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The 6TiSCH Protocol Stack: 6P and MSF

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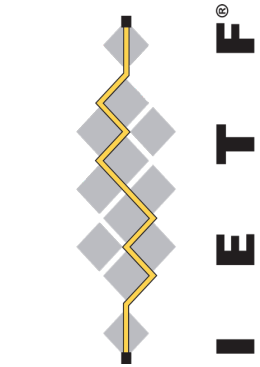
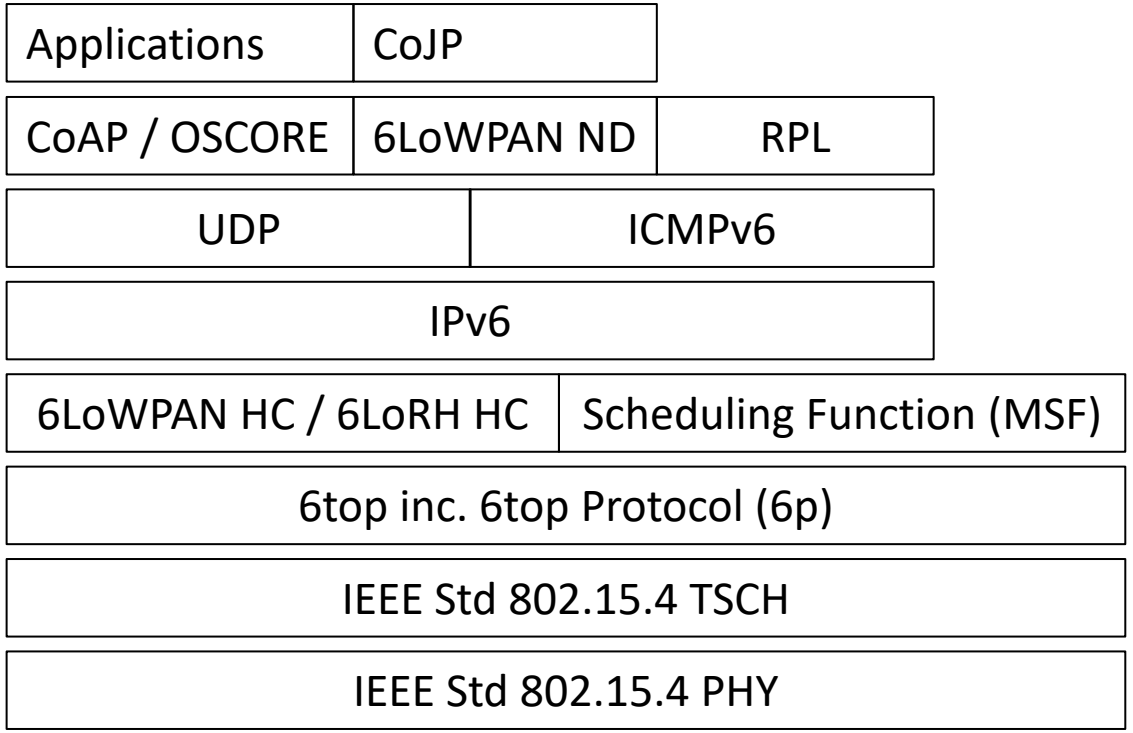
The 6TiSCH Protocol Stack

Overview





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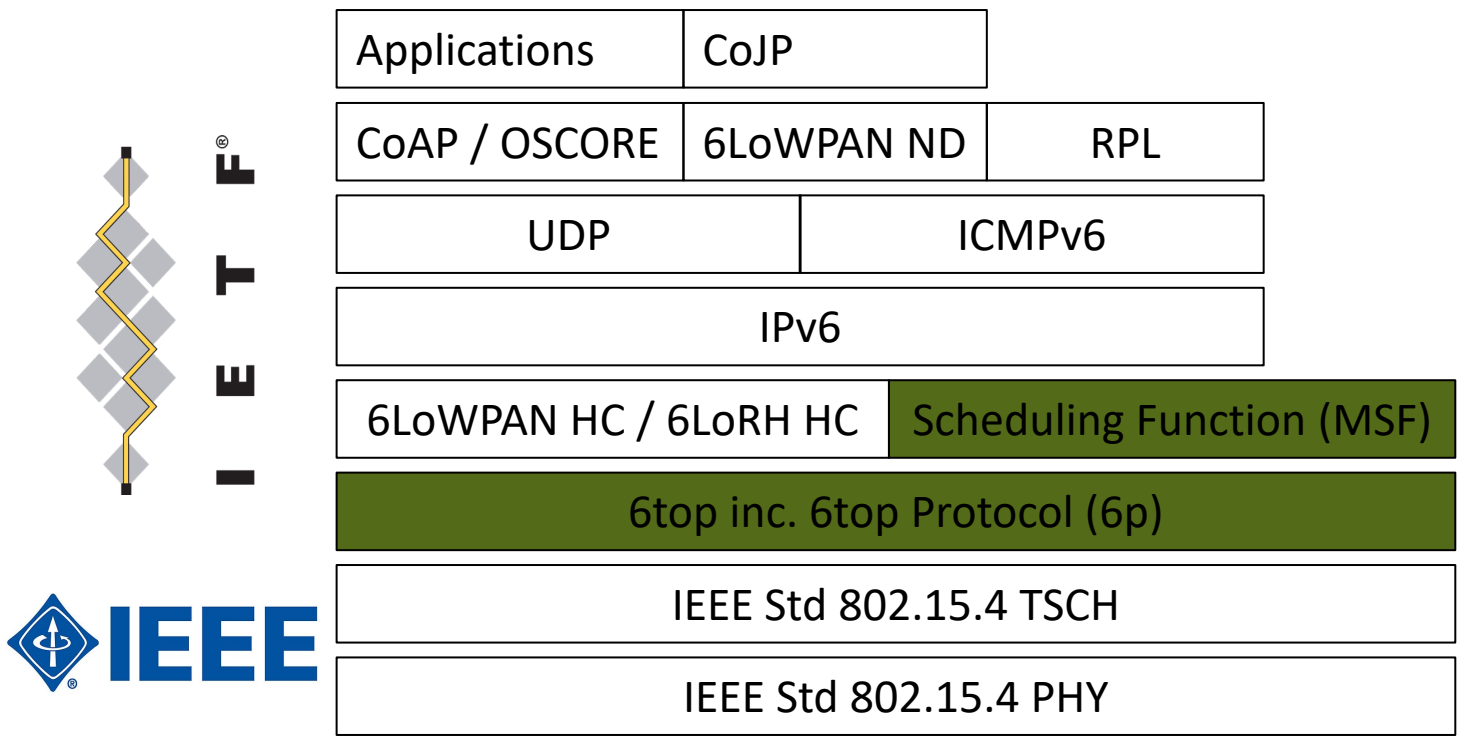
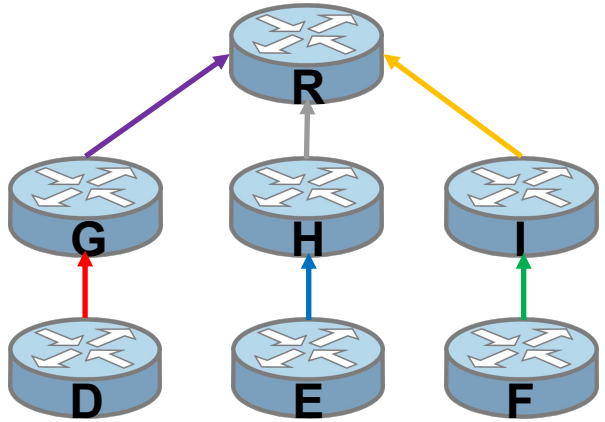
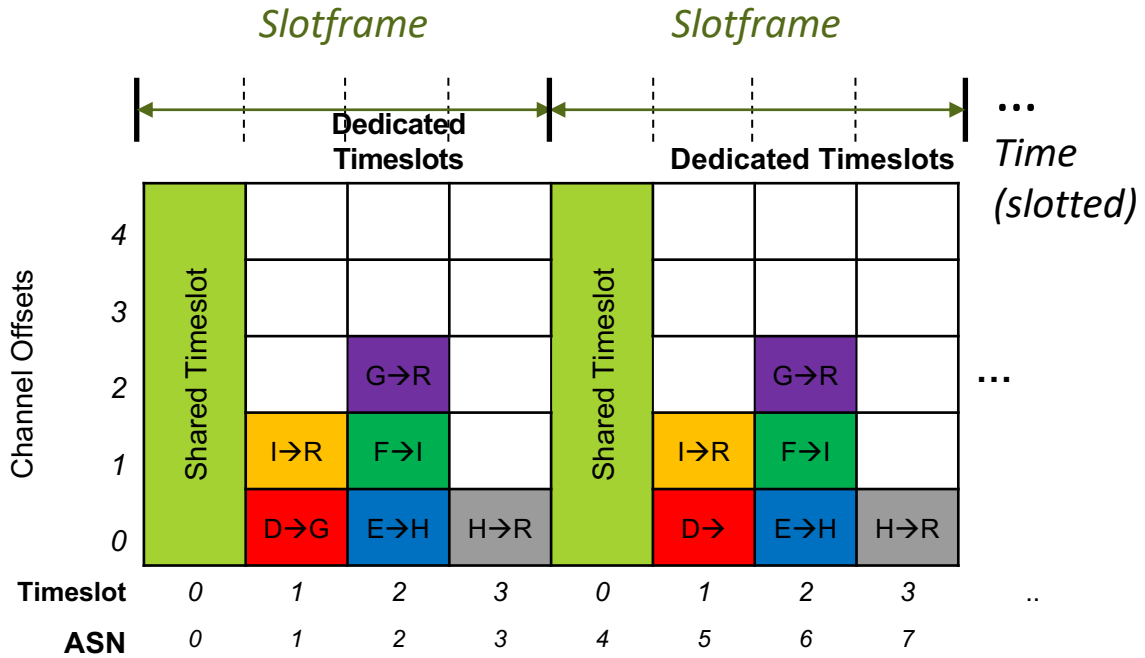


- Scheduling Function: MSF
- 6TiSCH Operation Sublayer: 6P

The 6TiSCH Protocol Stack
Schedule

- All nodes follow a common communication *schedule.*
- A *schedule* is a matrix of *cells*:
  - Consists of a *timeslot* & *channel offset*.
  - *Shared* (contention-based) and *dedicated* (contention-free) *cells*.





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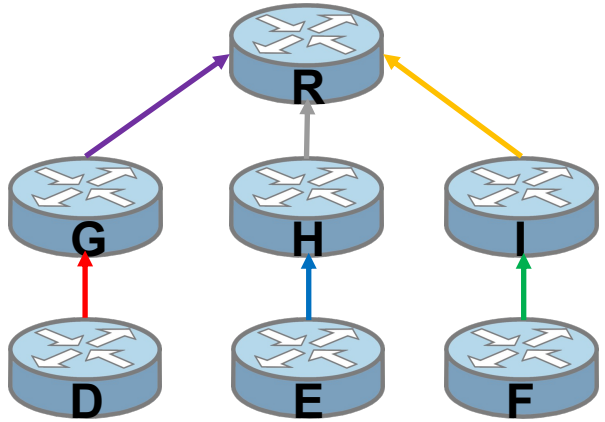
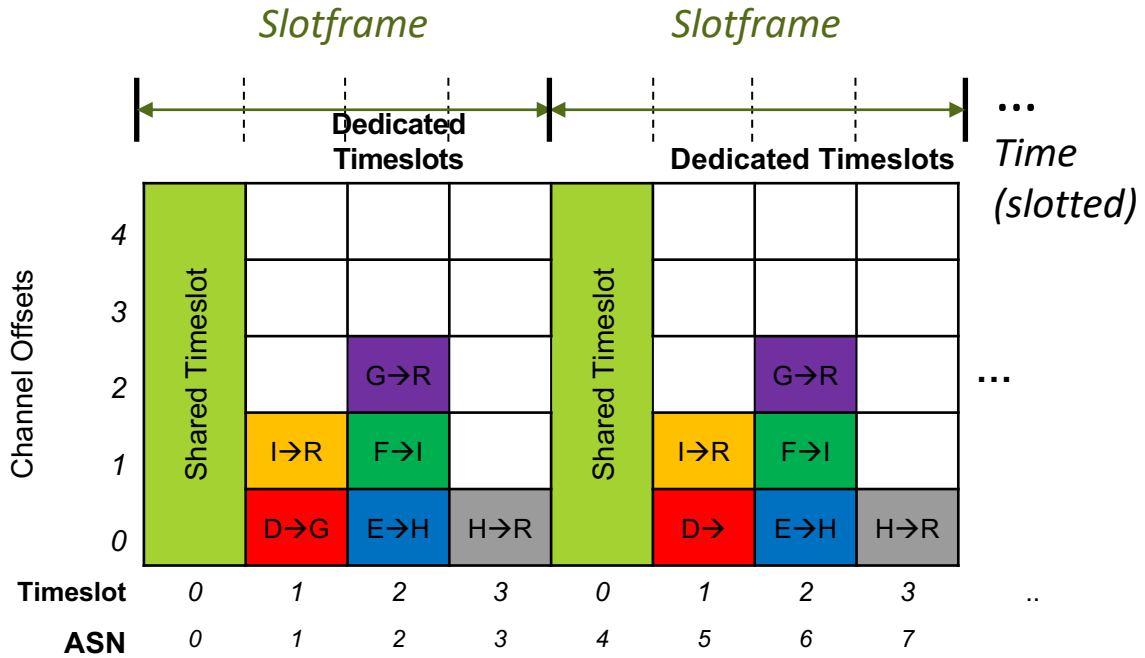
- *Distributed* (6P & MSF) or *centralized* (PCE) approaches.





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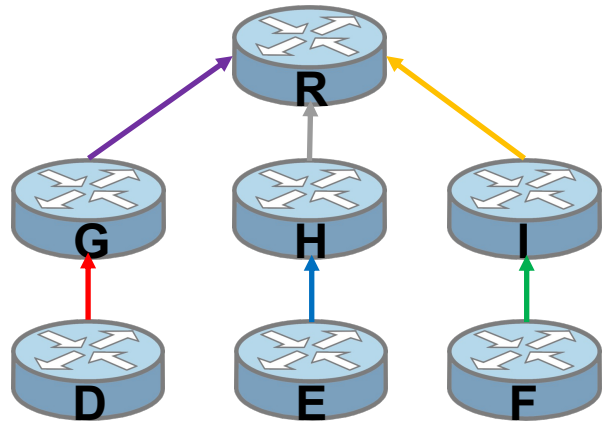
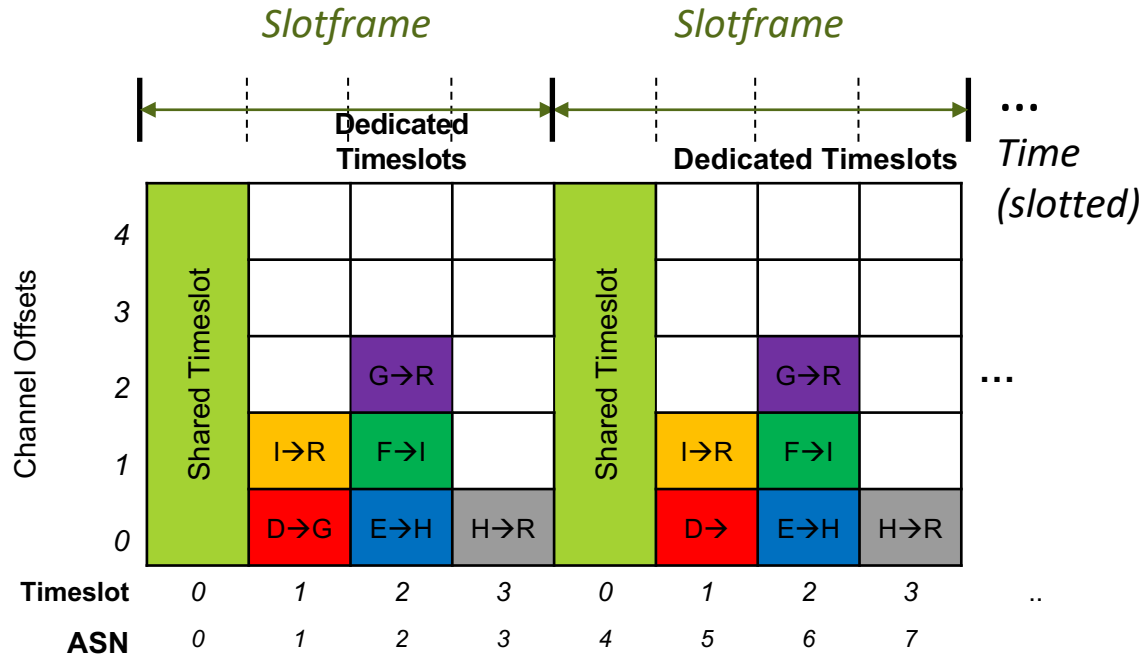
- A schedule provides a tunable trade-off:
  - Network capacity.
  - Bounded latency.
  - Network reliability.
  - Energy consumption.





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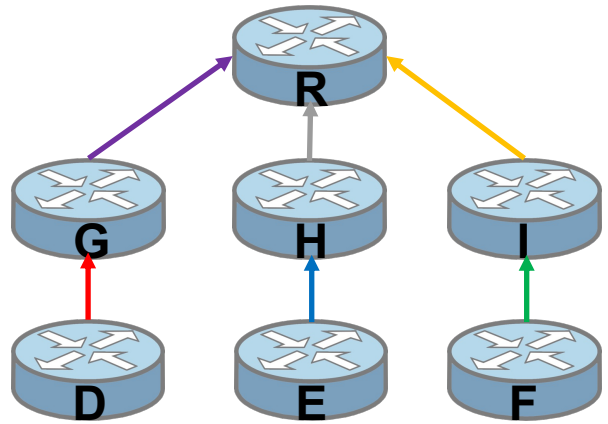
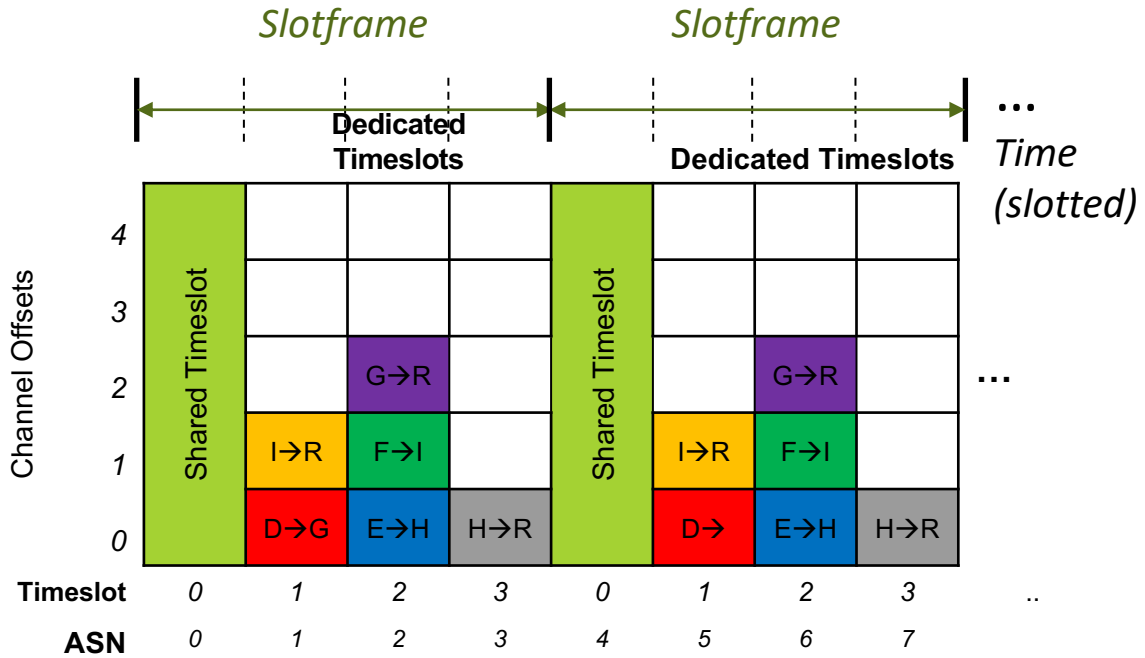
- A schedule provides a tunable trade-off:
  - Network capacity.
  - Bounded latency.
  - Network reliability.
  - Energy consumption.
- A typical industrial *trade-off* scenario:

to target *network reliability* and *bounded latency*
at the cost of *network capacity* and *energy*.





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The 6TiSCH Minimal Scheduling Function (MSF): RFC 9033

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6TiSCH MSF (RFC 9033)

Overview

- Bootstrap process for a node to join the network.
- Reactive scheduling function:
  - Adapt to traffic changes.
  - Adapt to routing changes.
  - Handle possible schedule collisions.

6TiSCH MSF (RFC 9033)

Traffic Adaptivity: General Principle

- Estimate the number of resources actually used for transmission.
- Per neighbour and for TX and RX transmission.
- Decision to allocate/deallocate:
  - usage ≥ 75% ⇒ allocate.
  - usage ≤ 25% ⇒ deallocate.

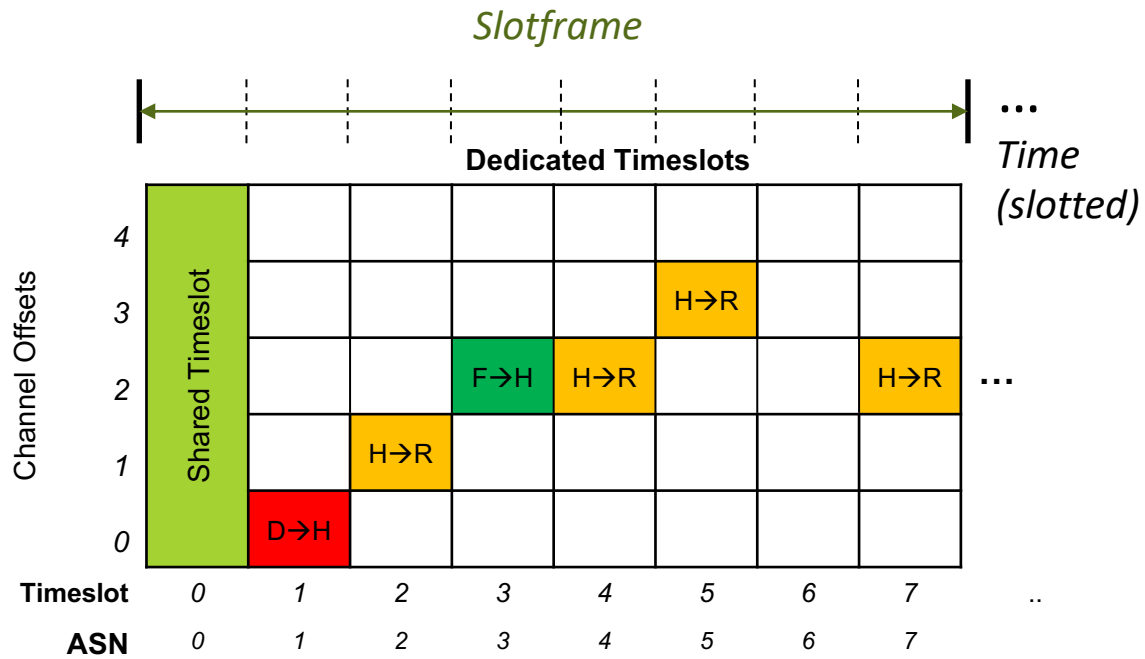
6TiSCH MSF (RFC 9033)

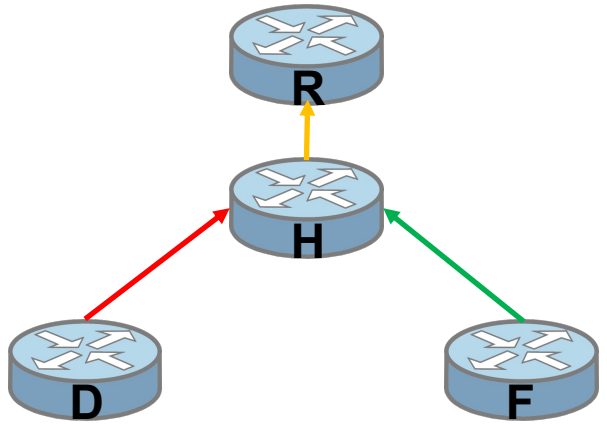
Traffic Adaptivity: Estimation of resources usage (per neighbour)

- Estimate the number of resources actually used for transmission.
- Per neighbour and for TX and RX transmission.
- Decision to allocate/deallocate:
  - usage ≥ 75% ⇒ allocate.
  - usage ≤ 25% ⇒ deallocate.

- NumCellsPassed: **Elapsed number of negotiated cells**.
- NumCellsUsed: **Number of cells actually used for transmission**.
- NumCellsPassed **=** MAX_NUM_CELLS ⇒
  - $\text{usage} \leftarrow \frac{\text{NumCellsUsed}}{\text{NumCellsPassed}}$
  - **Reset** NumCellsPassed **and** NumCellsUsed **to 0**
- **By default** MAX_NUM_CELLS = **100**

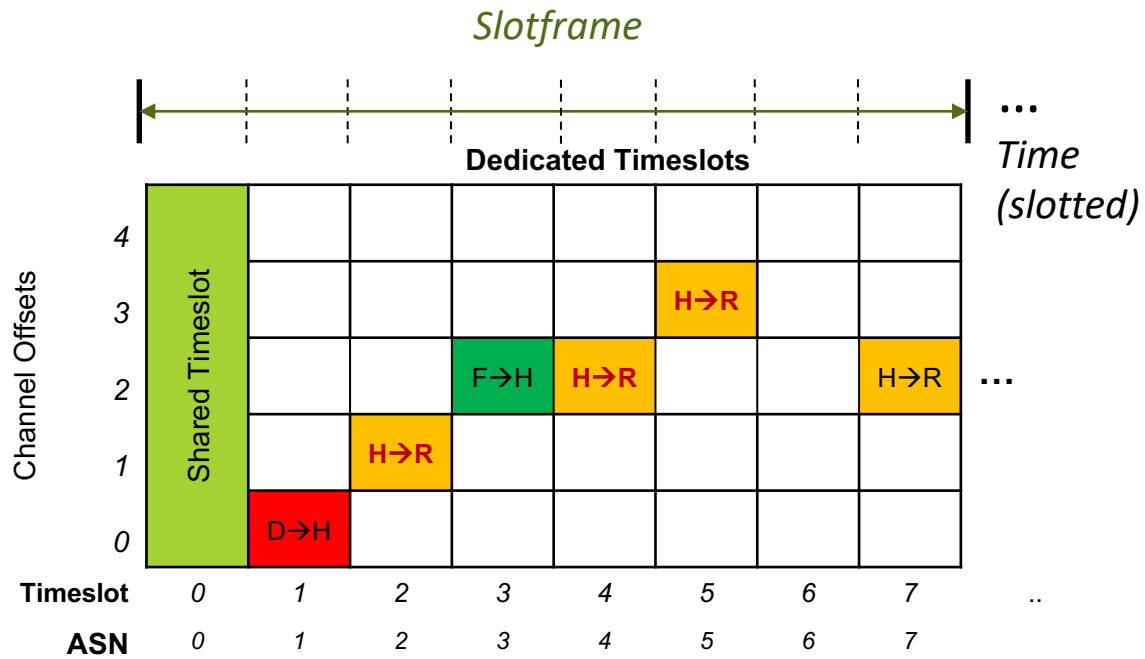
MSF
Traffic Adaptation

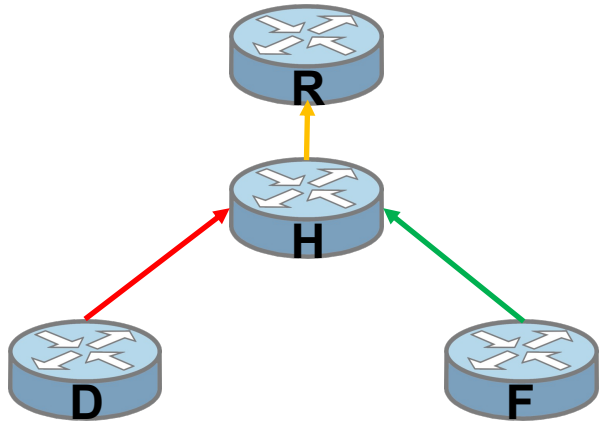




The schedule of the node H.

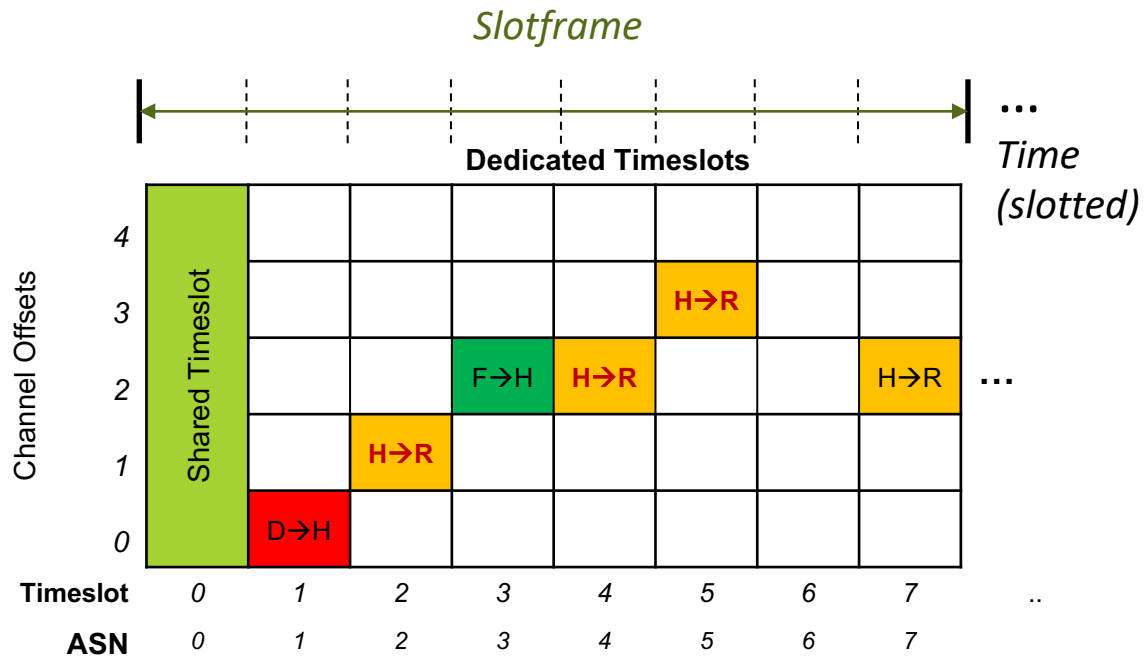
MSF
Traffic Adaptation

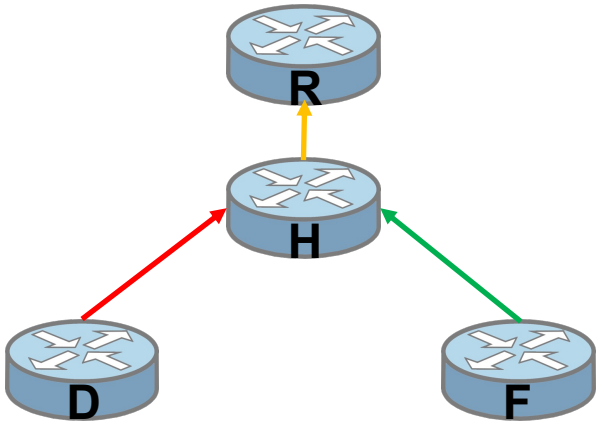




Note: 3 cells are employed out of 4 for **H→R** link.

MSF
Traffic Adaptation

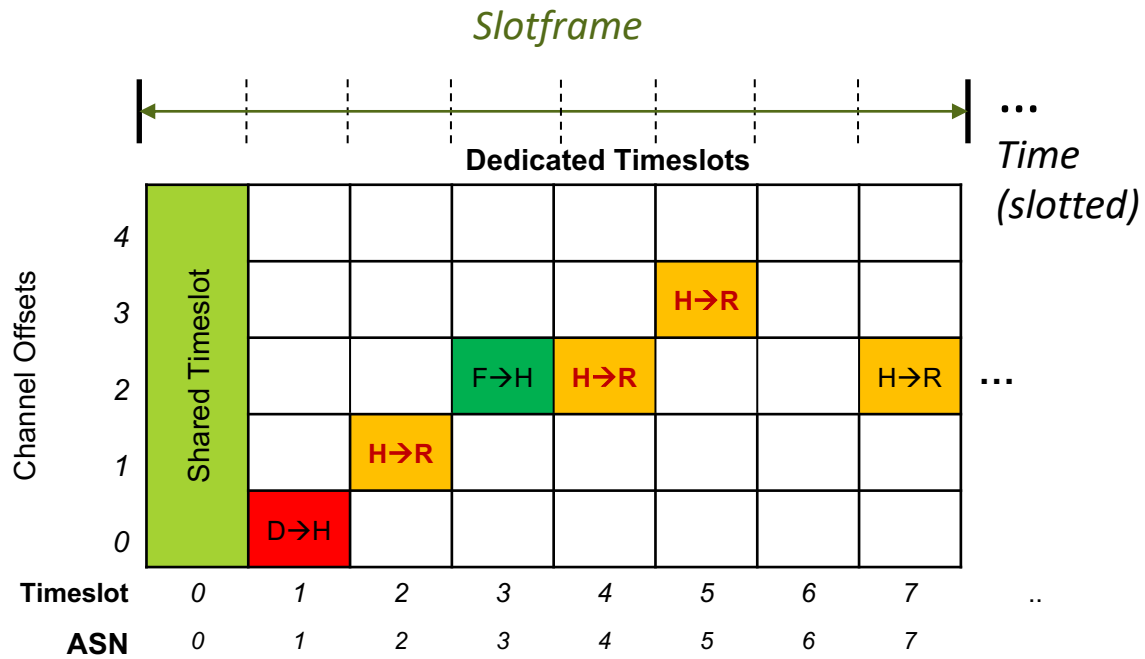


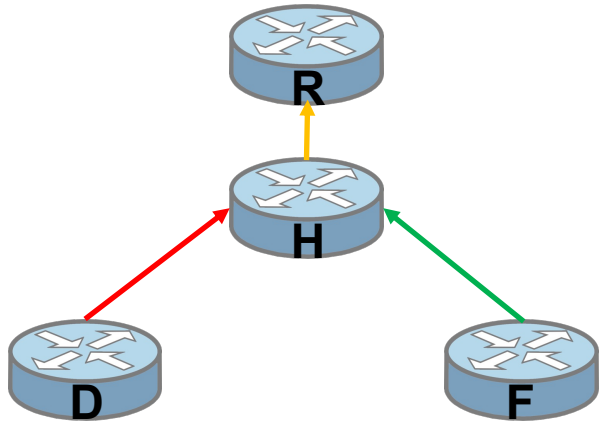


Note: 3 cells are employed out of 4 for **H→R** link.

Employed cells from node H to R: $^{3}/_{4}$ = 75%

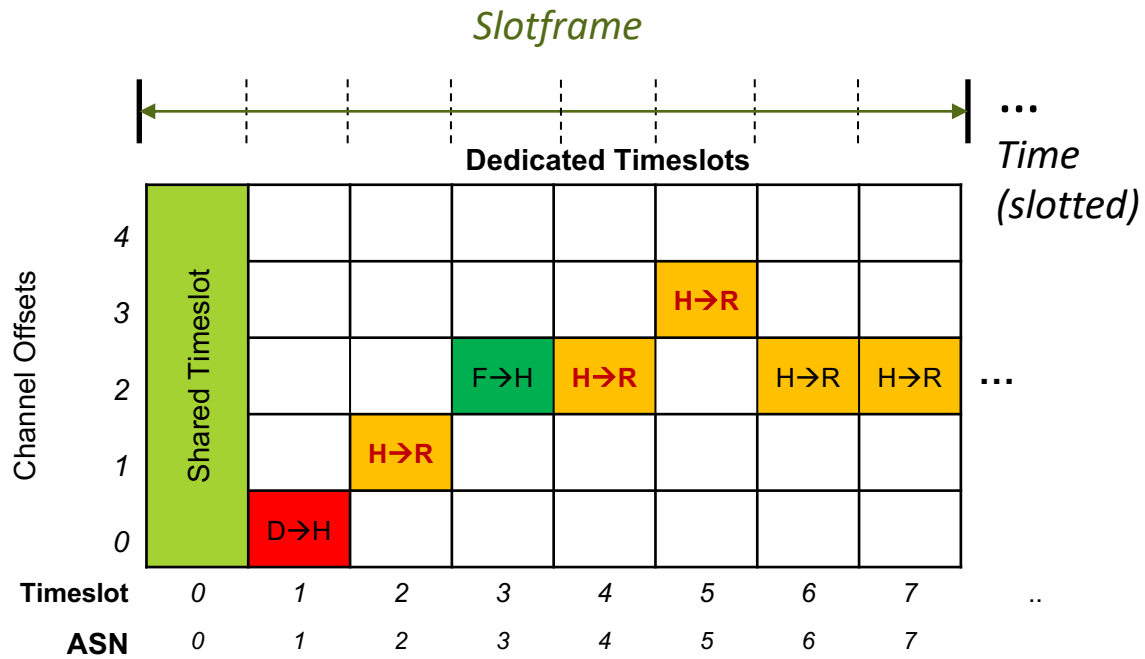
MSF
Traffic Adaptation

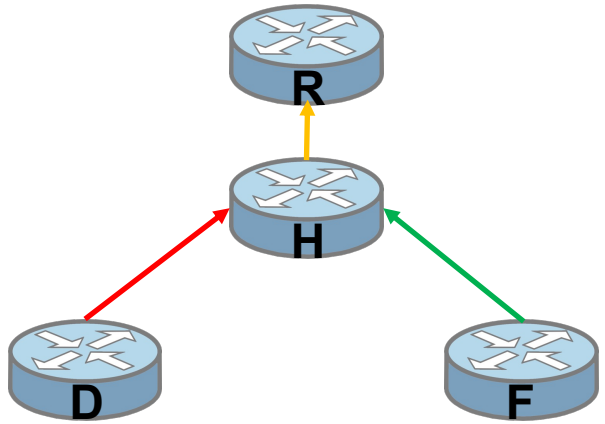




75% ≥ 75% (MSF high Threshold) → Add a new cell toward the node B.

MSF
Traffic Adaptation

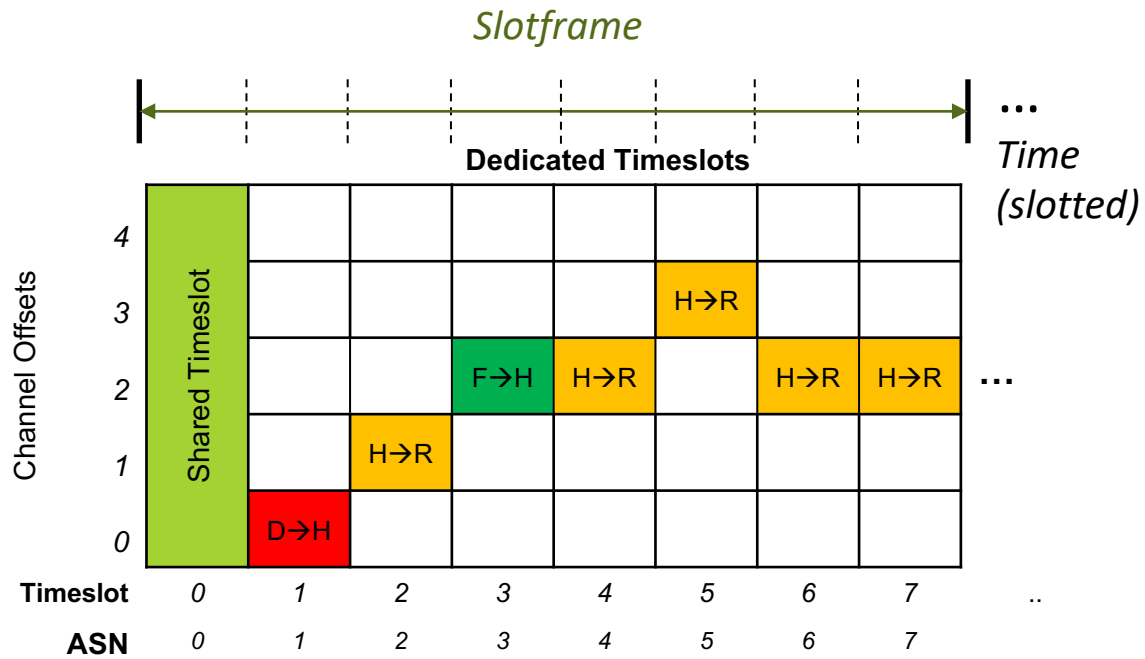


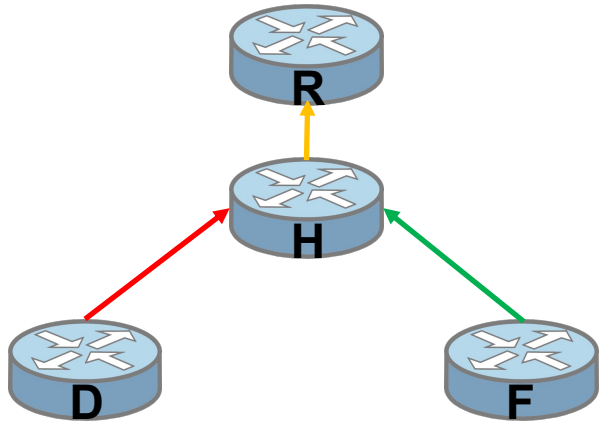


Note: a new cell is added for the link **H→R**.

75% ≥ 75% (MSF high Threshold) →
Add a new cell toward the node B.

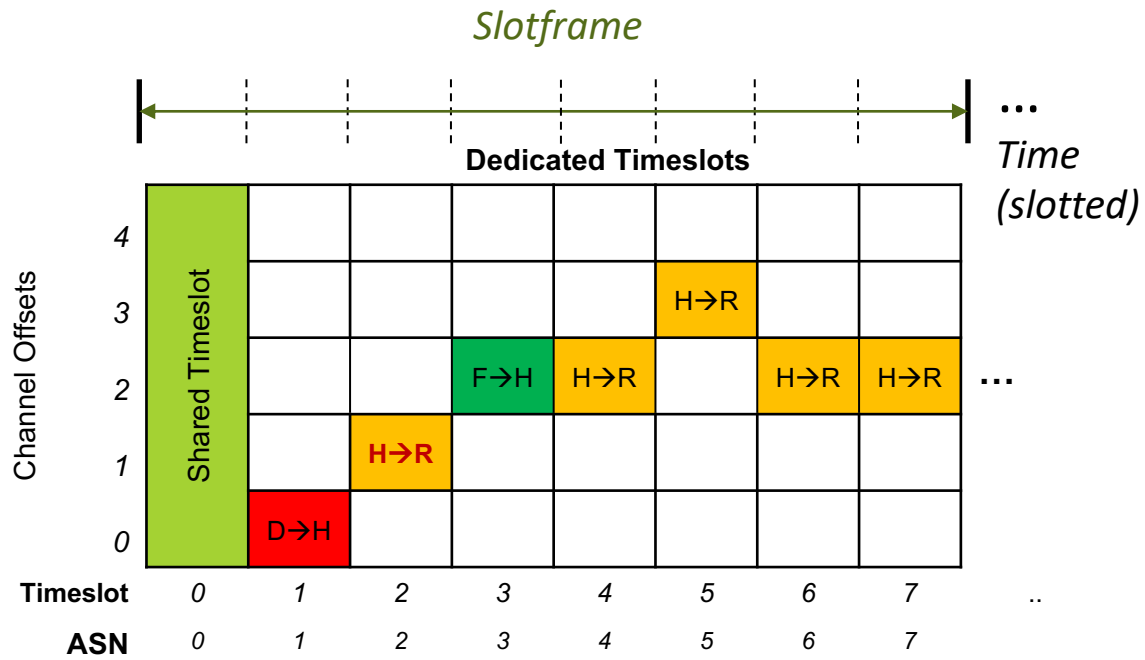
MSF
Traffic Adaptation

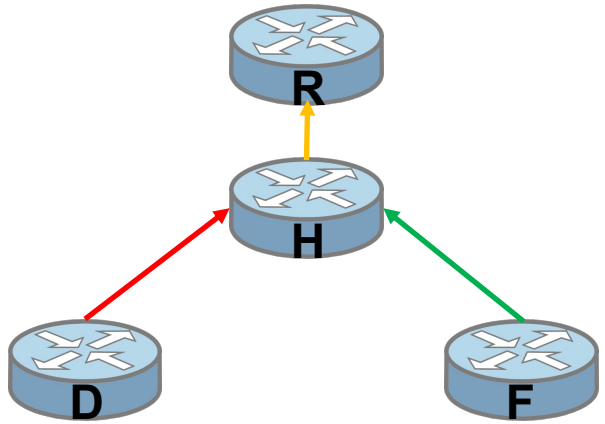




Node H has 5 transmission cells toward B.

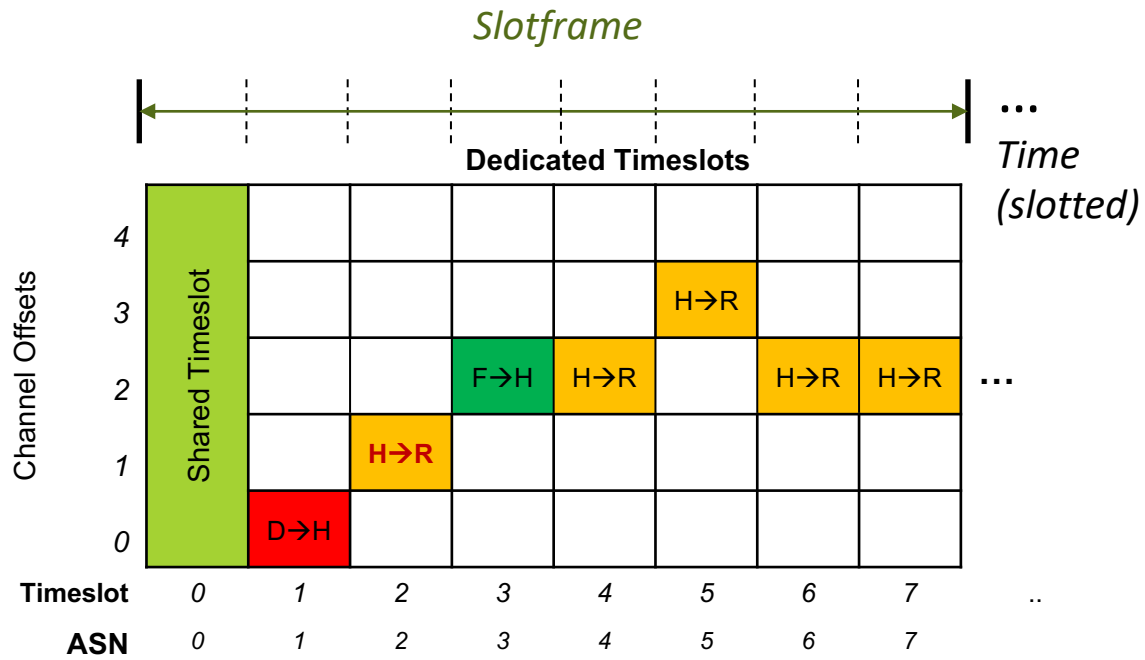
MSF
Traffic Adaptation

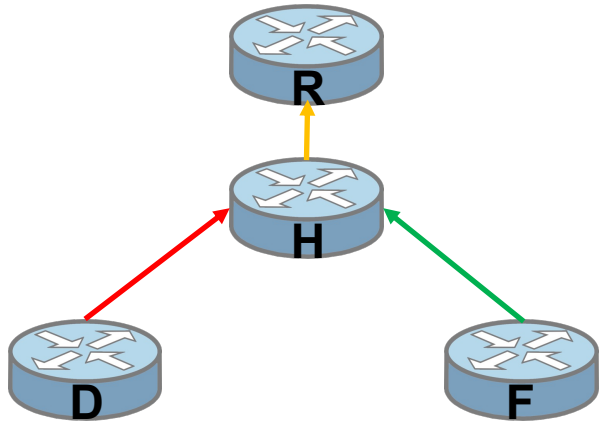




Note: now, only 1 cell is employed out of 5 for **H→R** link.

MSF
Traffic Adaptation

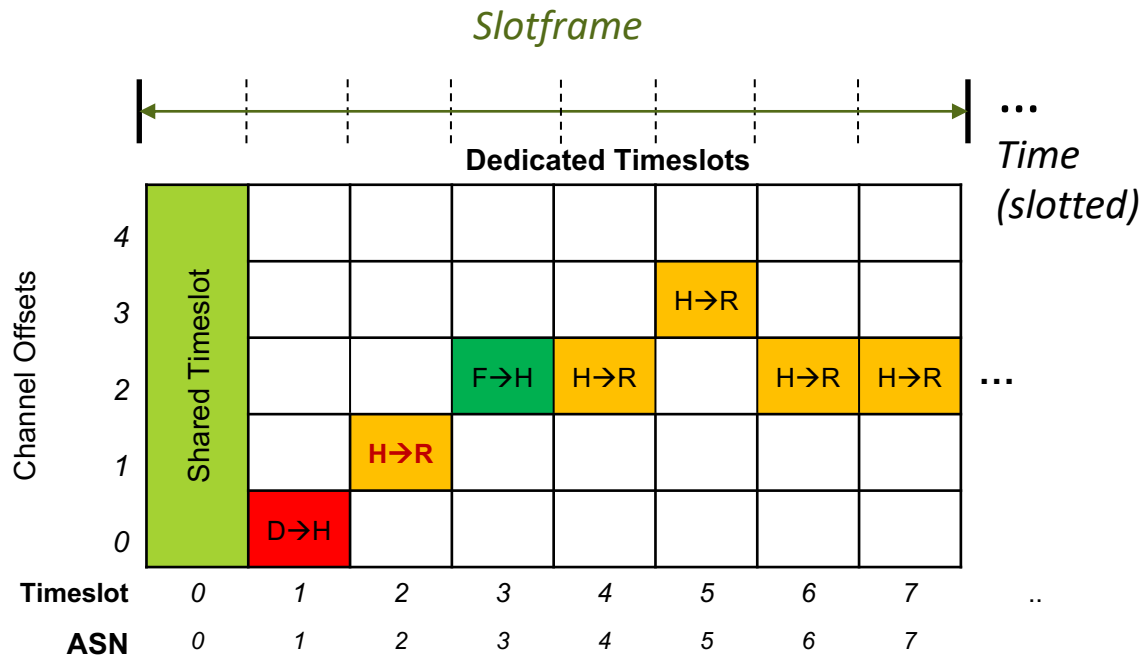


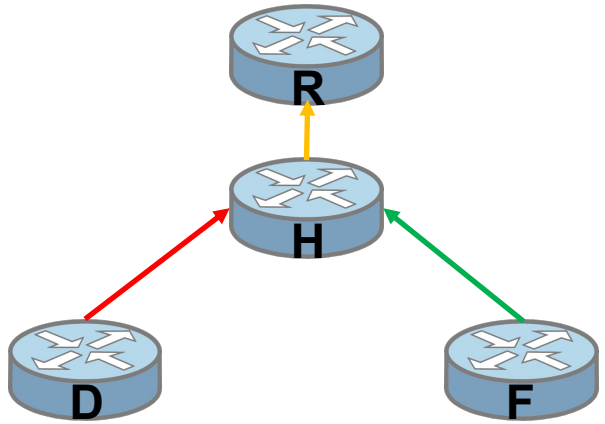


Note: now, only 1 cell is employed out of 5 for **H→R** link.

Employed cells from node H to R: $^1/_5$ = 20%

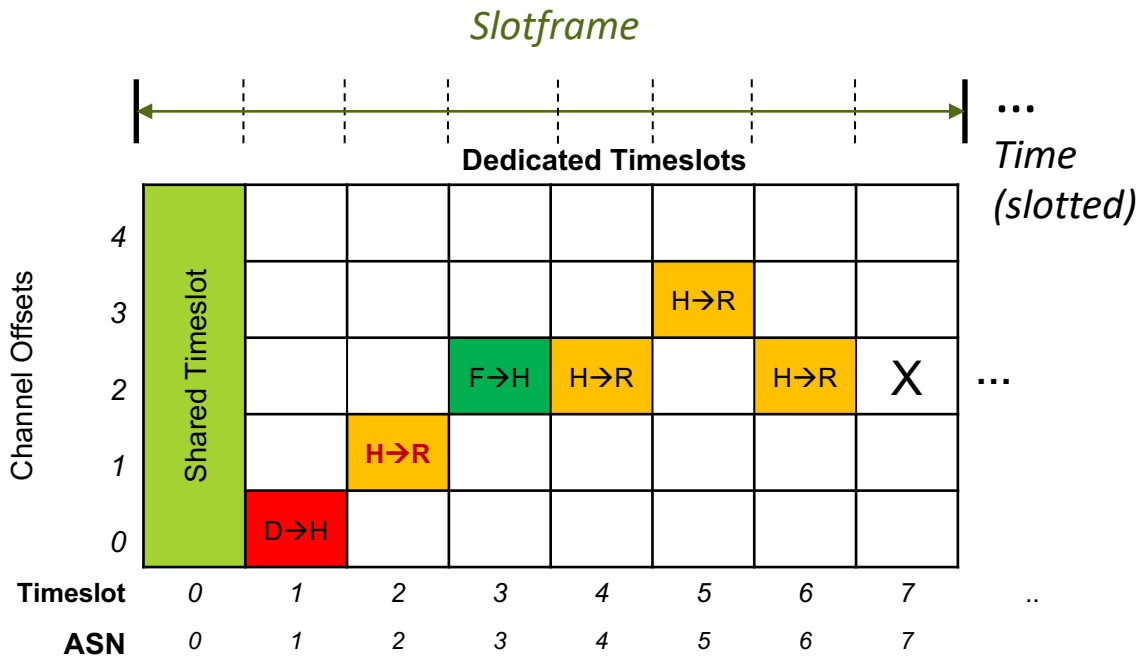
MSF
Traffic Adaptation

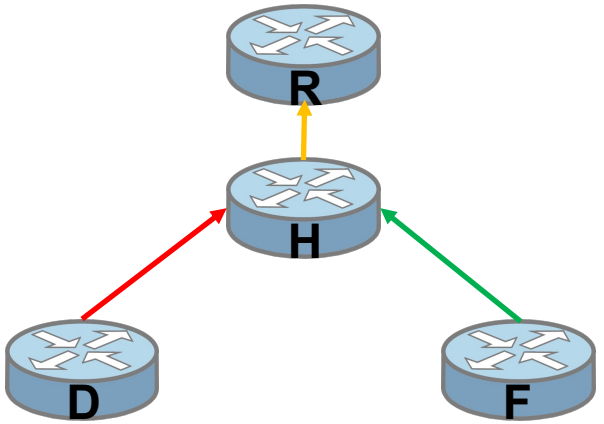




20% ≤ 25% **(MSF low threshold) ⇒**
Remove cell to B

MSF
Traffic Adaptation





20% ≤ 25% **(MSF low threshold) ⇒ Remove cell to B**

The 6TiSCH Operation Sublayer (6top) Protocol (6P): RFC 8480

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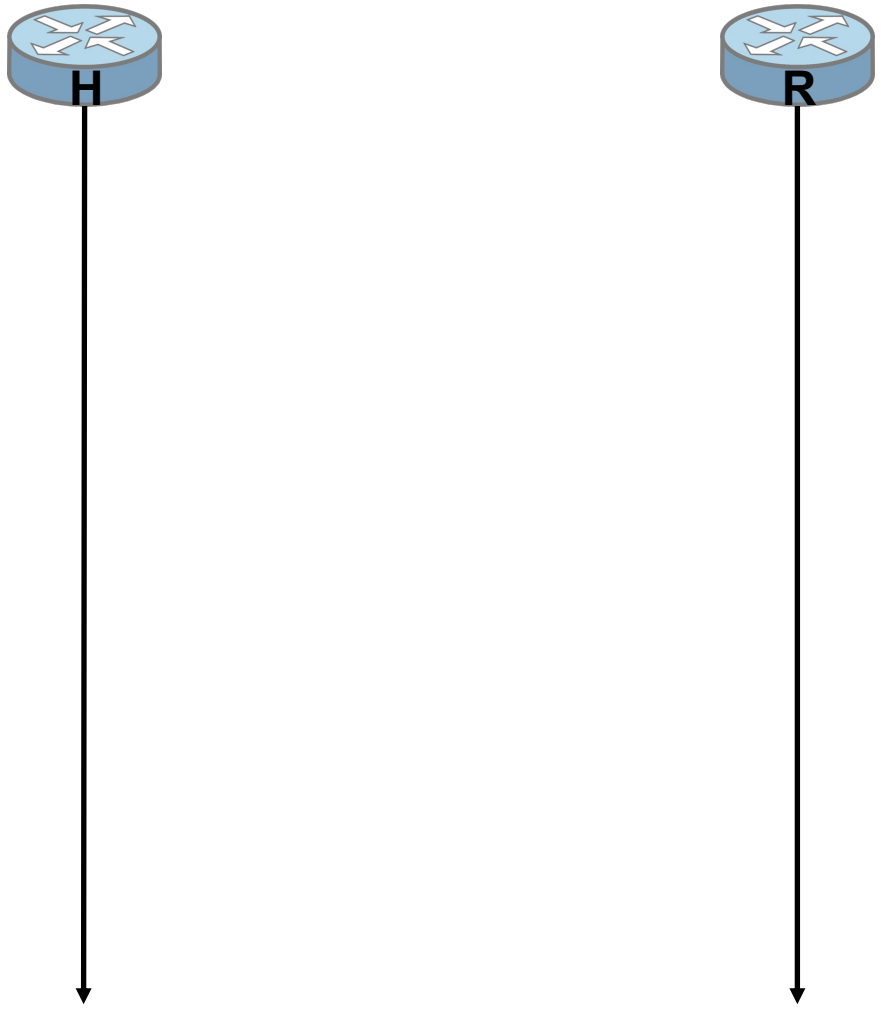
6P (RFC 8480)
Overview

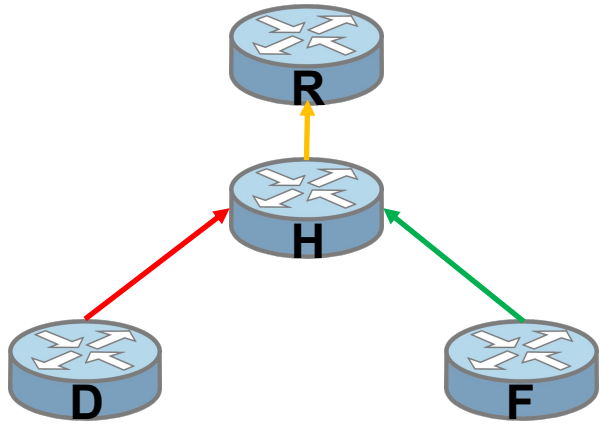
- 6TiSCH Operation Sublayer (6top) and Protocol (6P):
  - Means to add, delete, move cells in a neighbour schedule.
- A Scheduling Function → MSF:
  - Decides when and how many cells to add or delete.

6P only manipulates cells → The scheduling function decides when and how many!

6P (RFC 8480)

Example of a 2-step 6P ADD transaction

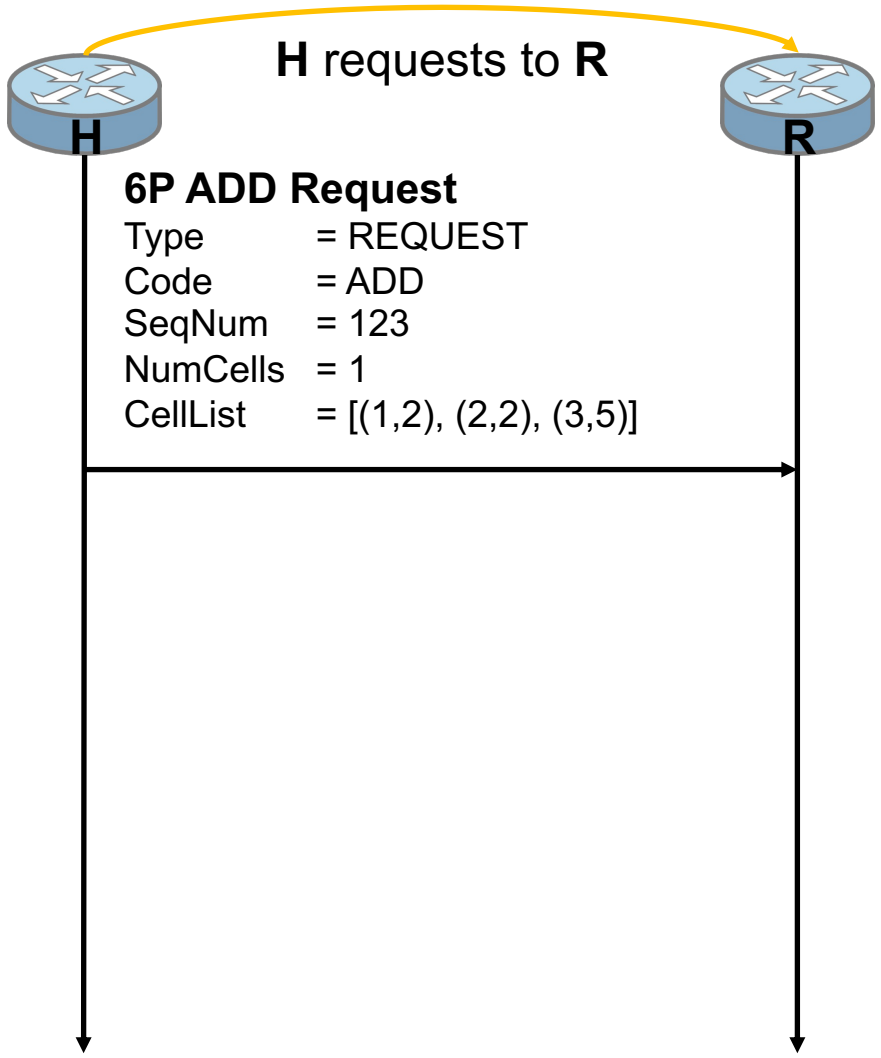


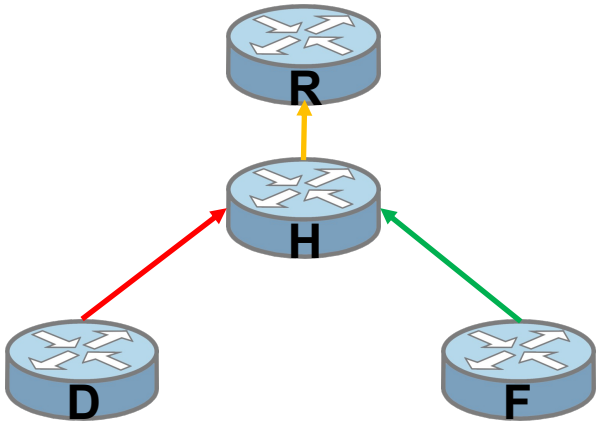


The SF running on node H determines that one extra cell needs to be scheduled to R.

6P (RFC 8480)

Example of a 2-step 6P ADD transaction





The SF running on node H selects candidate cells for node R to choose from.

6P (RFC 8480)

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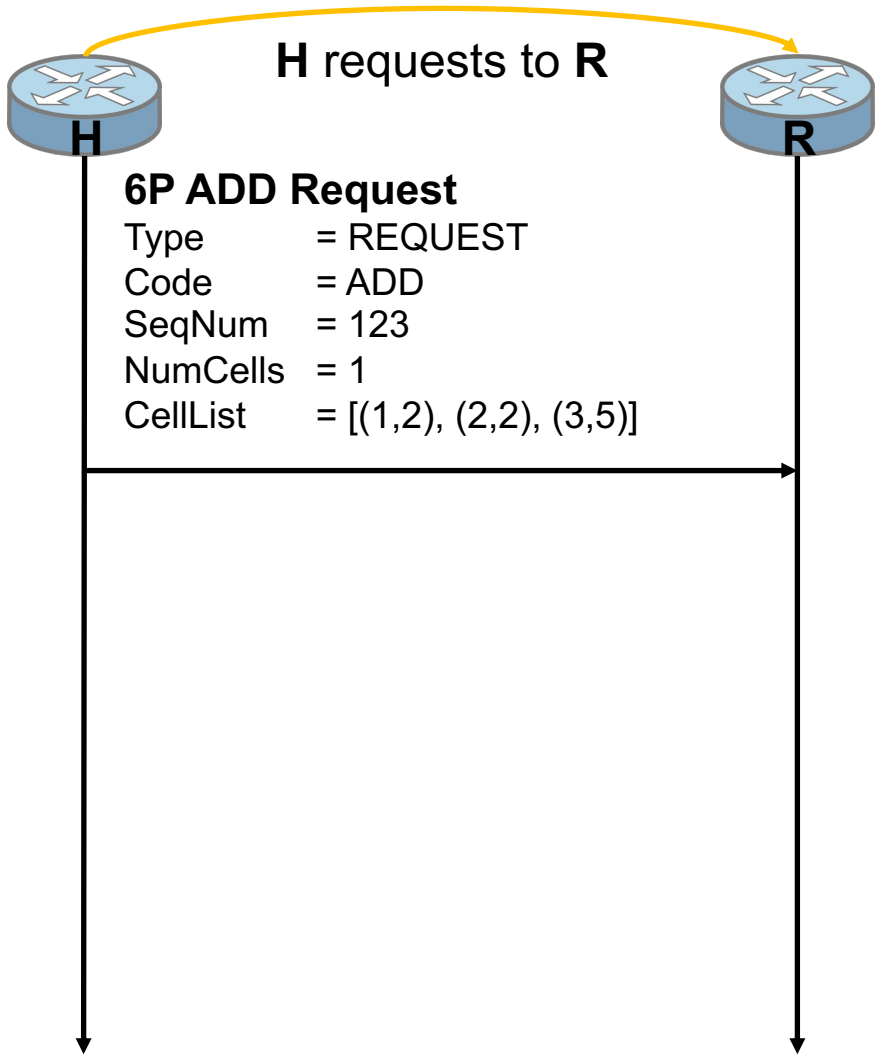
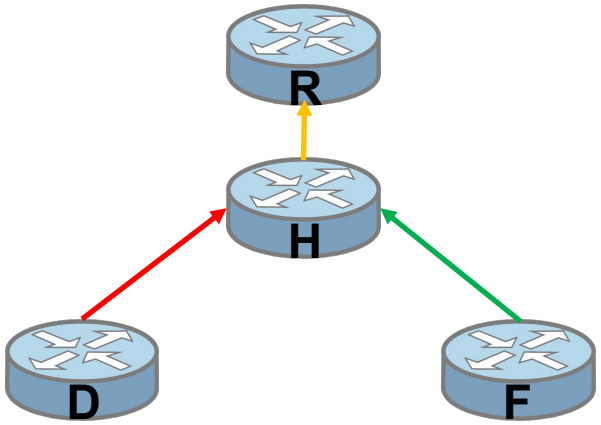
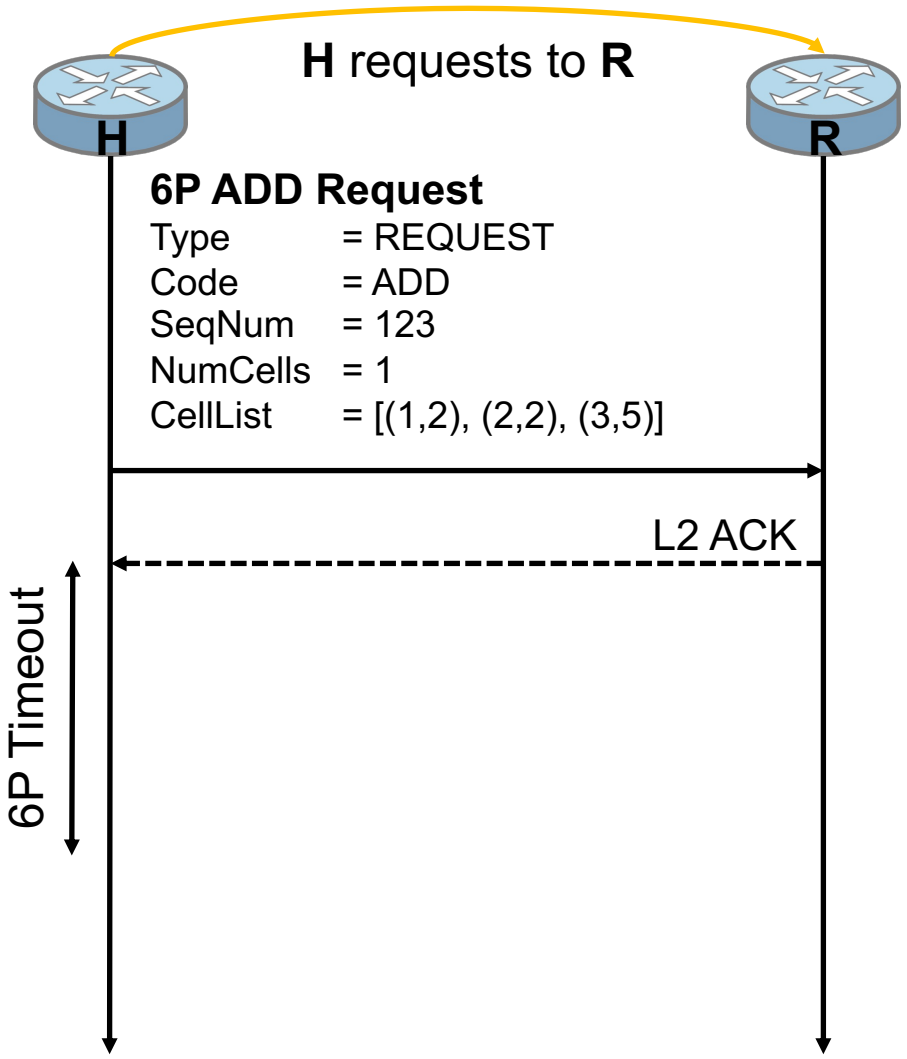


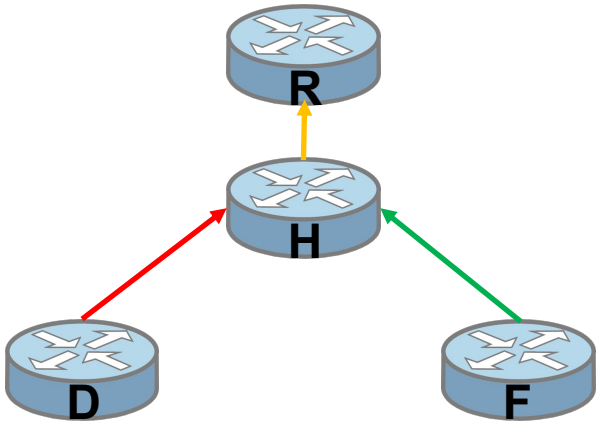


Each cell in the CellList is a (timeslotOffset, channelOffset) tuple.

6P (RFC 8480)

Example of a 2-step 6P ADD transaction

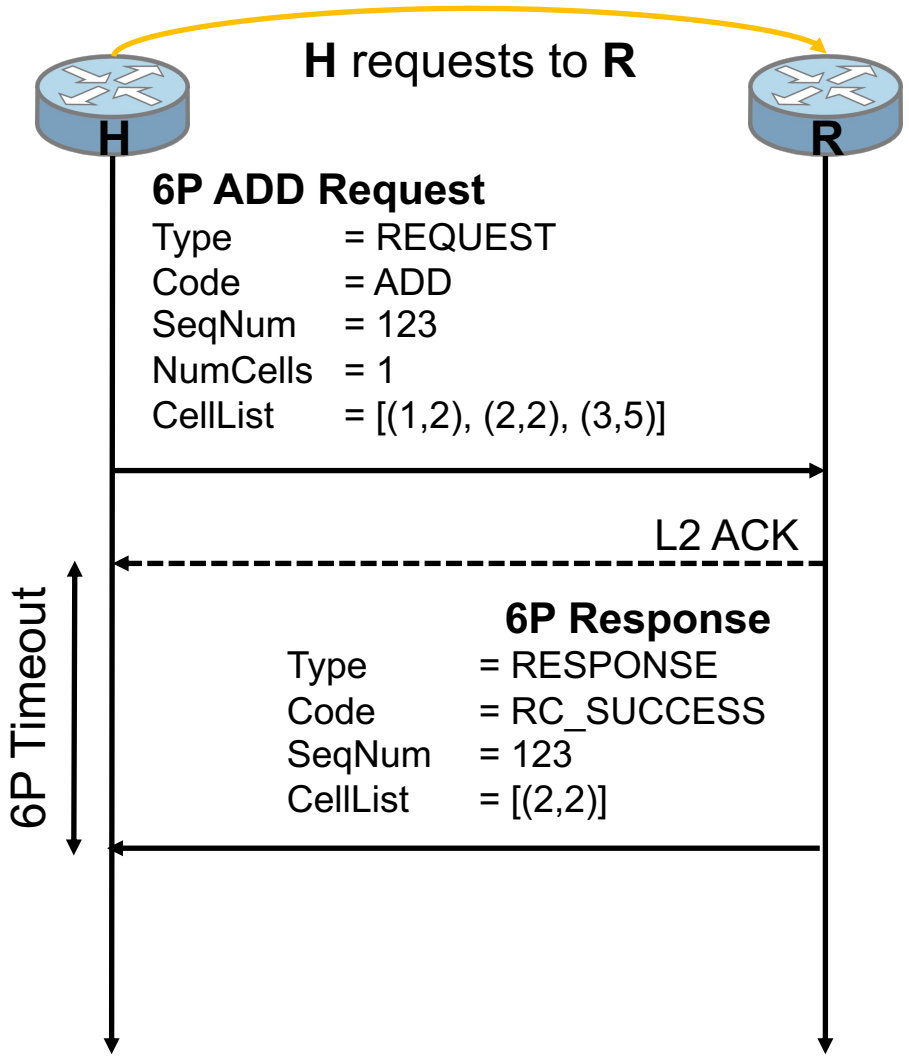


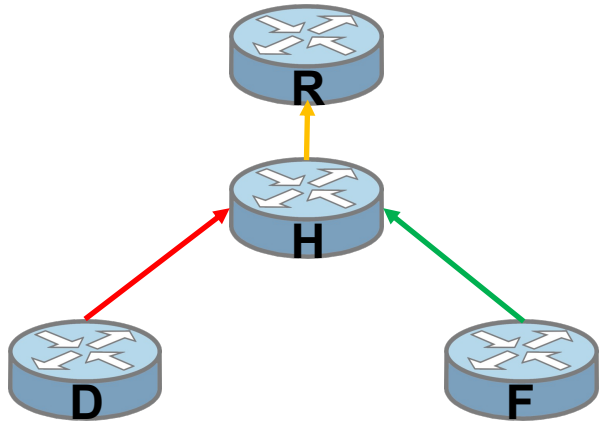


After having successfully received an L2 ACK, node H starts a 6P Timeout to abort the 6P Transaction in the event that no response is received from node R.

6P (RFC 8480)

Example of a 2-step 6P ADD transaction

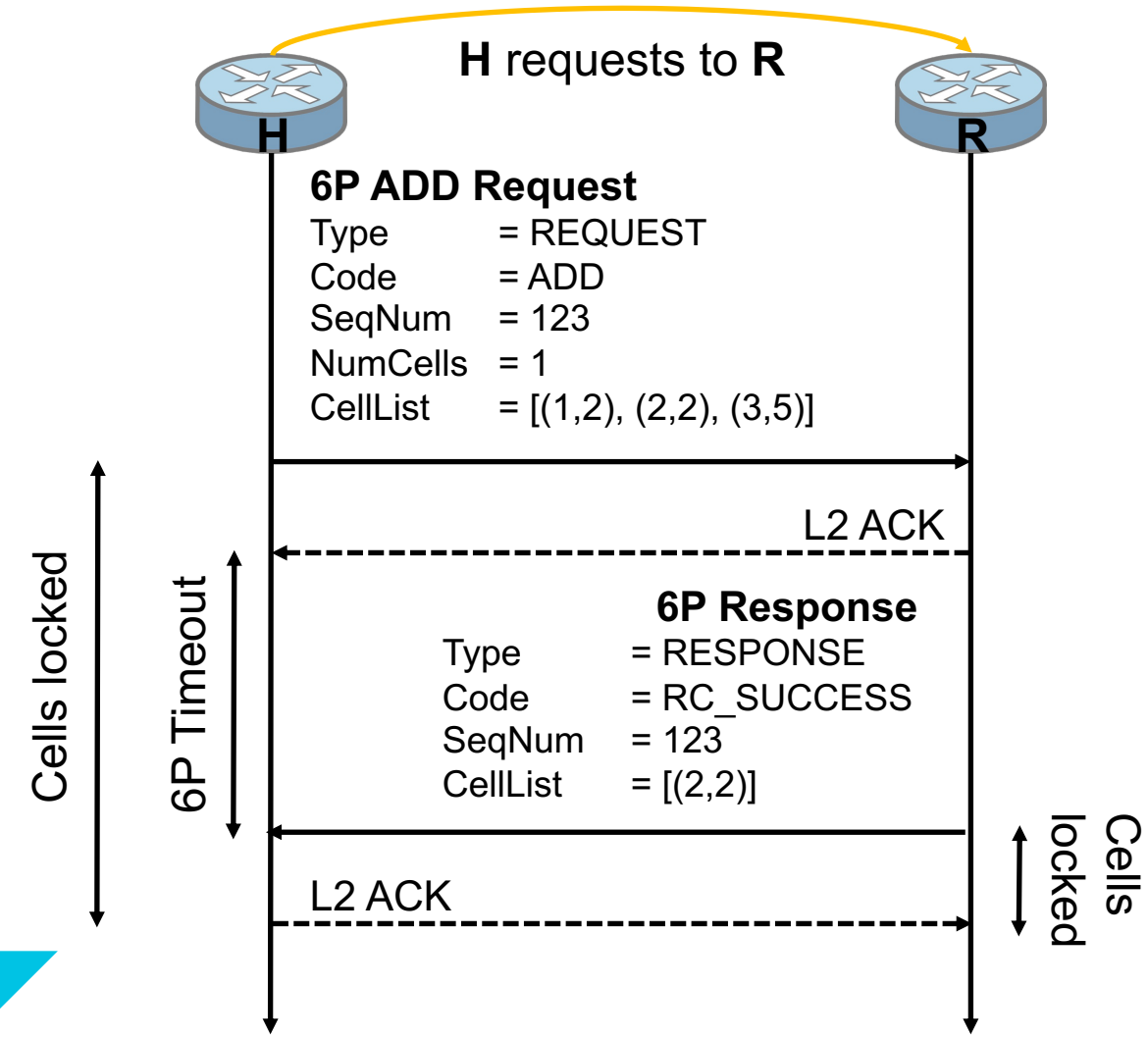


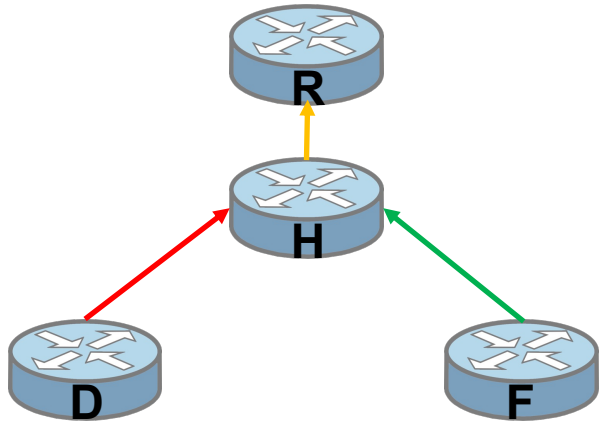


The SF running on node R selects one out of the three cells from the CellList of the 6P ADD Request.

6P (RFC 8480)

Example of a 2-step 6P ADD transaction

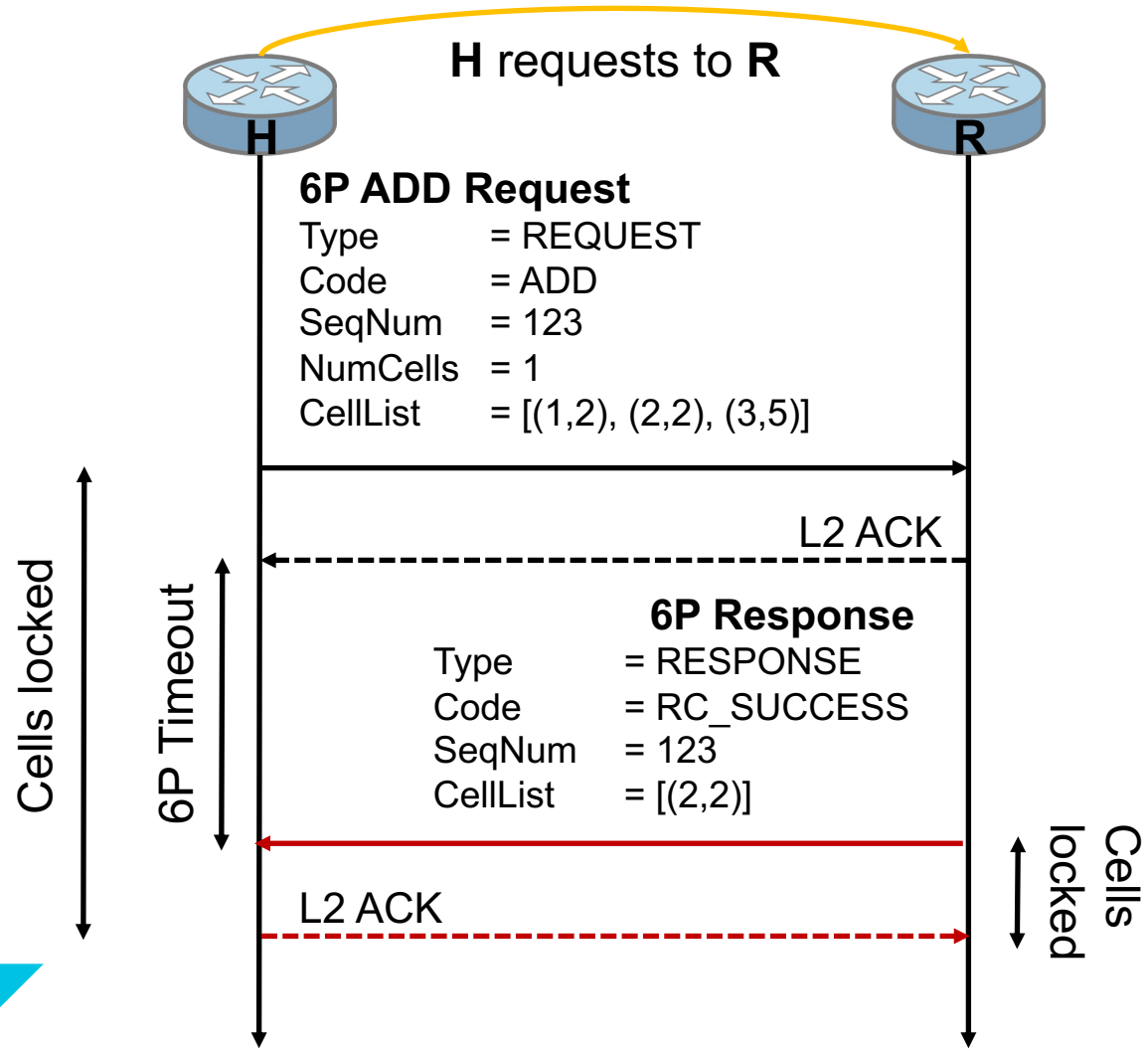


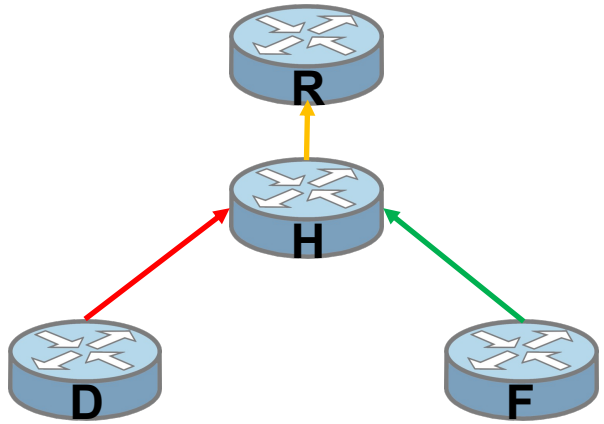


Upon completion of this 6P Transaction, one cell from node H to node R have been added to the TSCH schedule of both nodes H and R.

6P (RFC 8480)

Example of a 2-step 6P ADD transaction





An inconsistency in the schedule can happen if the 6P Timeout expires when the 6P Response is in the air, or if the last link-layer ACK for the 6P Response is lost!

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