



Reliable Wireless Communications for Industry 4.0 Applications

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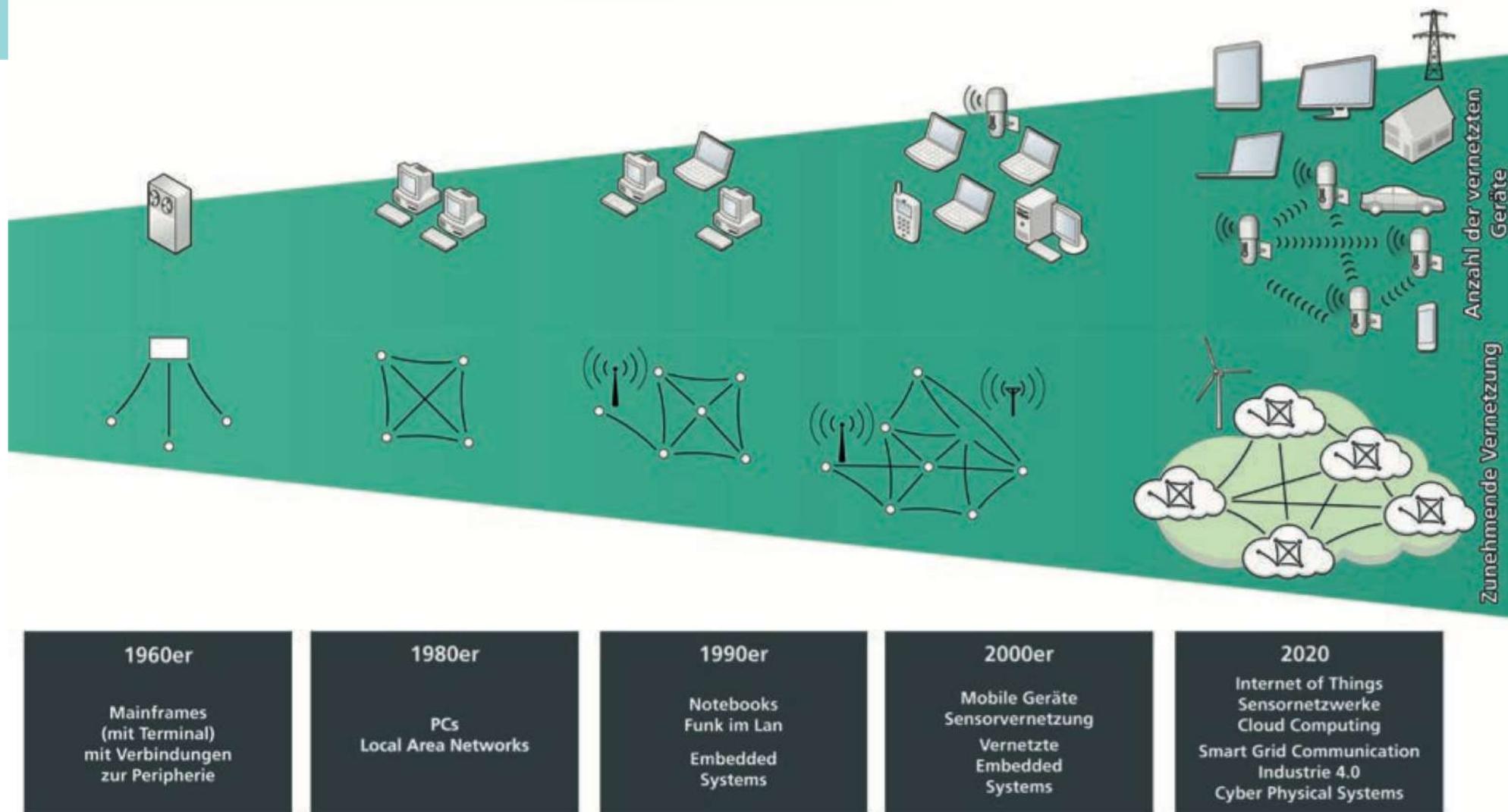


Figure is taken from www.industrialradio.de - "Funktechnologien für Industrie 4.0", available on www.industrialradio.de/Attachments/Funktechnologien_Industrie_4.0_Web.pdf, accessed on 14.05.2019

Industry 4.0 Applications - Requirements

	Diagnose & Wartung		Diskrete Fertigung		Lager und Logistik			Prozess-automatisierung	Augmented Reality	Funktionale Sicherheit
	Generell	Condition Monitoring	Generell	Motion Control	Generell	AGV	Kran-szenario			
Latenz (Sensor zu Controller zu Aktor)	> 20ms	100ms	1 ms – 12 ms	250 μ s – 1 ms	> 50 ms	15 ms – 20 ms	15 ms – 20 ms	50 ms – Xs	10 ms	10 ms
Zuverlässigkeit (i.S. „erfolgreich“ innerh. der Latenzanf.)	$1 - 10^{-4}$	$1 - 10^{-5}$	$1 - 10^{-9}$	$1 - 10^{-9}$	$> 1 - 10^{-2}$	$> 1 - 10^{-6}$	$> 1 - 10^{-6}$	$1 - 10^{-5}$	$1 - 10^{-5}$	$1 - 10^{-9}$
Datenrate	kbit/s – Mbit/s	kbit/s	kbit/s – Mbit/s	kbit/s – Mbit/s	kbit/s – Mbit/s	kbit/s – Mbit/s	kbit/s – Mbit/s	kbit/s	Mbit/s – Gbit/s	kbit/s
Paketgrößen	> 200 Byte	1 – 50 Byte	20 – 50 Byte	20 – 50 Byte	< 300 Byte	< 300 Byte	< 300 Byte	< 80 Byte	> 200 Byte	< 20 Byte
Reichweiten (zw. komm. Geräten)	< 100 m	100 m – 1 km	< 100 m	< 50 m	< 200 m	~ 2 m	< 100 m	100 m – 1 km	< 100 m	< 30 m
Bewegungsgeschwindigkeit	0 m/s	< 10 m/s	< 10 m/s	< 10 m/s	< 40 m/s	< 10 m/s	< 5 m/s	Generell keine, sonst < 10 m/s	< 3 m/s	<10 m/s
Zeitkritische Mobilitätsunterstützung	nein	nein	nein	nein	nein	ja	nein	nein	nein	ja
Gerätedichte	0,33 – 3 m ⁻²	10 – 20 m ⁻²	0,33 – 3 m ⁻²	< 5 m ⁻²	~ 0,1 m ⁻²	~ 0,1 m ⁻²	~ 0,1 m ⁻²	10.000 / Fabrik	> 0,03 – 0,02 m ⁻²	> 0,03 – 0,02 m ⁻²
Energieeffizienz	n/a	10 Jahre	n/a	n/a	n/a	< 8h	n/a	10 Jahre	1 Tag	n/a
Lokalisierungsgenauigkeit	< 50 cm	< 50 cm	n/a	n/a	< 1 cm	< 5 cm	< 10 cm	< 50 cm	n/a	< 50 cm

DETERMINISTIC BEHAVIOUR

Table is taken from www.industrialradio.de - "Funktechnologien für Industrie 4.0", available on www.industrialradio.de/Attachments/Funktechnologien_Industrie_4.0_Web.pdf, accessed on 14.05.2019



Dependability

- **Availability** – ability of a system to be in a state to perform a required function within a given time interval
- **Reliability** – ability of a system to be in a state to perform a required function under given conditions within a given time interval
- **Maintainability** - ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance

ULTRA LOW RELIABILITY AND
LOW POWER CONSUMPTION

“ZDKI-FG1_Zuverlässigkeit_EN_210917_v2.pdf”, available on <http://www.industrialradio.de>, accessed on 16th of May



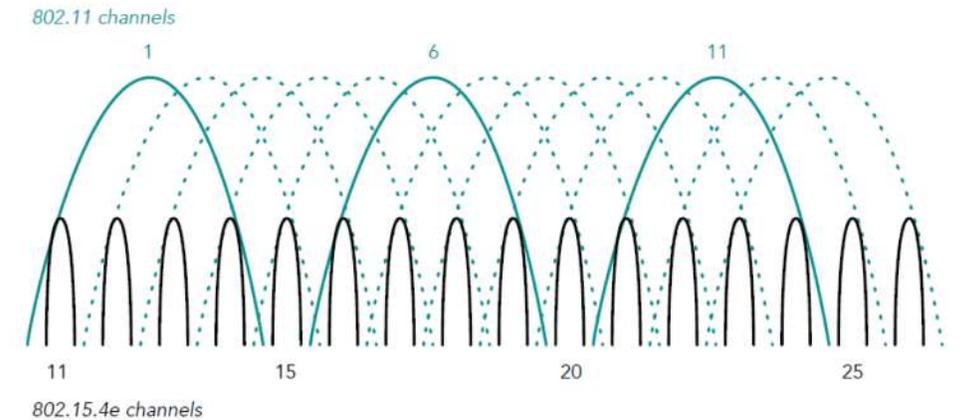
Legacy IEEE 802.15.4

- Low power, low price, well accepted communication protocol for IoT.
but,
 - Unpredictable latency: if CSMA/CA random access is used
 - Prone to interference: no frequency hopping
 - High energy consumption of routing nodes: always on listening mode regardless of the traffic pattern

Operation of Wireless Sensor Networks (WSN) in industrial environments

Challenges

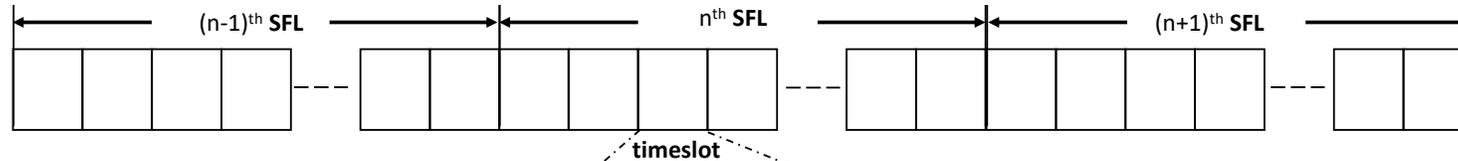
- Interference from co-located networks (WLANs, Bluetooth, etc.)
- Impaired radio channels, e.g. interference from production lines, multi-path fading, etc.
- Frequently changing topologies
- ...



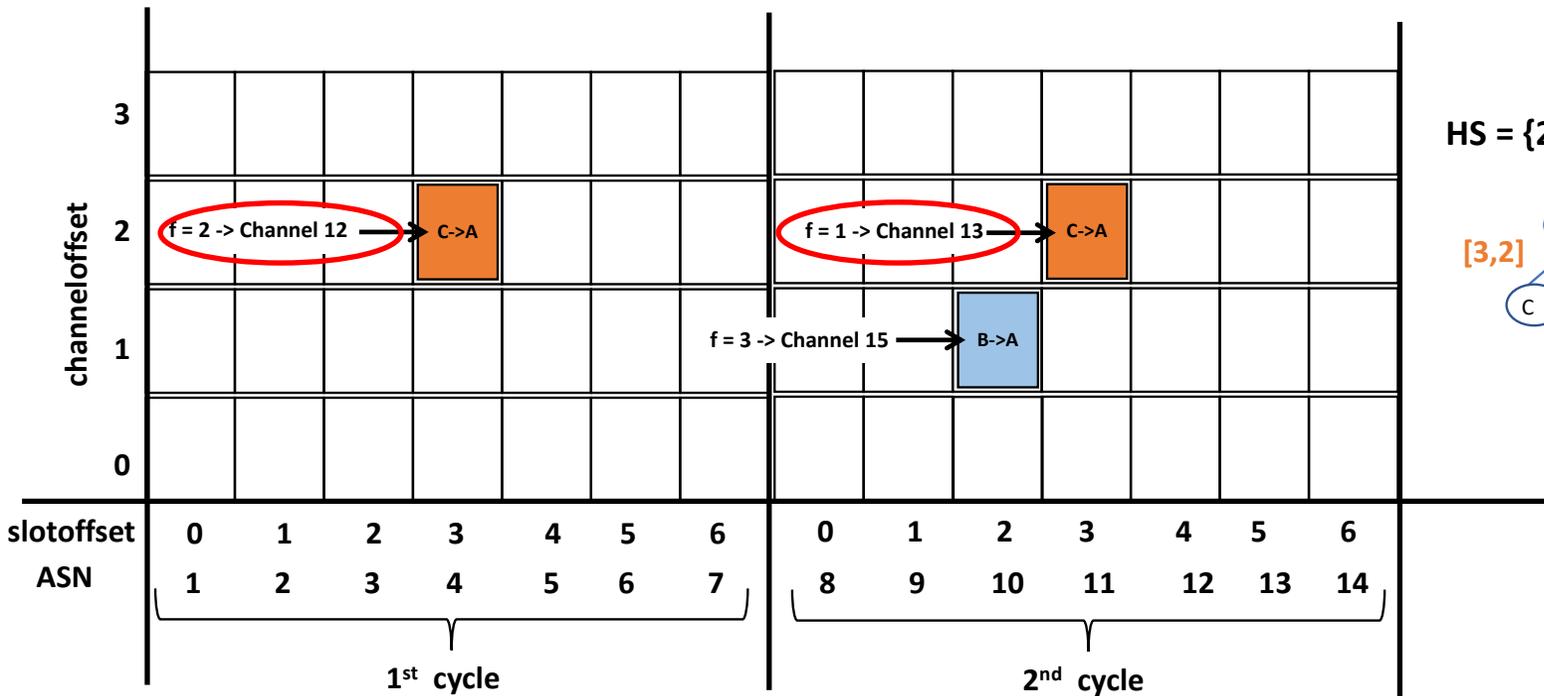
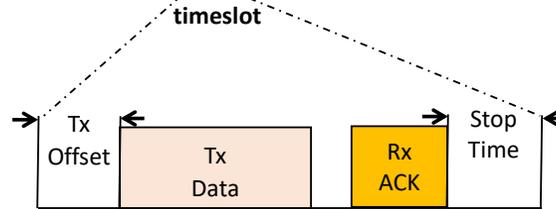
Overlap between 802.11 and 802.15.4 Channels

- 2006: Dust Networks's Time Sync Mesh Protocol (TSMP)
- 2008: WirelessHART
 - TDMA with fixed time slots
 - Vendor driven
- 2011: ISA 100.11a
 - TDMA (variable time slots) + CSMA
- 2012: **IEEE 802.15.4 TSCH** (Time Slotted Channel Hopping) mode
 - Configurable TDMA – predictable latency, avoids idle listening and extends the lifetime
 - Channel hopping - improves the reliability in the presence of narrowband interference
 - Also known as IEEE 802.15.4e
 - Only MAC layer was modified

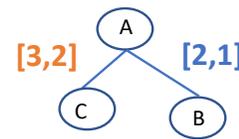
TSCH – Time Slotted Channel Hopping



Slot frames repeat over time



HS = {25,13,12,15}



Link [slotoffset, channeloffset] is also called as a cell

- SFL: Slot Frame Length
- HS: Hopping Sequence
- f: position of the HS
- ASN: Absolute Slot Number

$$f = [(ASN + channelOffset) \bmod [hoppingSequenceLength]]$$

SCHEDULING !!!!!: Trade off between throughput, delay and power consumption

- Centralized vs distributed
 - Timeslot length
 - How many slots per node pair / Matching with the traffic pattern
 - Avoiding internal collisions
 - Adaptive cell allocations
 - Spectrum sensing – blacklisting of channels
-
- Synchronization
 - Scalability and Deployment
 - ...

6TiSCH Protocol Stack

Simple web like interfaces

CoAP on UDP

Interworking with IP based protocols

IETF 6LoWPAN / IPv6

IETF 6TiSCH WG
6top : add/remove/relocate cells
Distributed dynamic scheduling to match with IP traffic
DetNet WG
6TiSCH architecture
...

IETF 6top sublayer

IETF

Scheduling function (SF)

6top protocol (6P)

Low power, reliability

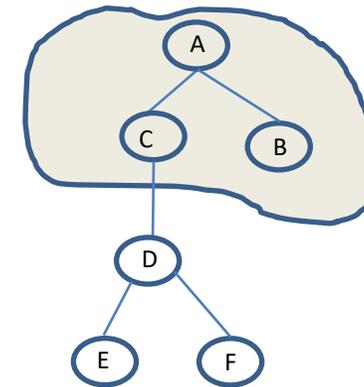
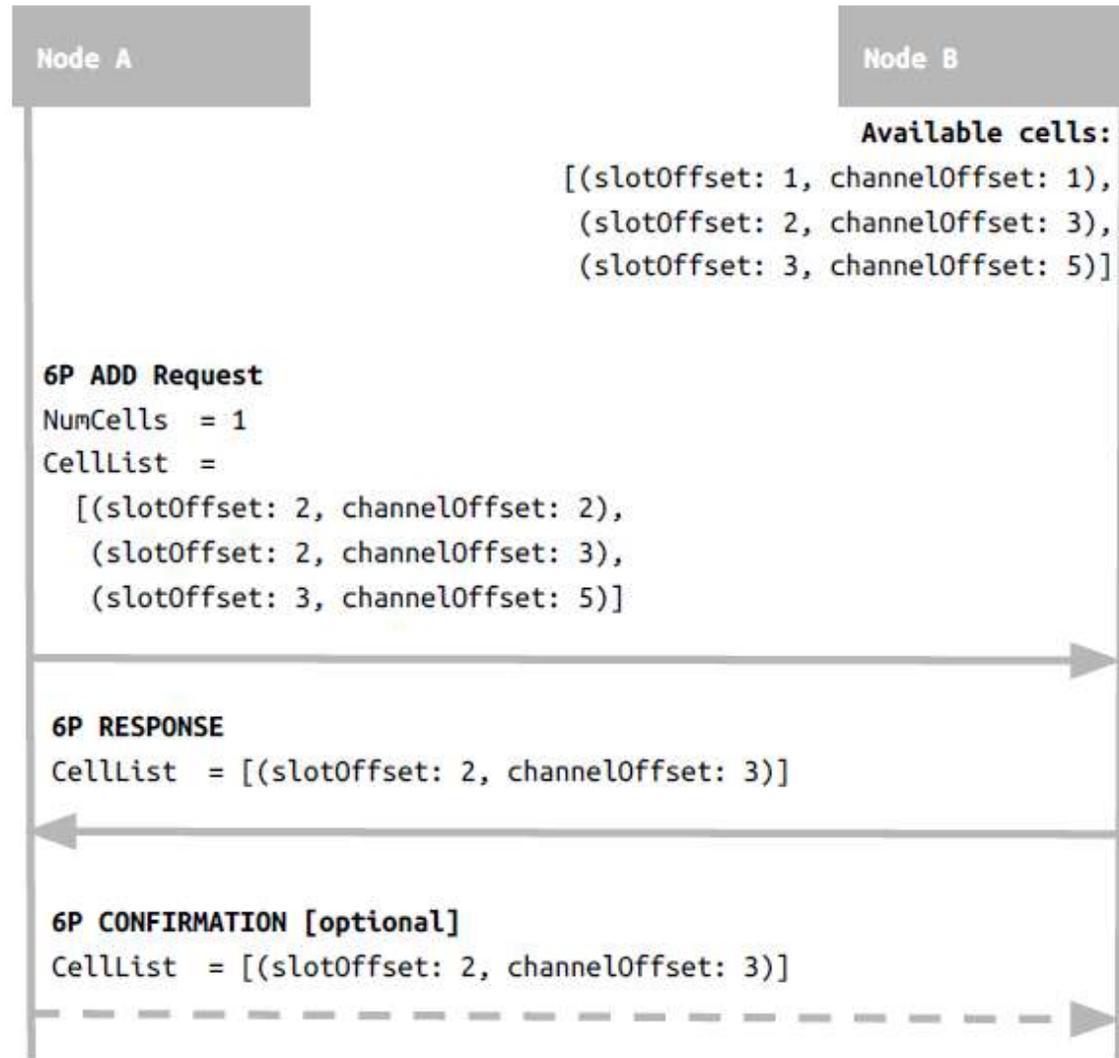
IEEE 802.15.4 TSCH

IEEE

Simple hardware

IEEE 802.15.4 PHY

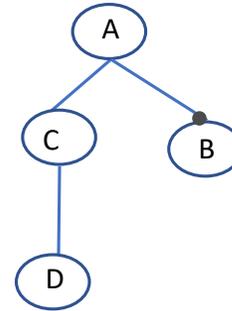
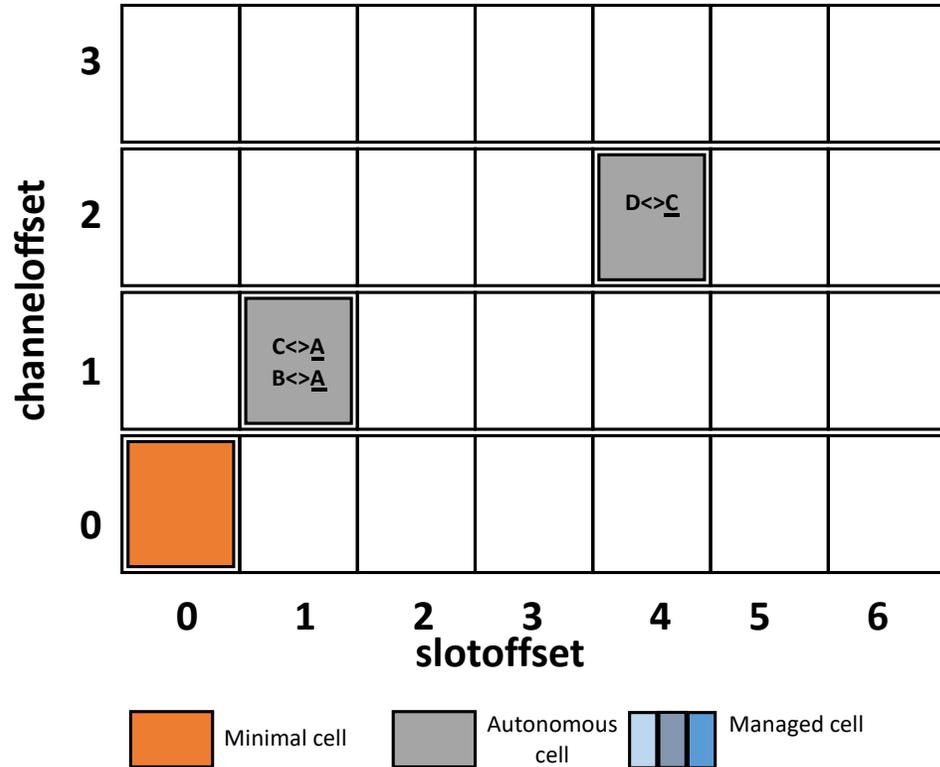
6P Protocol



No cell collisions

6P Messages for allocating dedicated cells among neighbours

6TiSCH Minimal Scheduling Function - MSF



- **Minimal cell**

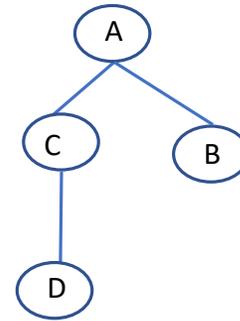
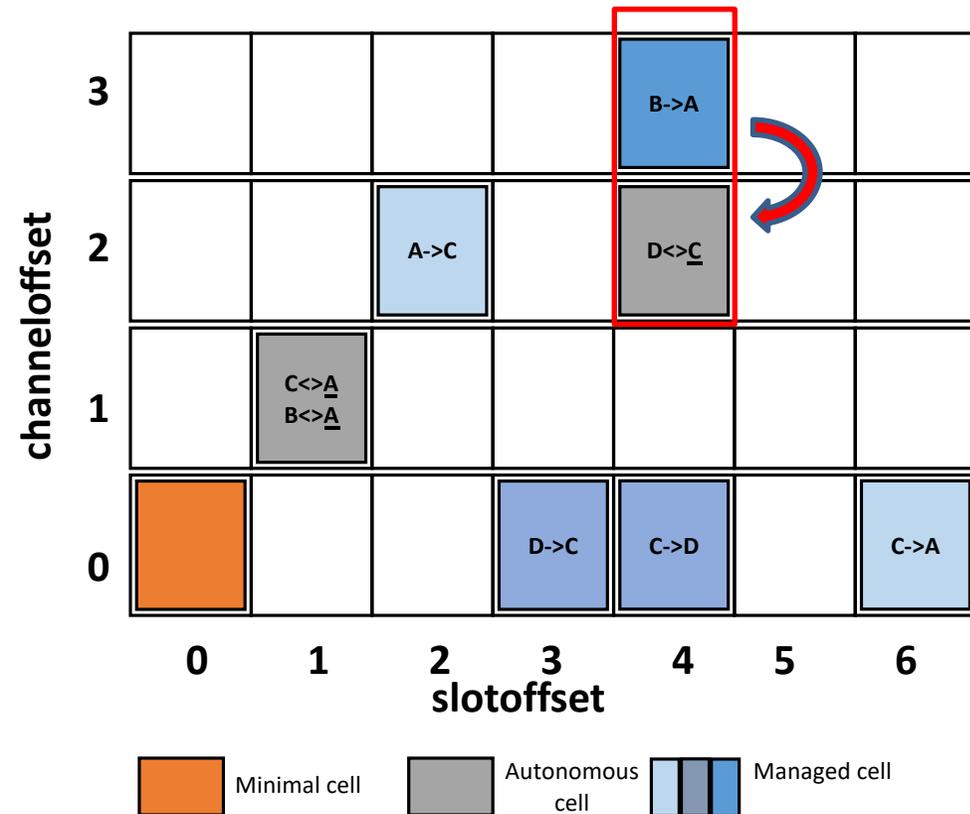
- Shared cell for whole network – Slotted Aloha behavior
- Enhanced Beacons, broadcast routing info

Autonomous cell

- Only shared among neighbors
- 2 types:
 - **Upstream cell** - computed based on the MAC address of the upstream neighbor
 - **Downstream cell** – computed based on own MAC address
- Used to allocate dedicated cells among neighbors
 - Add/Delete/Relocate 6P messages

6TiSCH Minimal Scheduling Function - MSF

cell collisions



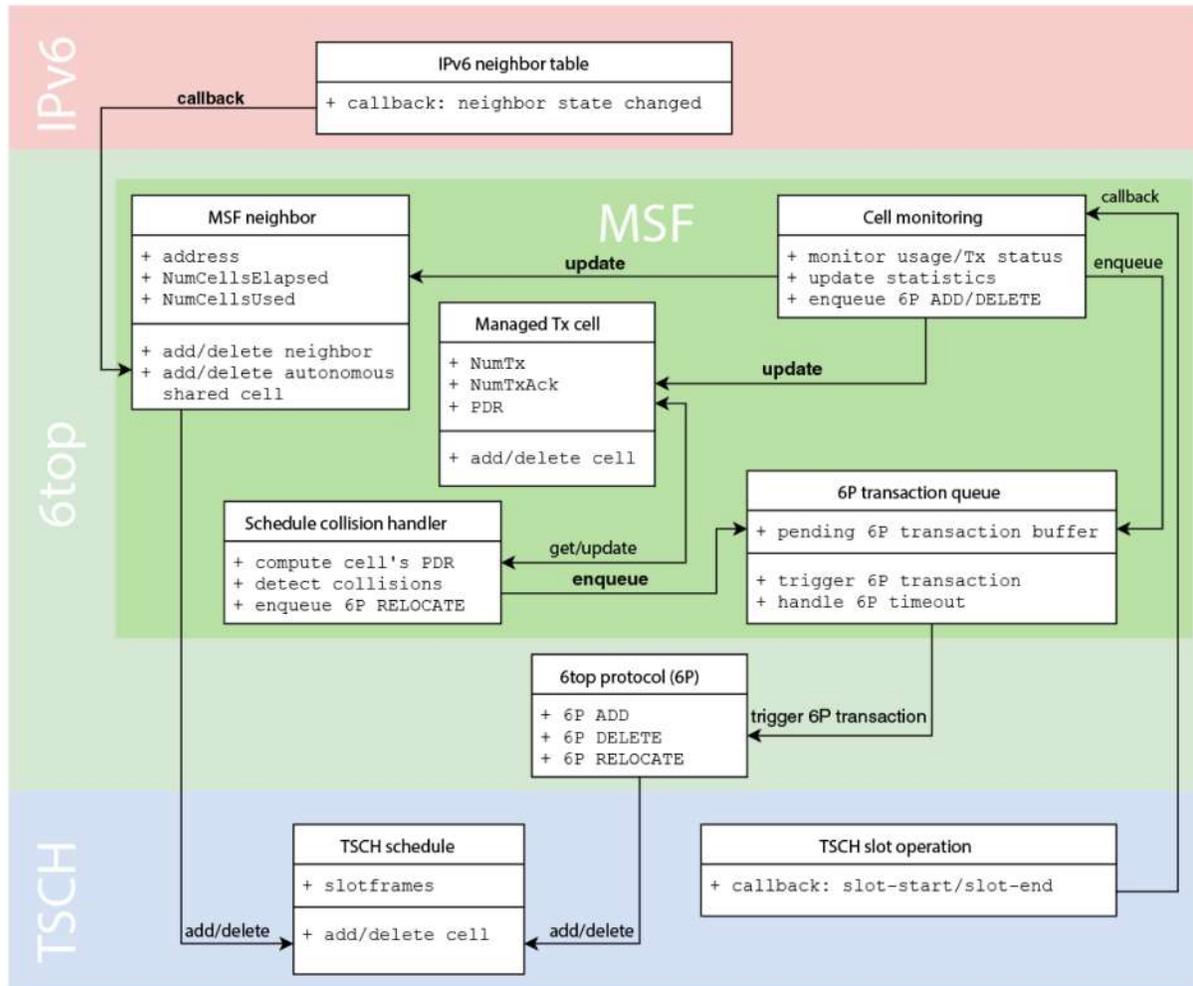
- **Managed cell**

- A pair of dedicated cells per neighbor for unicast traffic

- **Open Issues**

- To avoid cell collisions
 - By monitoring the PDR per cell
 - If PDR < “given threshold”, reallocate cells
- Adaptive cell allocation based on traffic
 - Based on cell usage [Cells-Used/Cells-Elapsed]

MSF – Implementation in Contiki OS



Marvin Jürgensen, Bachelor Thesis, May 2019, TUHH

DRAISE Project

DRAISE: Drahtlose, Robuste, Adaptive, Industrielle Systeme

- Duration: 02/2016 – 04/2019
- Funding: BMBF KMU-Innovativ

Goal: Develop reliable, low latency sensor network for industrial environments **based on existing protocols** (IEEE 802.15.4 TSCH mode, Wireless HART, ISA100.11a)

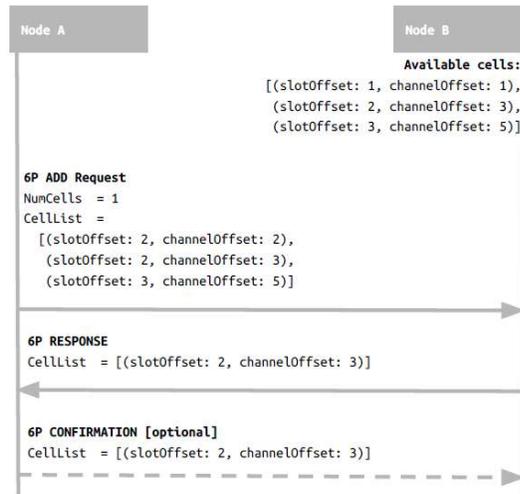
Methods: Redundancy on all layers, optimized schedule by Linear Programming, Cognitive Radio & Cooperative Spectrum Sensing, Mathematical modelling, testbed and simulation



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DRAISE - Robust and Reliable Wireless Communication

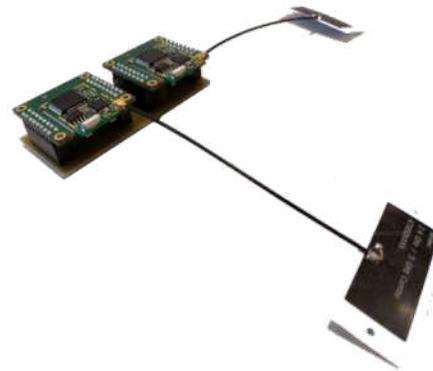
Initial Schedule Negotiation



Continuous Spectrum Sensing

Blacklisting

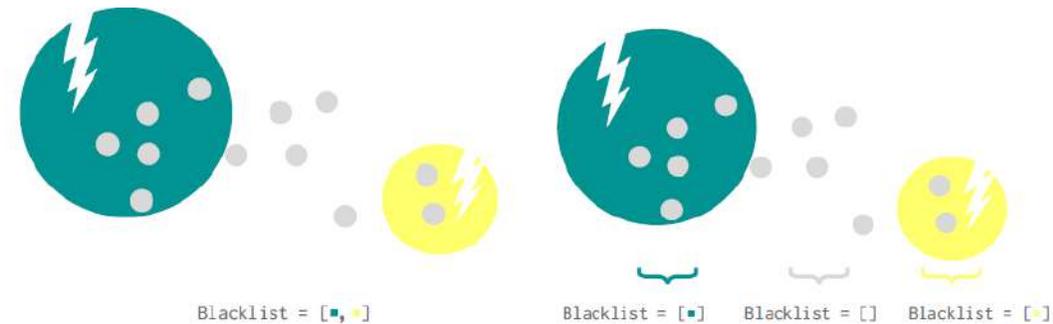
Interference Avoidance



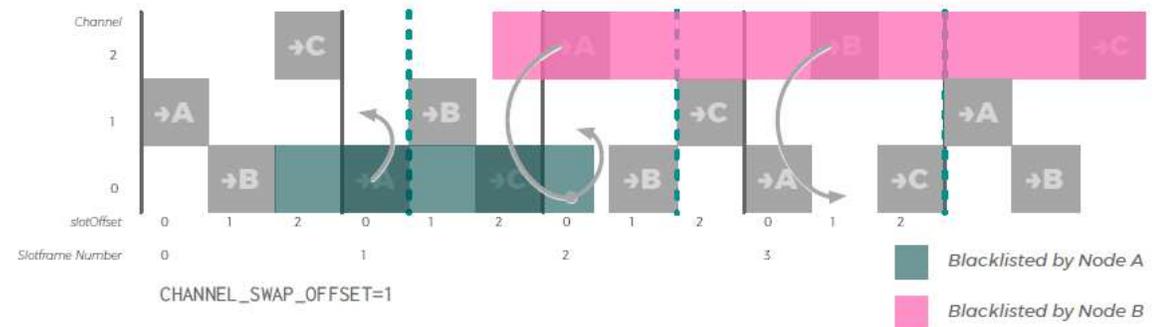
- Scheduling Function that adapts to interference locally
- Designed to be used within the IETF 6TiSCH stack

SFSB: Scheduling function based on dynamic cell allocation between node pairs with extended features

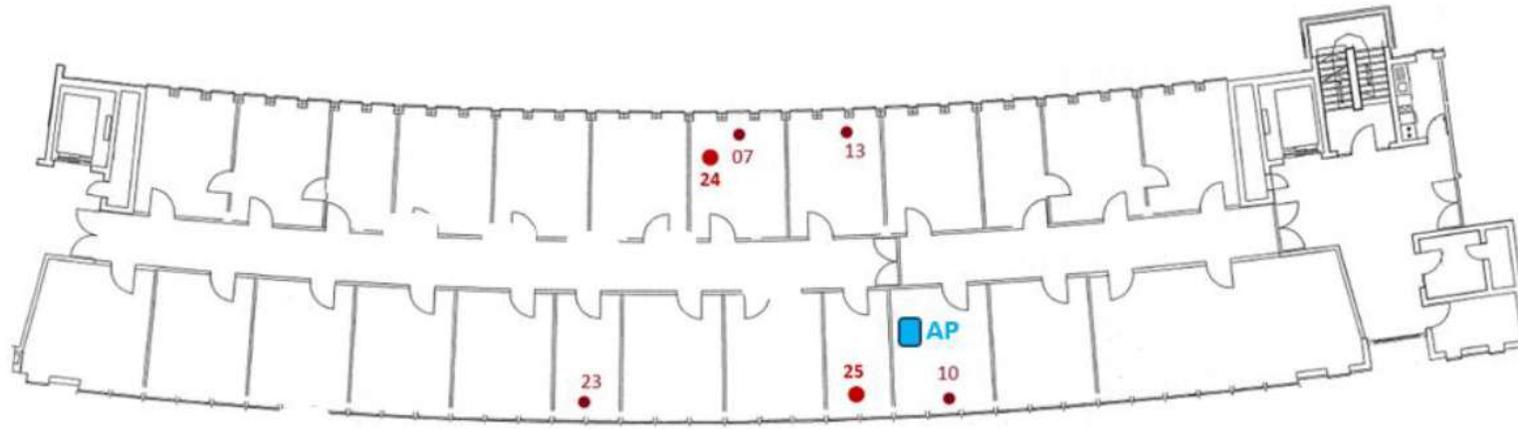
- Local Blacklisting for bad channels
 - **Private blacklist**
 - **Neighbor blacklist** per neighbor
- Channel swapping in case the node picks blacklisted channel from either private or neighbor blacklist



Local vs. global blacklisting



Channel diversion using channel swap offset in SFSB



Institute testbed

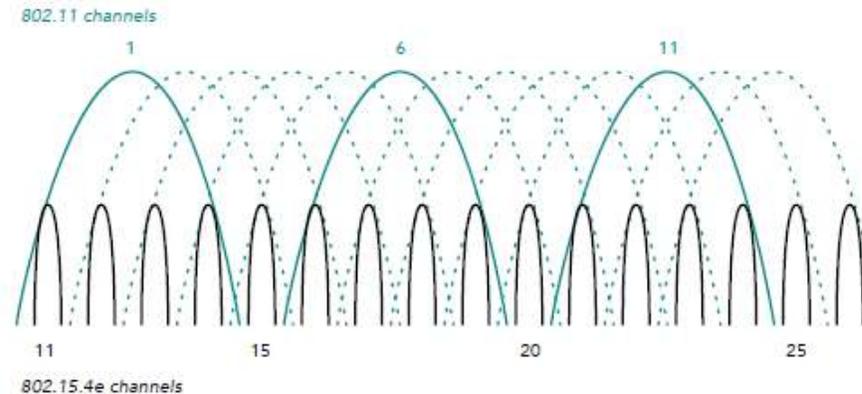


Virtenio Sensor Node with 6TiSCH

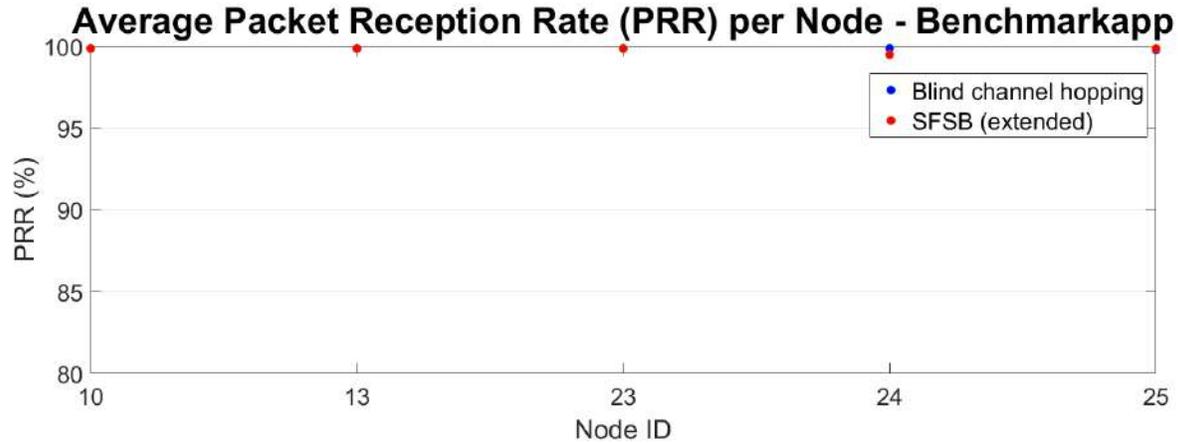
ComNets Testbed

6 Static Nodes and 1 Access Point

- Node-7 is the sink node
- Access Point – traffic on channel-6

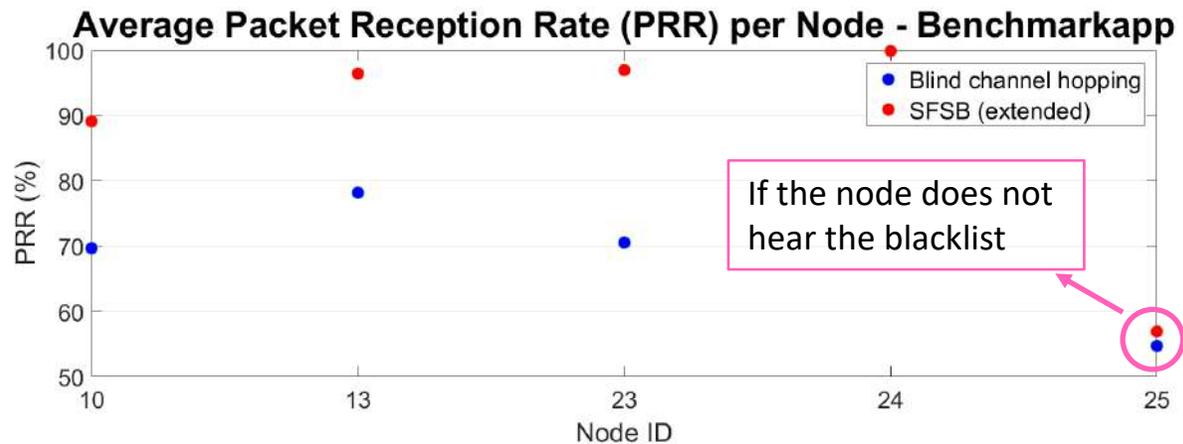


Overlap between IEEE 802.11 and 802.15.4 channels



Average PRR with low traffic

- ▶ Experiment with Low Traffic
 - 5 sec inter arrival time & 5 sec random offset
- ▶ Experiment with High Traffic
 - 1 sec inter arrival time & 100 ms random offset



If the node does not hear the blacklist

Average PRR with high traffic

Thank you! Questions?