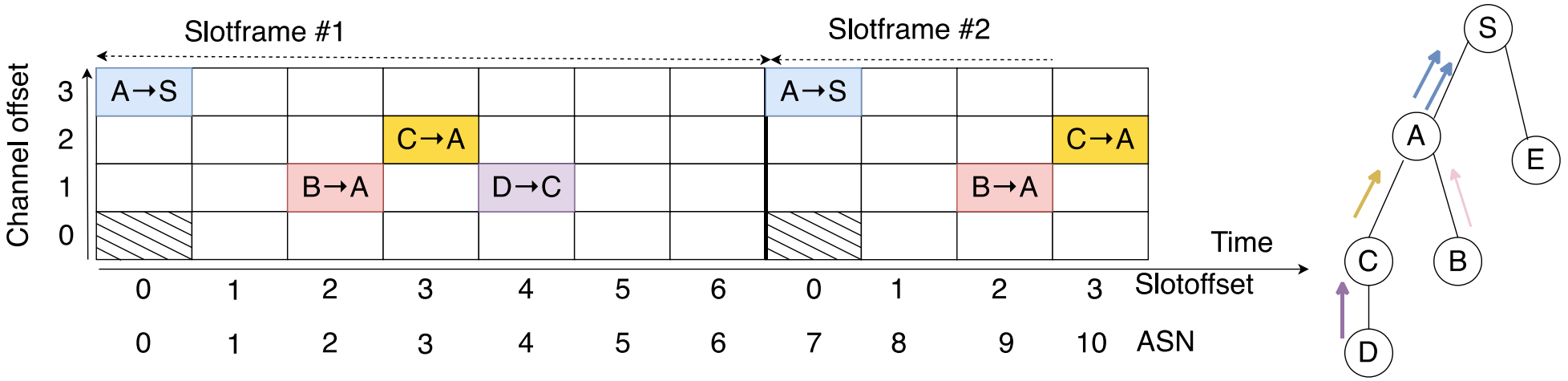
$$D(h) = \sum_{i=1}^{h} D_i = \sum_{i=1}^{h} \left(D_p + D_s + D_t + T_i\right),$$

- D_p is the propagation delay
- D_s is the processing delay
- D_t is the transmission delay
- T_i is the queuing delay (sojourn time)
  - Consists of the service time W and queuing time Q

Any delays to be ignored?

Service Time

- D transmits a packet at ASN = 4.
  - How many slots does this packet wait at C?
  - How many slots does this packet wait at A?



Queuing Time

- Assume the case where B transmits at ASN = 2 and D transmits at ASN = 4