

Orchestra: Robust Mesh Networks Through Autonomously Scheduled TSCH

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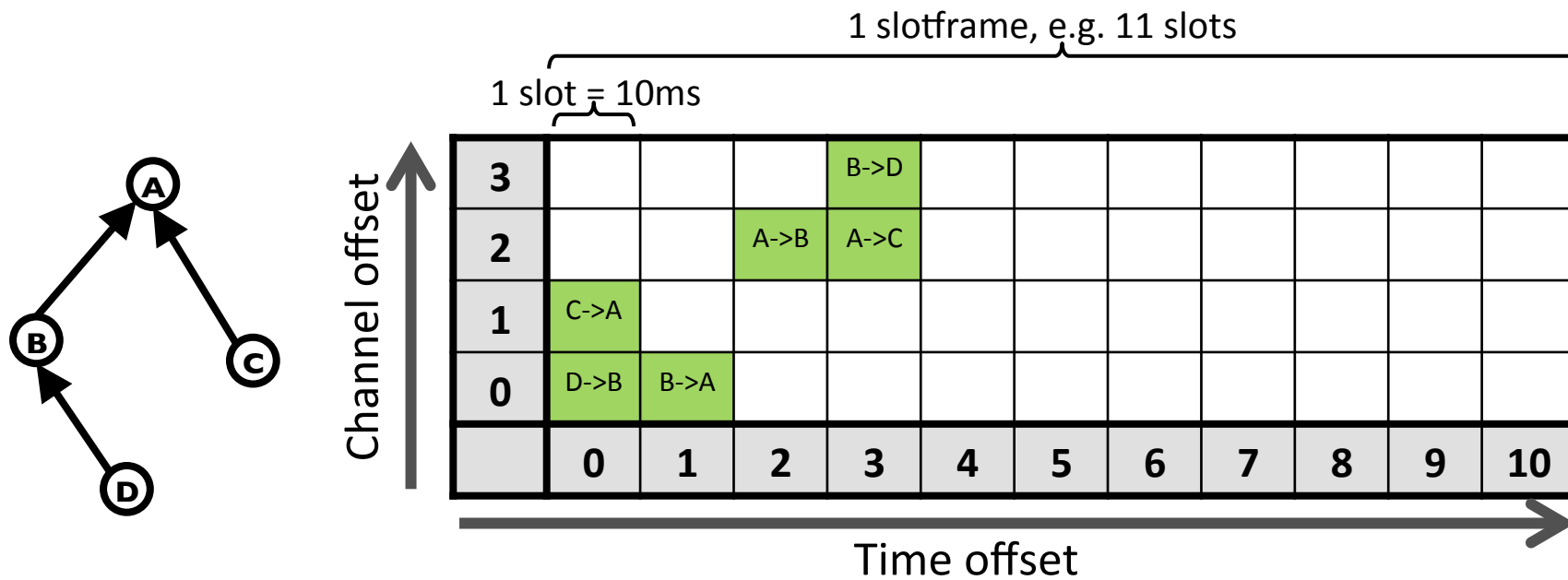


99.99% delivery

... vs. 99%

Reliability in WirelessHART / ISA-100

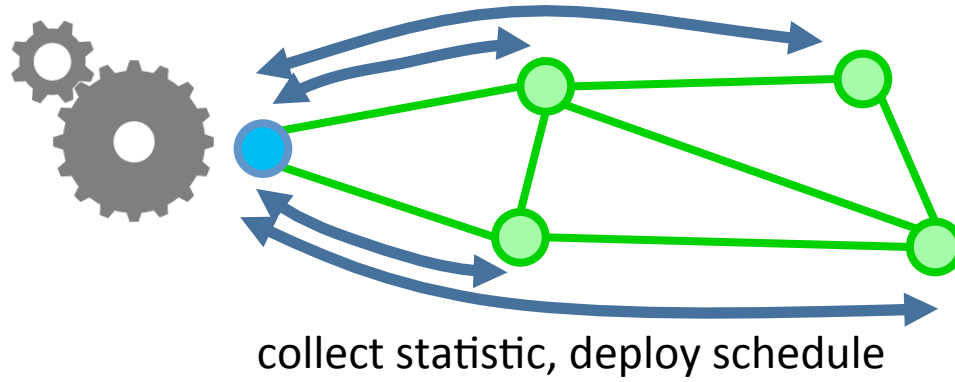
- MAC layer: TSCH (Time Slotted Channel Hopping)
 - TDMA reduces contention
 - Frequency diversity
 - Requires (centralized or decentralized) scheduling



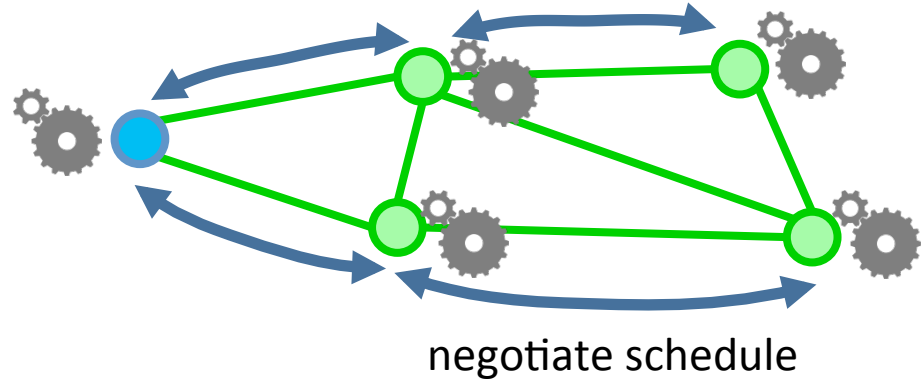
- Hard to apply in IoT networks
 - Scheduler expects deterministic traffic (*vs. random access*)
 - Integrated network (*vs. more dynamic / flexible*)

Introducing *Autonomous* Scheduling

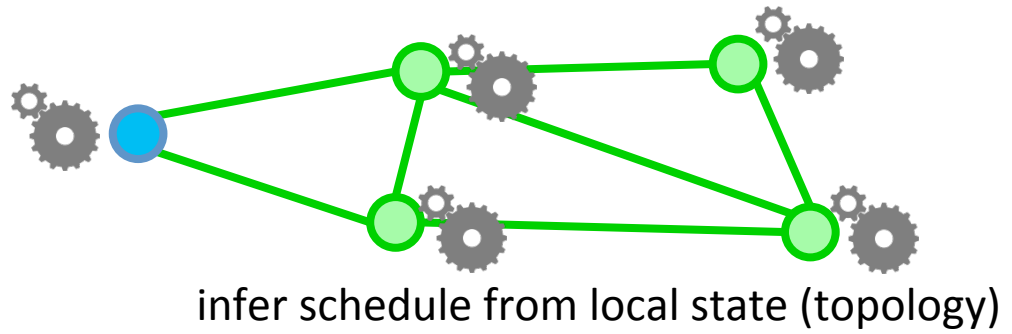
Centralized



Decentralized



Autonomous



Orchestra in a Nutshell

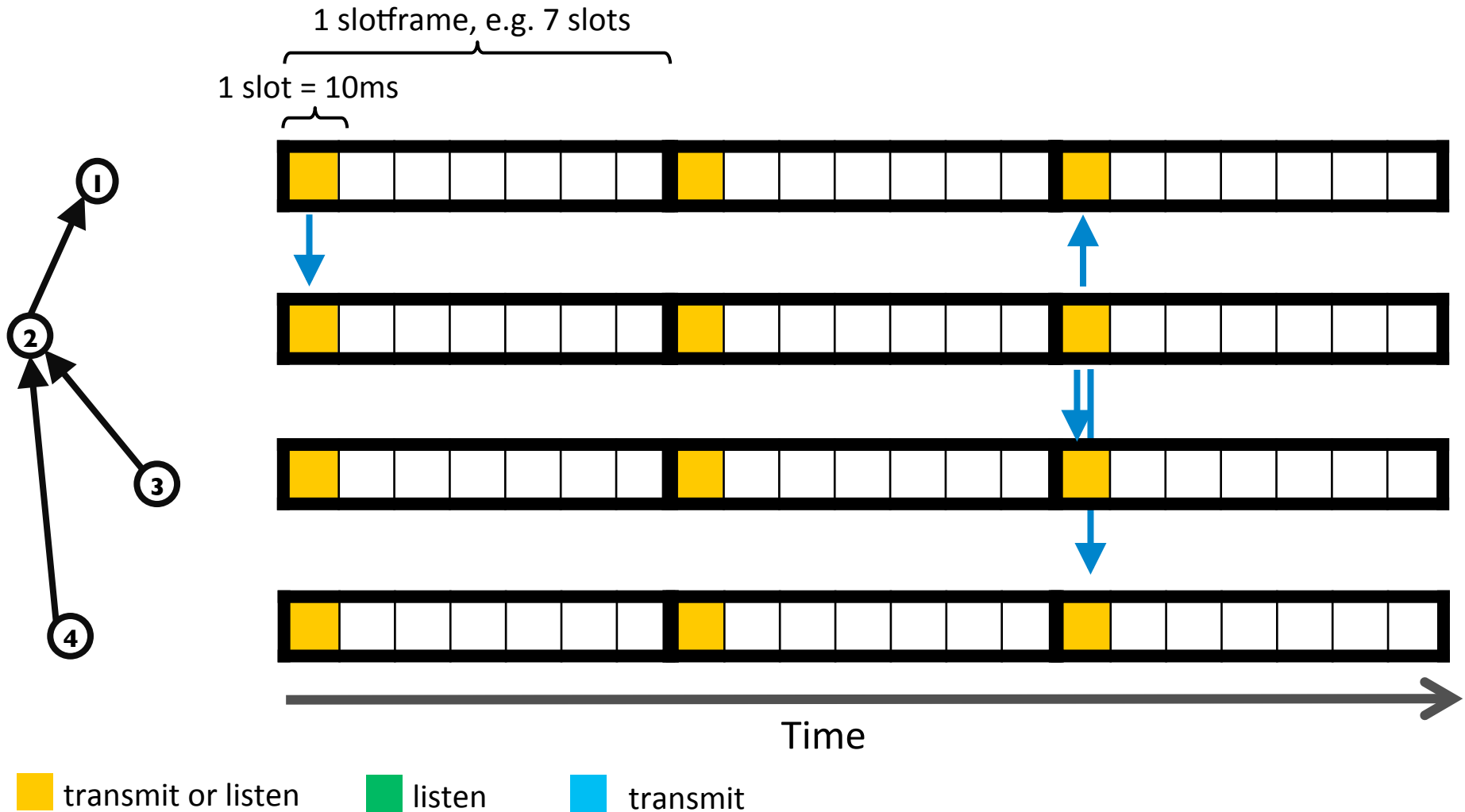
- Autonomous scheduling in TSCH networks
- Schedules are derived from routing state
 - Parent, children and neighbors properties
 - Rendez-vous, receiver-based and sender-based slots
 - Over-provisioning
 - Traffic plane isolation
 - Guarantees energy
- Reliable through
 - Routing–scheduling consistency by design
 - Controlled contention
 - TSCH channel hopping



Orchestra Slots Types

1. Rendez-vous
2. Receiver-based Shared
3. Sender-based Shared or Dedicated

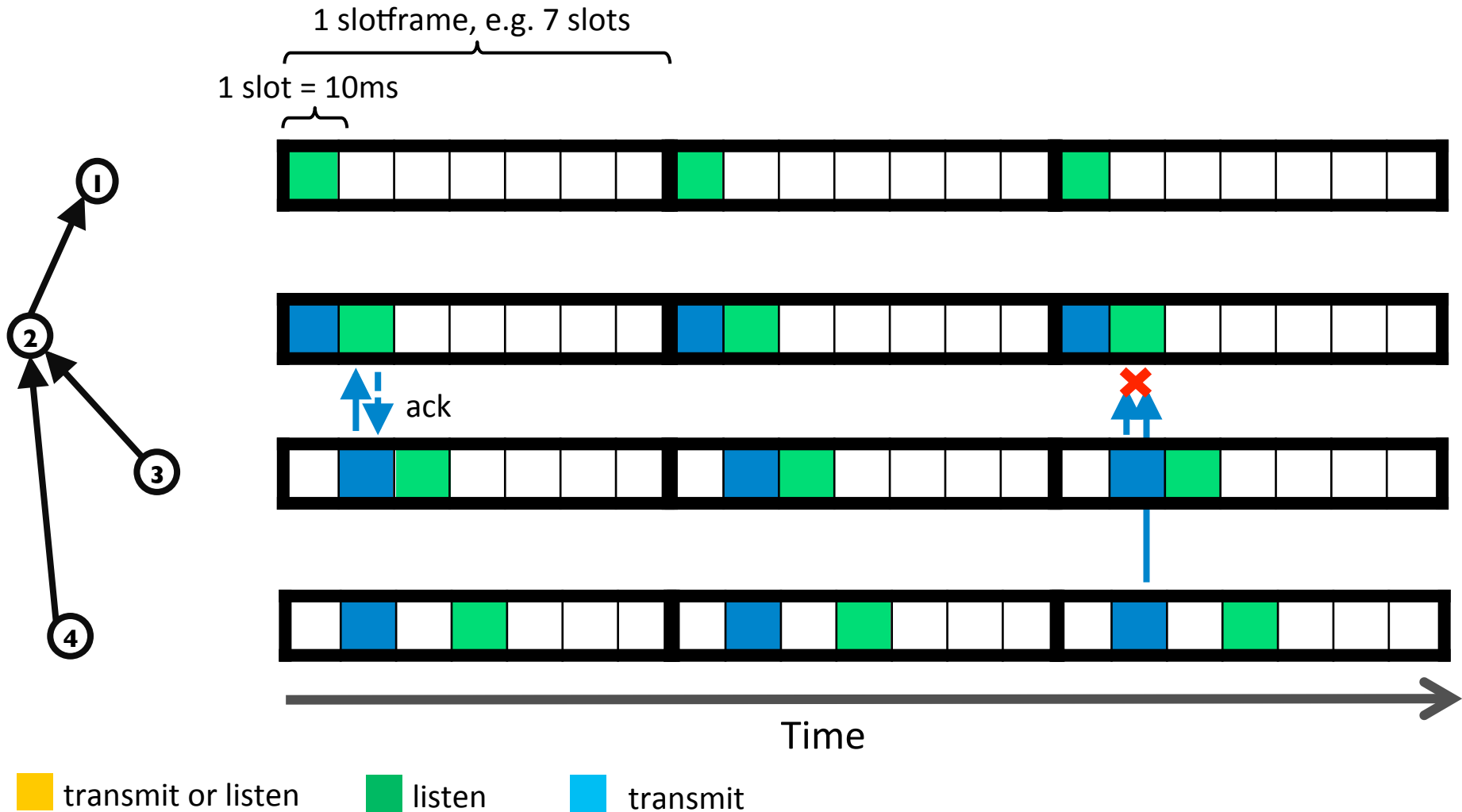
- Discovery
- Routing
- Contention-based



Orchestra Slots Types

1. Rendez-vous
2. **Receiver-based Shared**
3. Sender-based Shared or Dedicated

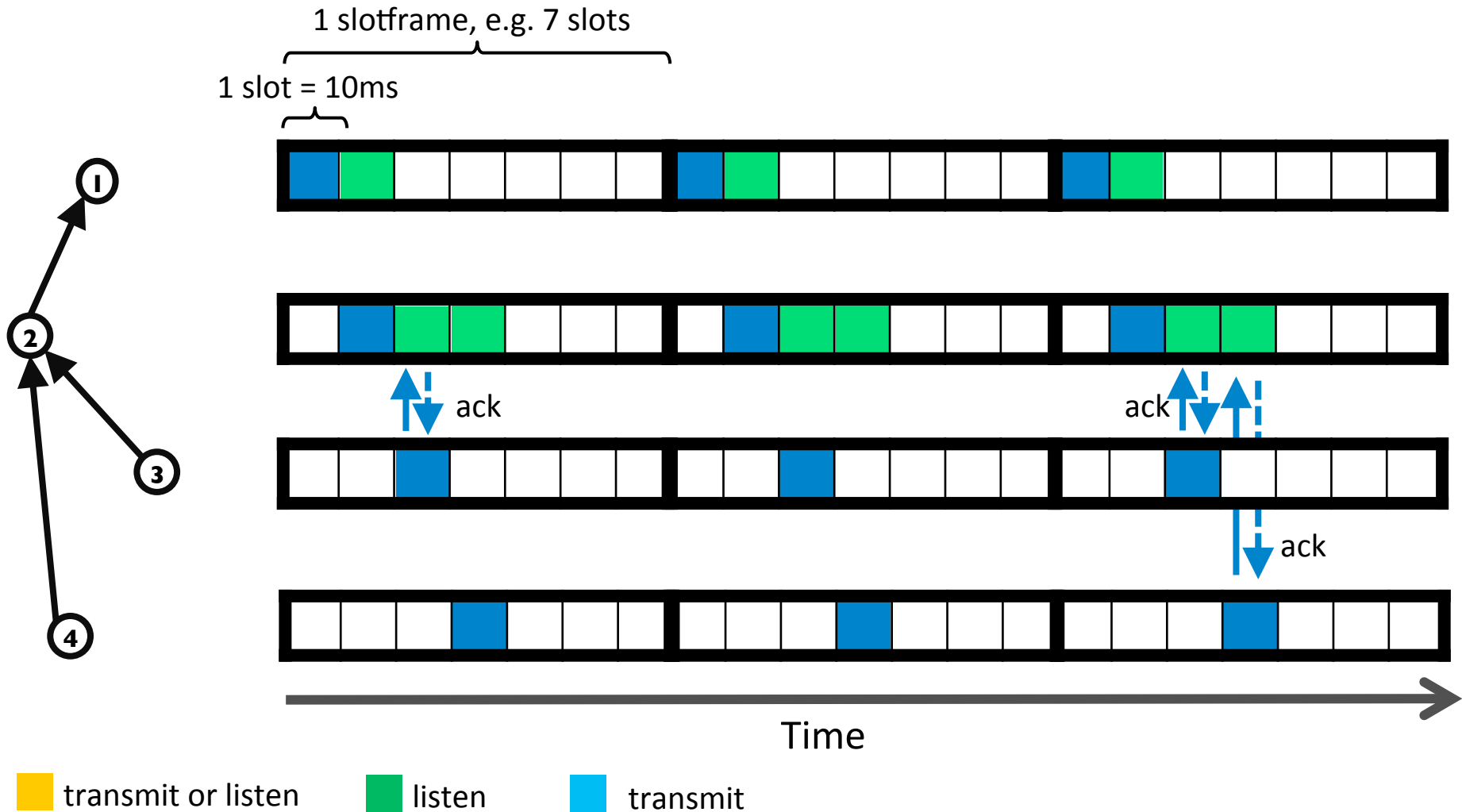
- For unicast
- Single Rx slot per node
- Contention-based



Orchestra Slots Types

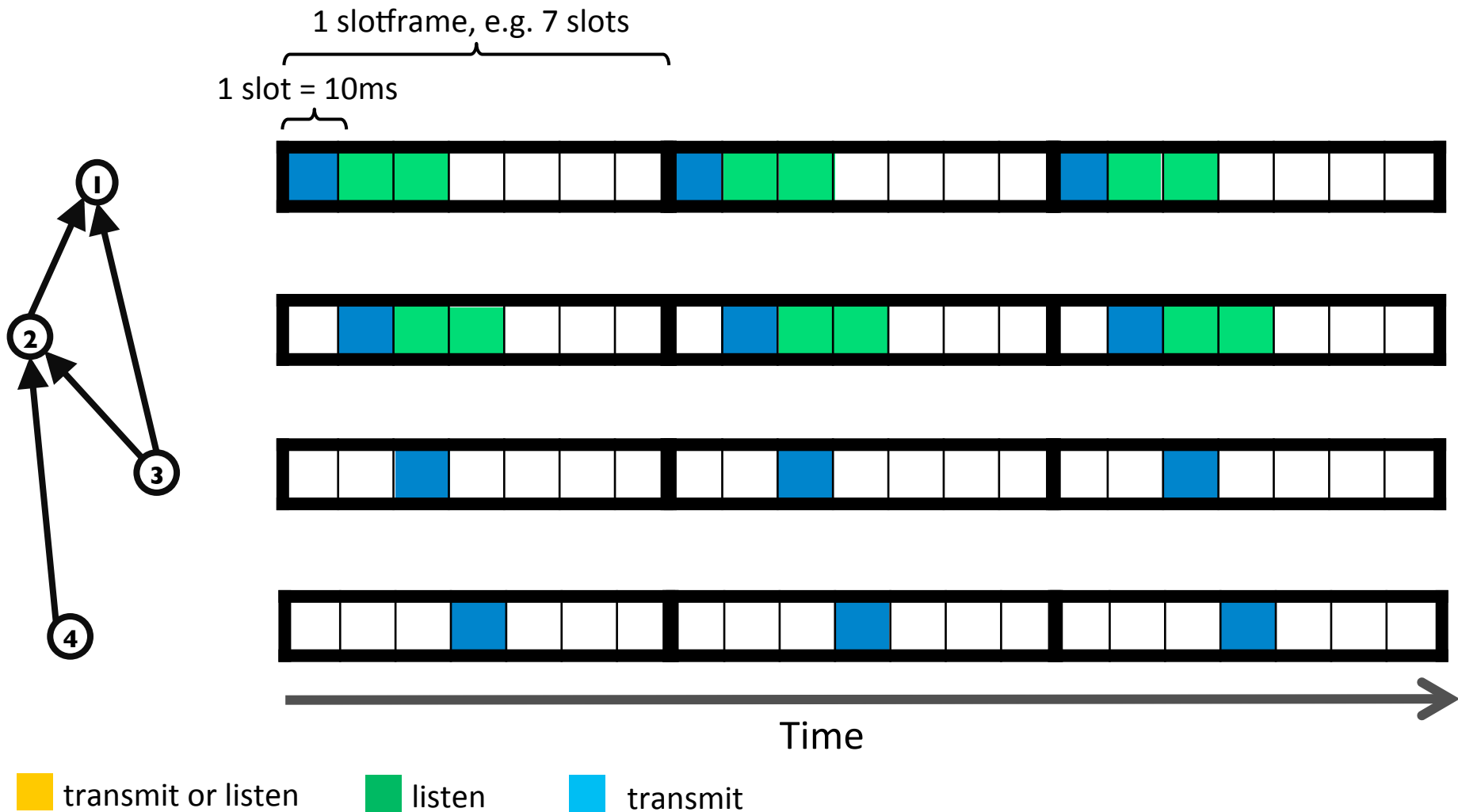
1. Rendez-vous
2. Receiver-based Shared
3. **Sender-based Shared or Dedicated**

- For unicast
- Several Rx slot per node
- Low or no contention



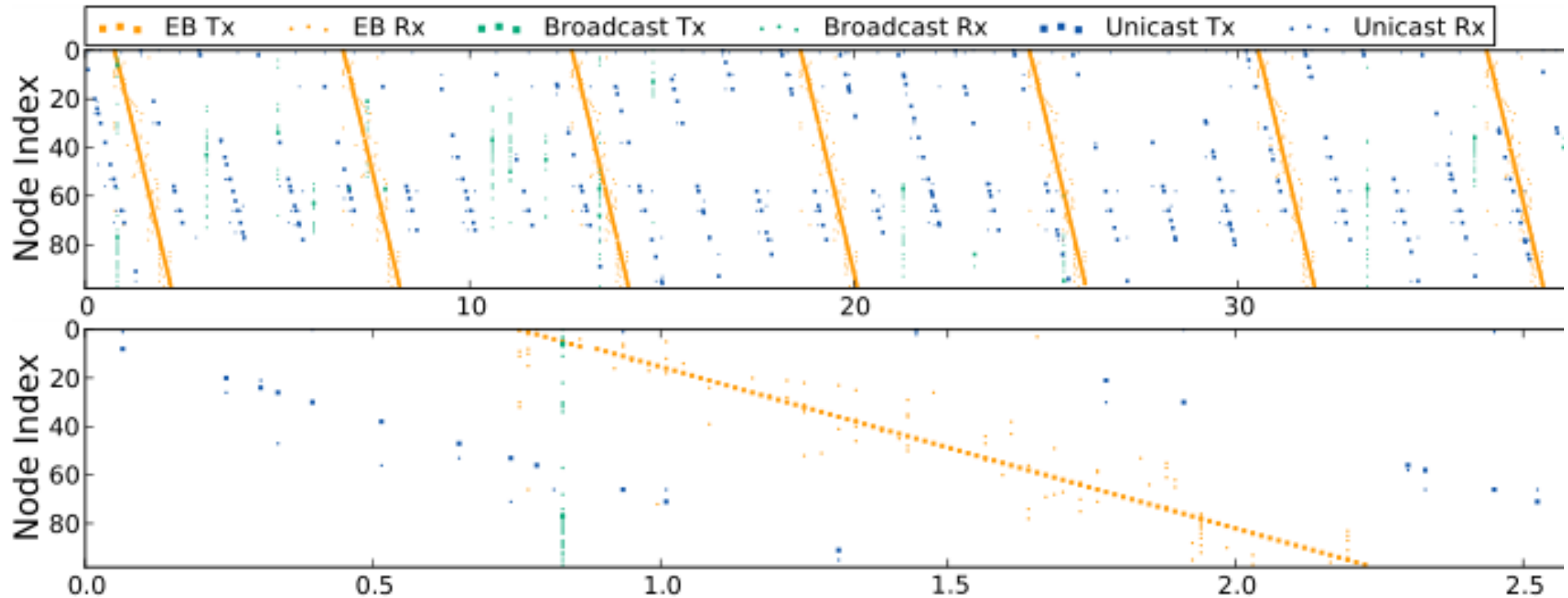
Orchestra Autonomous Slot Maintenance

- Solely based on local routing state (no extra traffic)
- Guarantees routing \leftrightarrow scheduling consistency



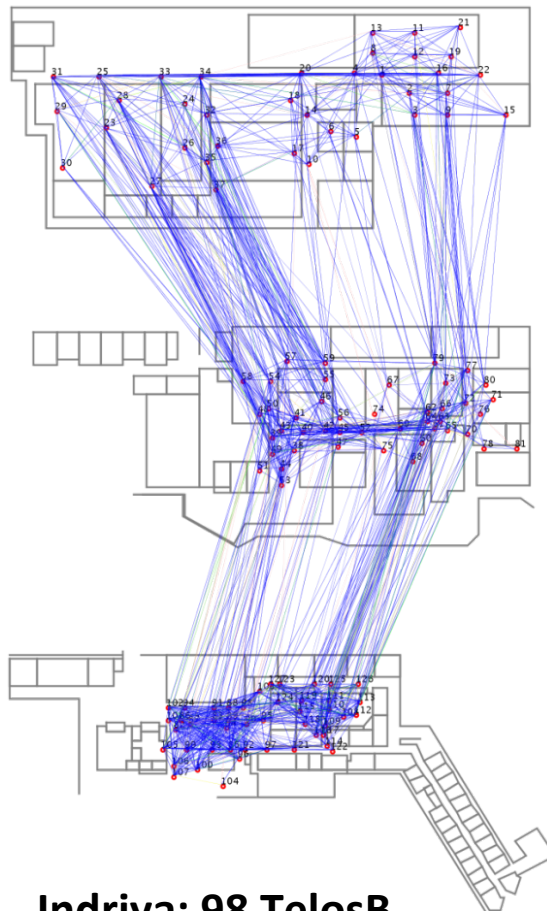
Orchestra Per-traffic Plane Scheduling

- Per traffic plane (over-)provisioning
- Slotframes cycle independently (co-prime lengths)
- Example

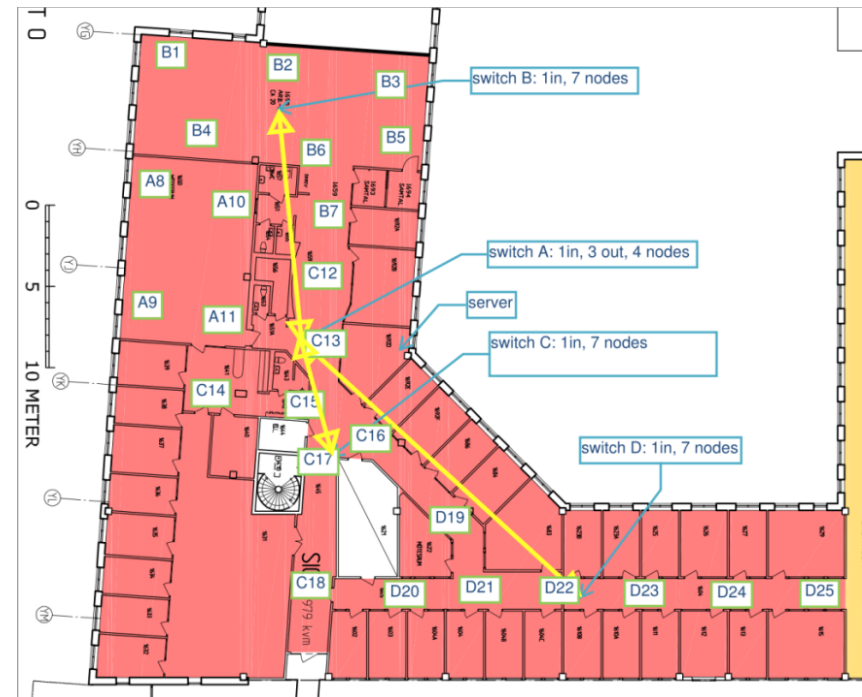


Evaluation Setup

- Integrated in Contiki
- >200 experiments in two testbeds, up to 72h long
- >1 million UDP packets sent



Indriya: 98 TelosB
16-bit MCU, 32kHz crystal



JN-IoT: 25 NXP JN516x
32-bit MCU, 16MHz crystal

Reliability (98 nodes Indriya)

Always-on:

plain CSMA

ContikiMAC:

low-power listening

TSCH-min:

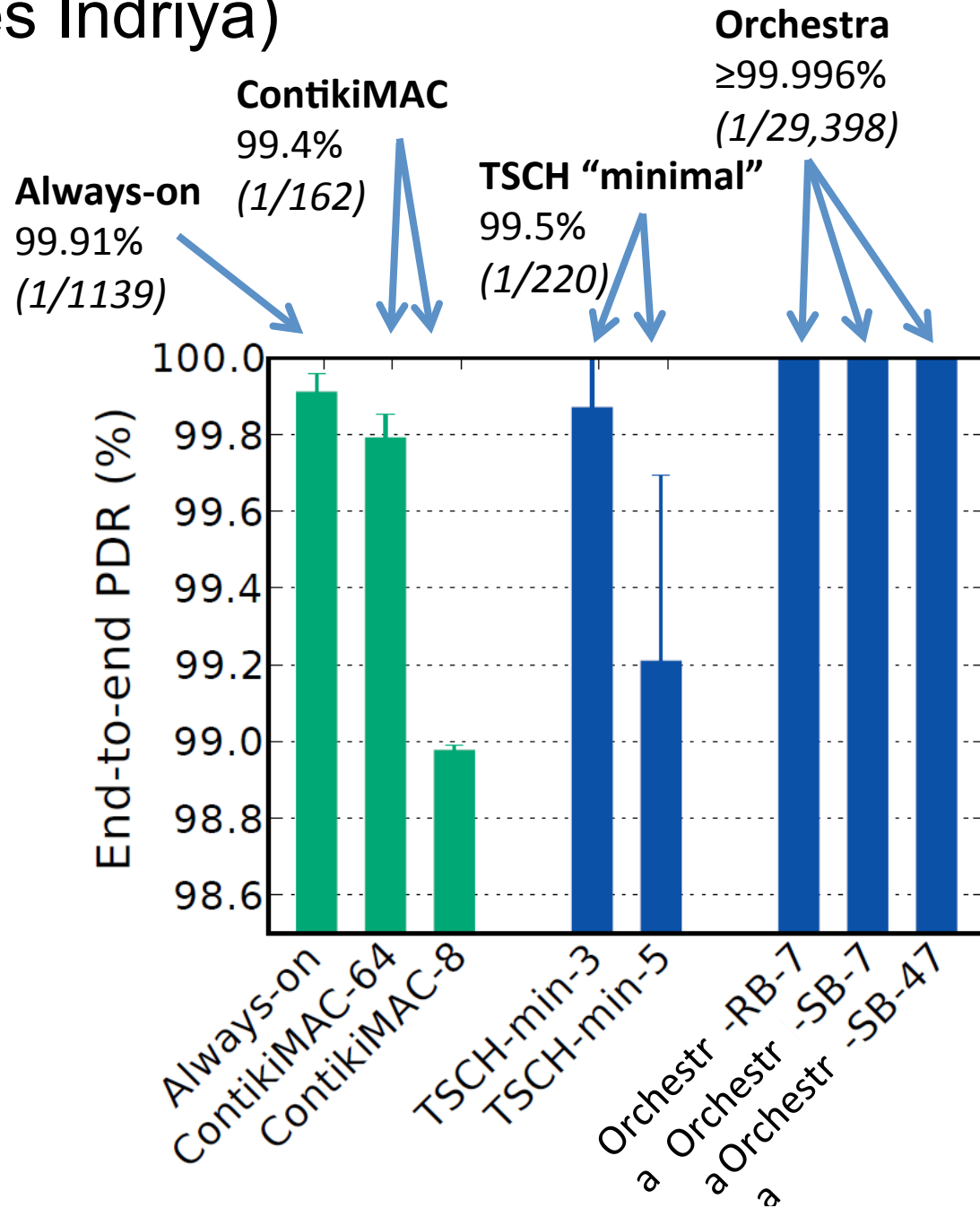
single rendez-vous slot

Orchestra-RB:

Orchestra receiver-based

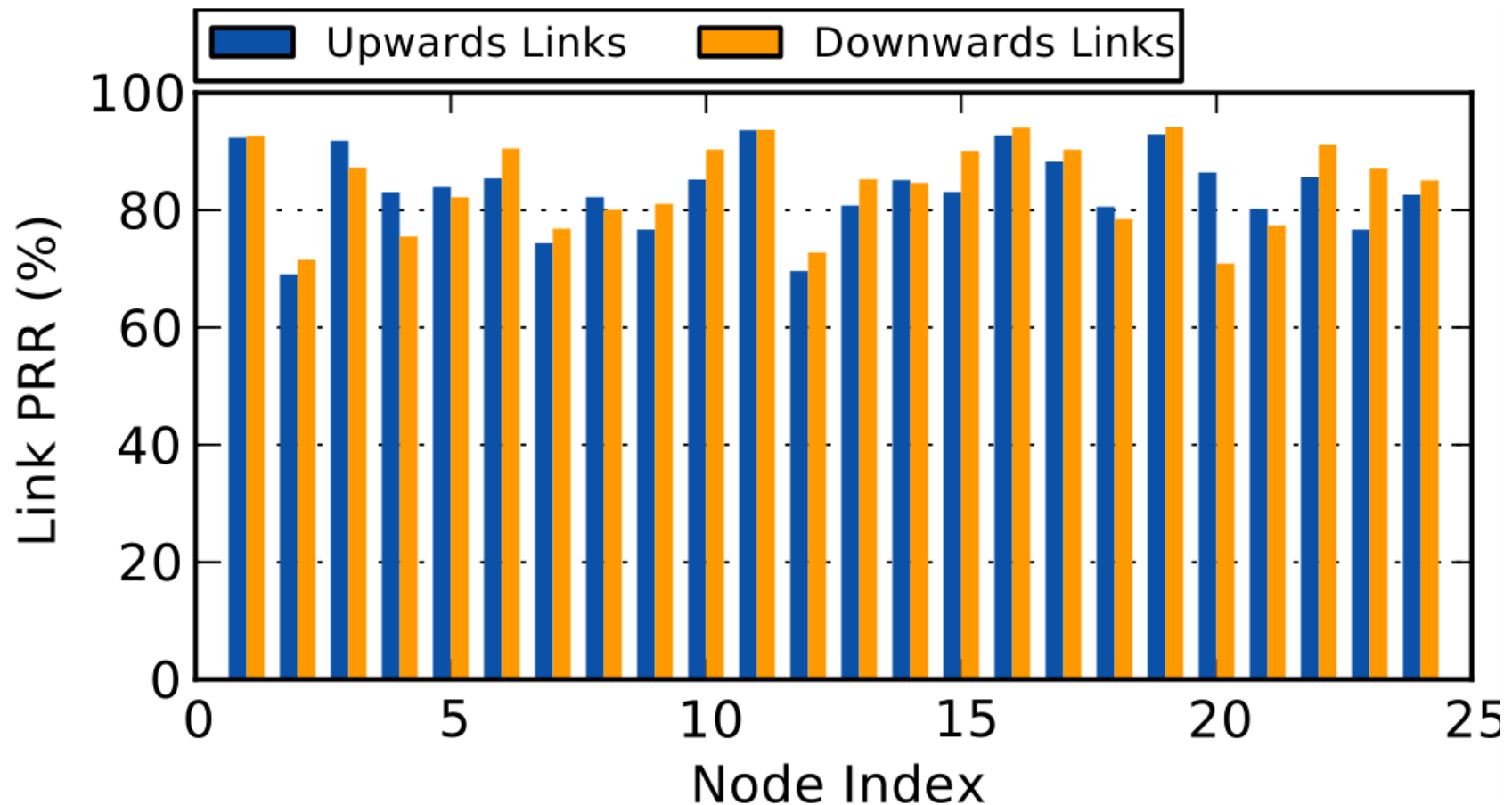
Orchestra-SB:

Orchestra sender-based



Request-response (25 NXP nodes)

- Every 50s, the root requests any node, waits for response
- Orchestra + RPL strong even on the down link (99.98% PDR)
- Links mostly symmetric (see *RPL enhancements in the paper*)



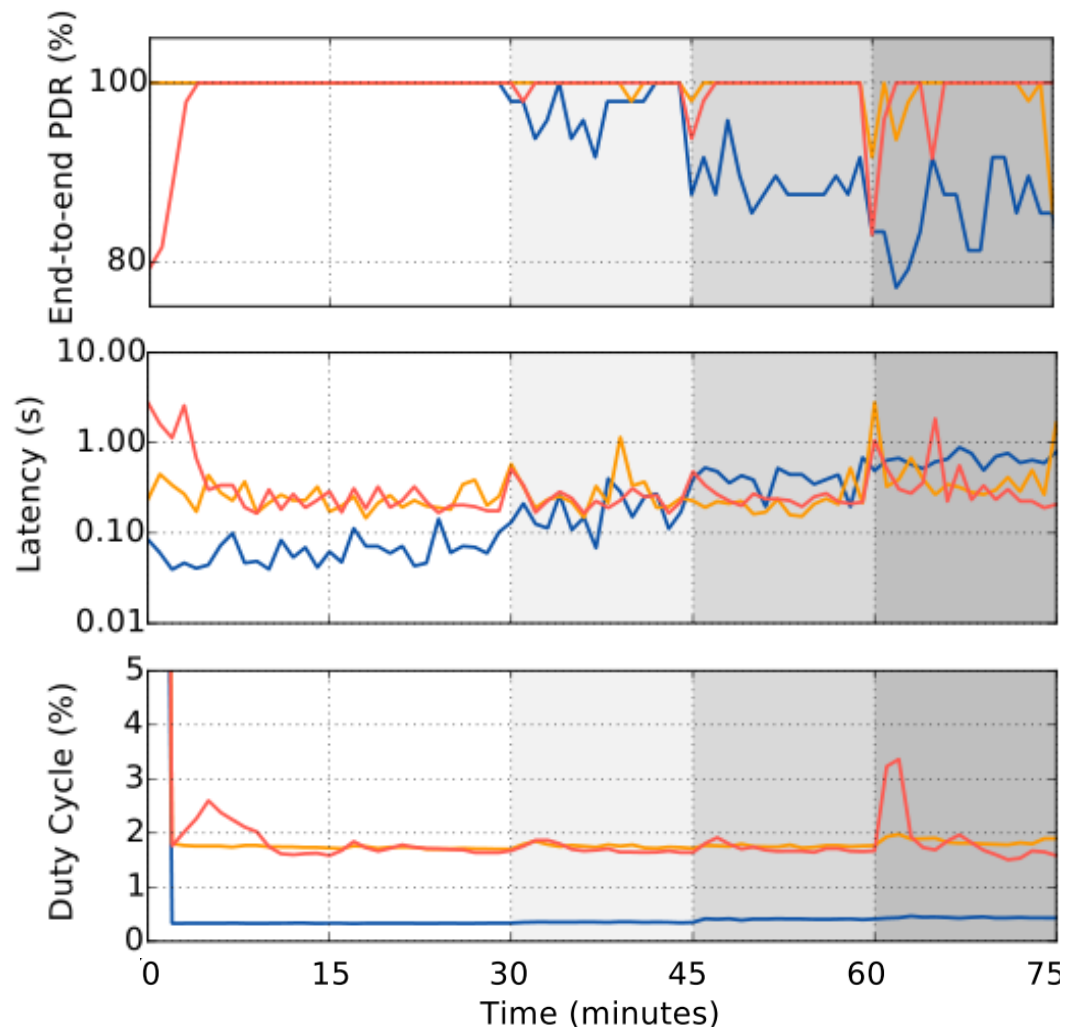
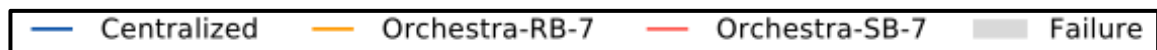
Energy Guarantees (98 nodes Indriya)

	Duty Cycle (%)			
	Experiments		Theoretical	
	Min	Max	Min	Max
Contikmac@8Hz	0.66	1.89	0.6	88
TSCH-min-7	1.30	2.56	1.14	4.48
TSCH-RB-29	0.68	1.90	0.54	3.00
TSCH-SB-29	0.38	2.75	0.28	31.19

- **ContikiMAC** has no usable energy bounds
- **Orchestra**, in some configurations, can provide tight bounds

Orchestra vs. Centralized Scheduling (simulation)

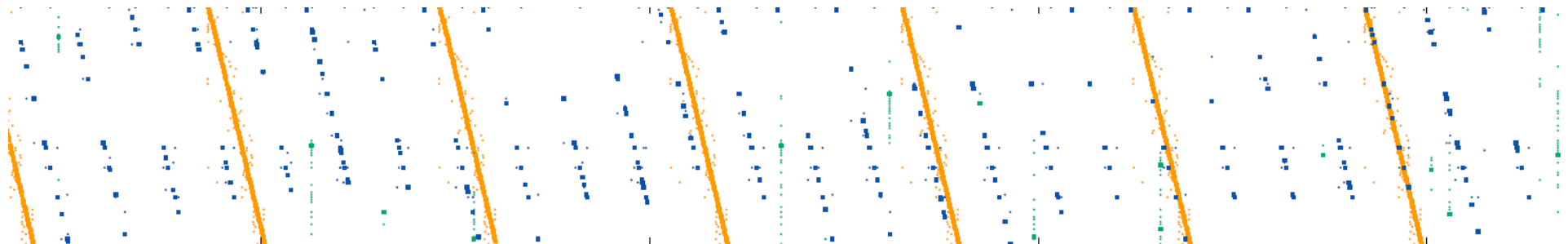
Every 15 minutes: 3 new nodes have their Rx rate reduced by 10 times



- **Orchestra** keeps operating as RPL repairs the topology
- **Orchestra** over-provisioning:
 - Duty cycle 4-8x
 - Latency 10x

Conclusion

- TSCH in non-deterministic IoT networks is possible
 - Autonomous scheduling
 - Achieved via over-provisioning
- High reliability is possible (from 99 to 99.99%)
 - Schedules consistent with routing by design
 - Reduced contention + channel hopping
- Try it!
 - TSCH interoperability tested in Prague, ETSI Plugtest this July
 - Now part of the official Contiki repository



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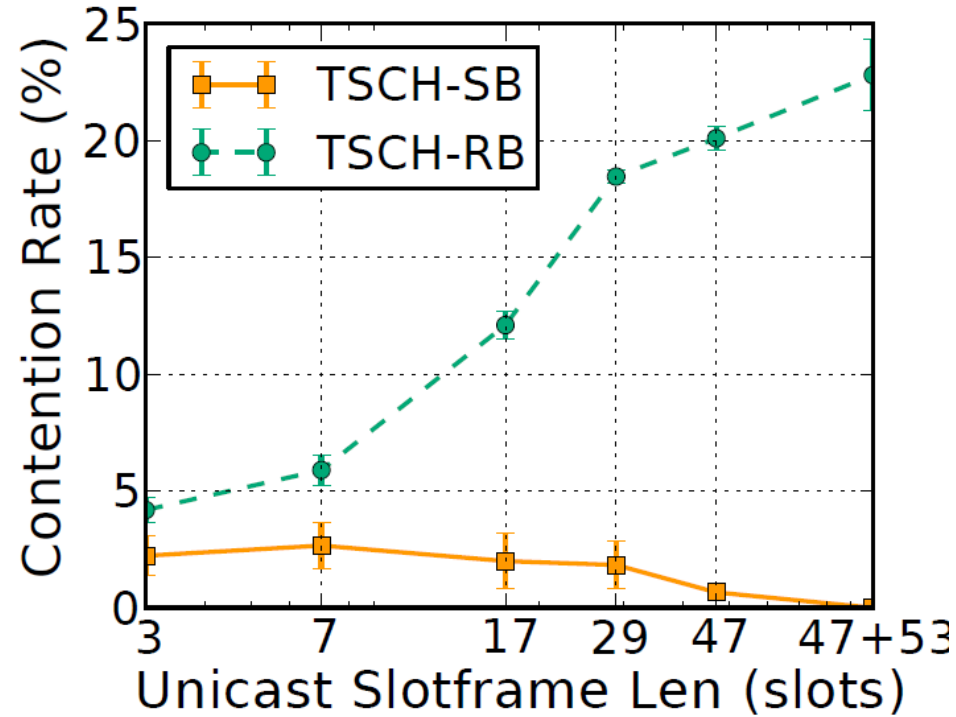
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Orchestra and Contention Control



- Slotframe length dictates contention level (and link quality)
- **TSCH-min** (100% shared links): PRR **89%**
- **TSCH-rb** (shared links per receiver): PRR **93%**
- **TSCH-sb** (dedicated links): PRR **96%**