BLACKLISTING IN IEEE 802.15.4 NETWORKS

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CONTEXT

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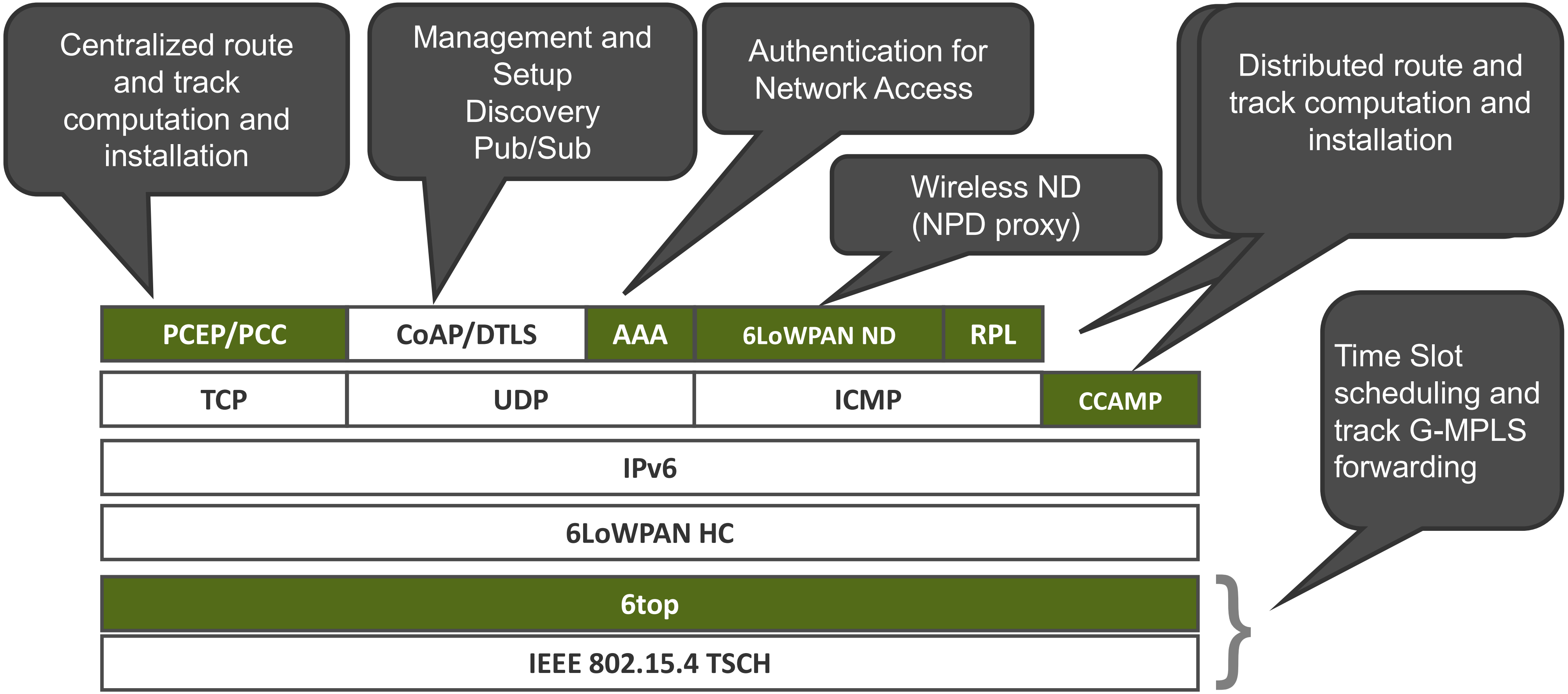
6TiSCH STACK



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Inspired from the slides of Pascal Thubert, “RPL 2017”

IEEE802.15.4 TSCH

▶ Prime characteristics

- Based on IEEE 802.15.4
- **TS**CH: Time-Slotted (synchronized), to allow for distributed implementation
- TS**CH**: Channel Hopping, to give resilience to interference and multi-path fading

IEEE STANDARDS ASSOCIATION ◆IEEE

IEEE Standard for Low-Rate Wireless Personal Area Networks (WPANs)

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.15.4™-2015
(Revision of
IEEE Std 802.15.4-2011)

TIMELINE

- ►2006: TSCH approach emerges in the proprietary *Time Synchronized Mesh Protocol* (TSMP)
- ►2008: TSMP is standardized in ISA100.11a
  - The IEEE 802.15.4e Working group is created:

    Issue: IEEE 802.15.4-2006 MAC is ill-suited for low-power multi-hop network because of
    (i) high energy consumption due to relay/router nodes
    (ii) use of a single channel that implies interference and multi-path fading

    Final aim: to redesign the existing IEEE 802.15.4-2006 MAC Std. and make it suitable for low-power multi-hop networks in industrial applications

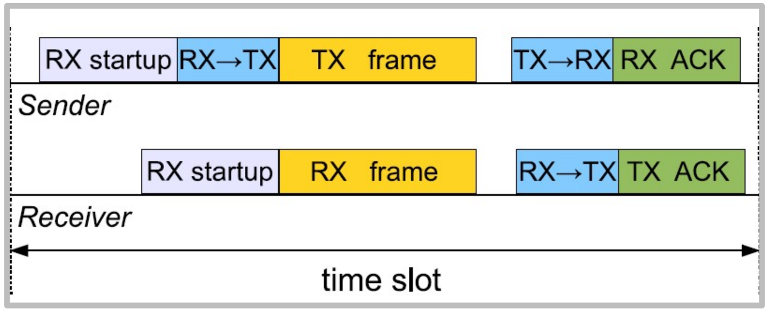
- ►2009: TSMP is standardized in WirelessHART
- ►2010: Part of IEEE 802.15.4e draft
- ►2011: IEEE802.15.4e draft in Sponsor Ballot (opened on 27 July 2011 and closed on 28 August with 96% of votes being affirmative)
- ►2012: IEEE802.15.4e TSCH published
- ►2016: IEEE802.15.4-2015-TSCH published

IEEE 802.15.4 TSCH SCHEDULE

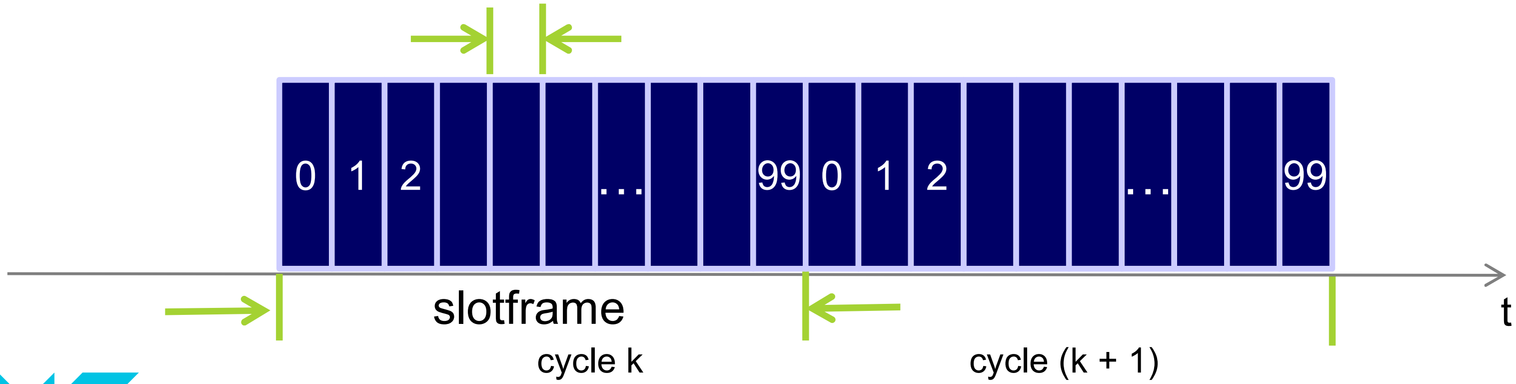
- Each mote follows a communication schedule
- A schedule is a matrix of cells, each of them indexed by a ***timeslot*** and a ***channelOffset***
- Each cell can be ***assigned to a pair of nodes***, in a given direction

IEEE802.15.4 TIME-SLOTTED CH

- Time is divided in ***timeslots***
- All nodes are *synchronized* to a given slotframe
- ***Slotframe****:* group of time slots which repeats over time
- Number of time slots per slotframe is tunable



A single slot is long enough for the transmitter to send a maximum length packet and for the receiver to send back an ACK



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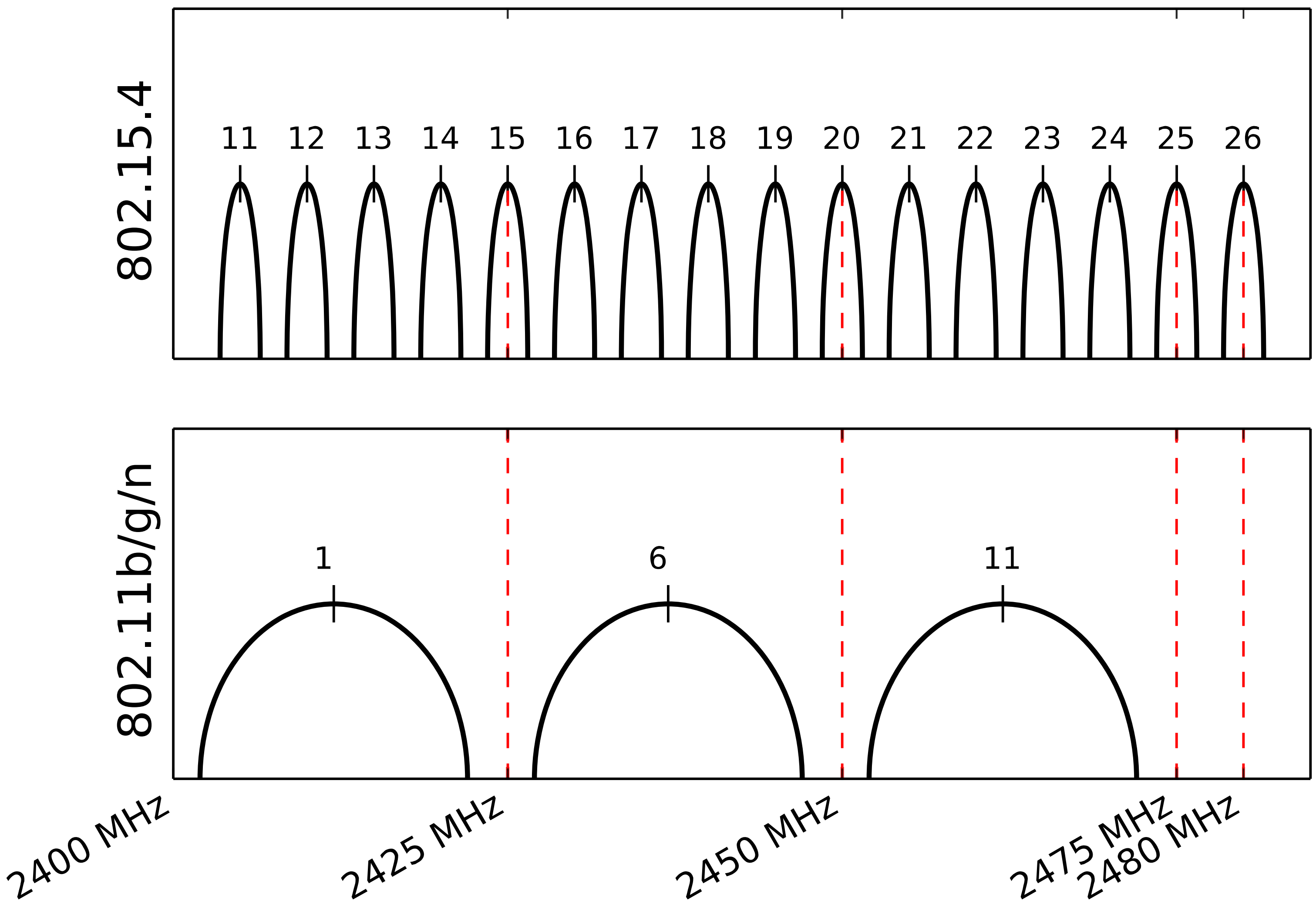
IEEE 802.15.4 TS CHANNEL HOPPING



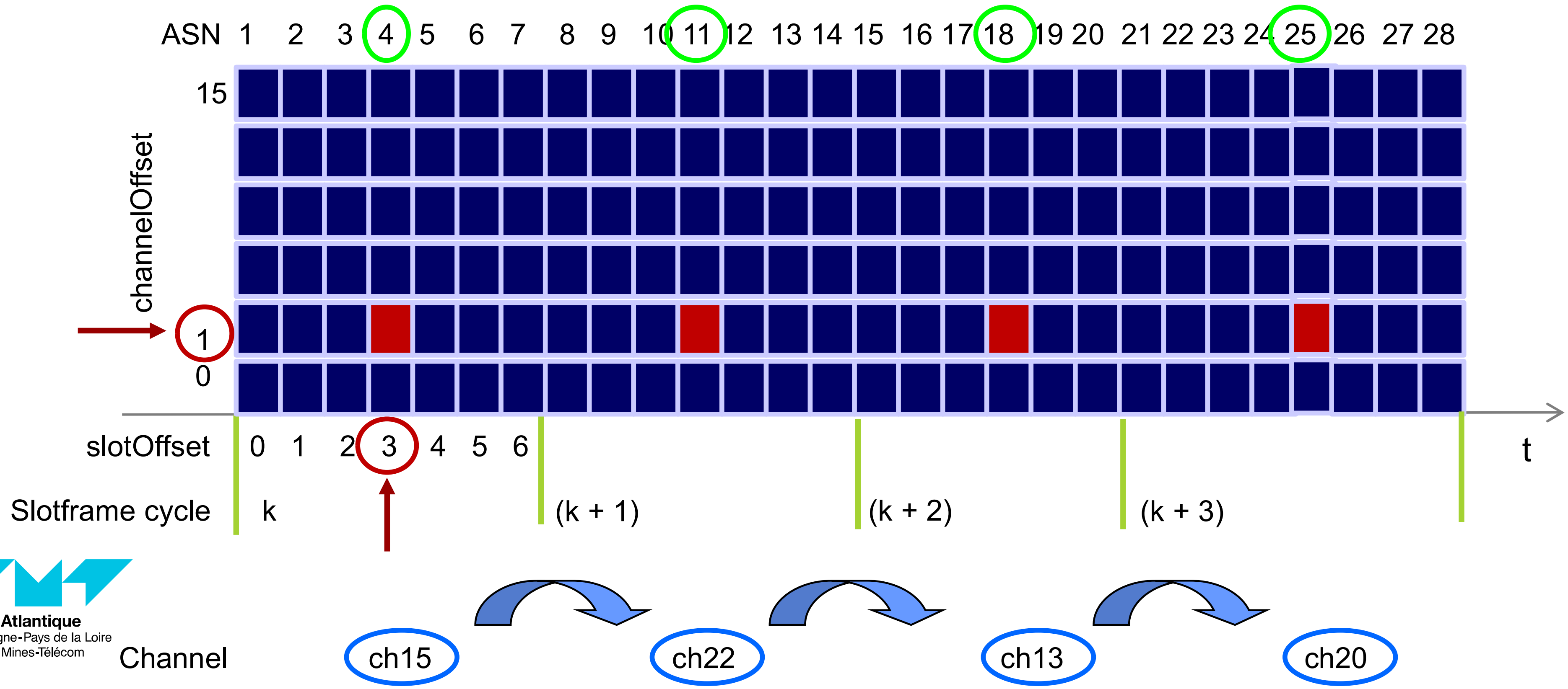
IEEE 802.15.4 TS CHANNEL HOPPING (1/2)

- The channel offset is translated to a radio channel

$$f = F\{(\mathrm{ASN} + chOf) \mod n_{ch}\}$$

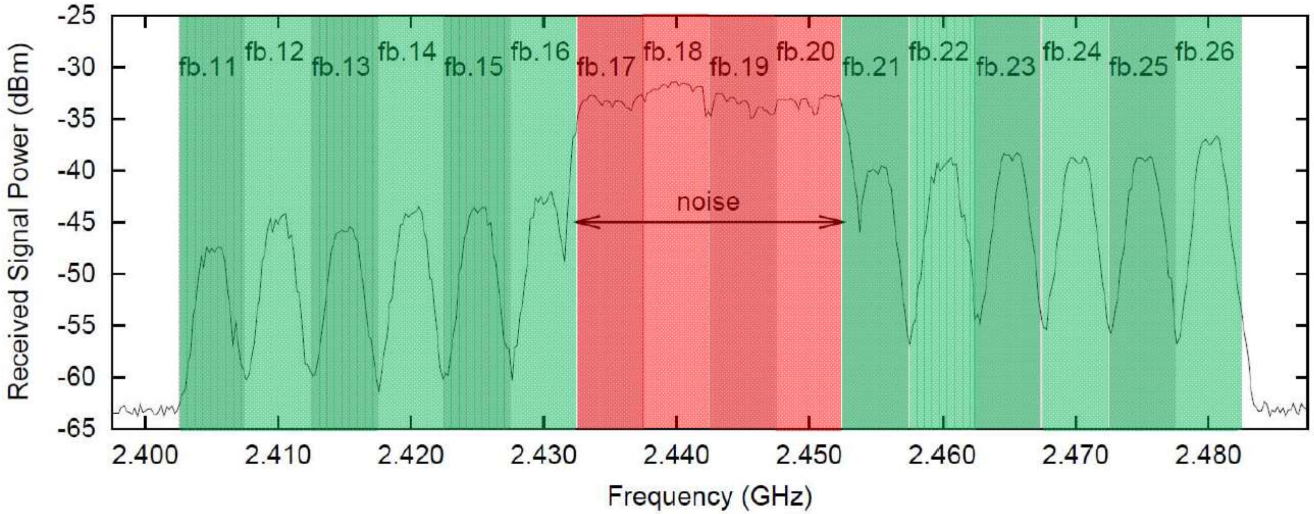
Table I. FrequencyTranslation

k	ASN	$chOf$	f
0	4	1	5
1	11	1	12
2	18	1	3
3	25	1	10



IEEE 802.15.4 TS CHANNEL HOPPING (2/2)

- A node sends subsequent packets on different channels
  - Interference and multipath fading are mitigated
  -



- 16 channels are available in the 2.4GHz frequency band (optional ***blacklist***)
- A single timeslot can be used by multiple pairs of nodes
  - Network capacity is increased

IS BLACKLISTING RELEVANT?

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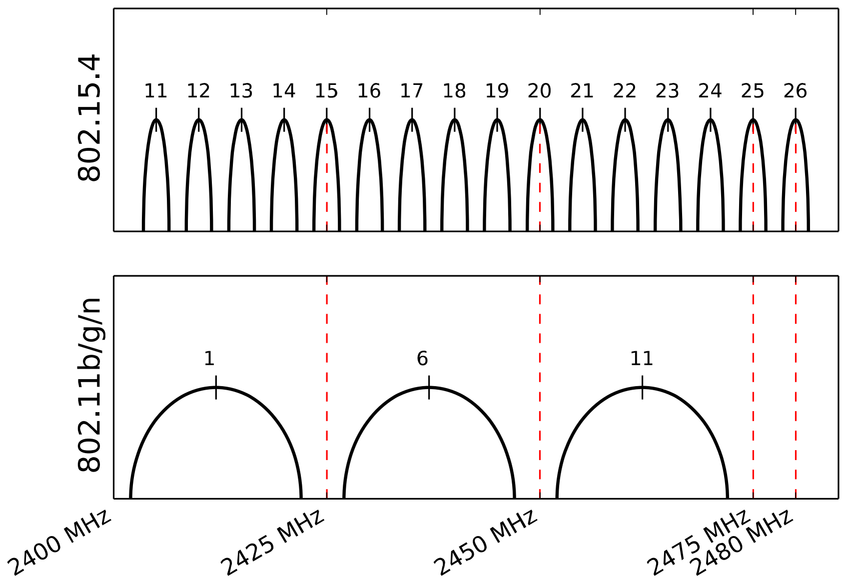
[1] **V. Kotsiou**, G. Z. Papadopoulos, P. Chatzimisios, and F. Theoleyre. ”*Is Local Blacklisting Relevant in Slow Channel Hopping Low-Power Wireless Networks?”*, ***IEEE International Conference on Communications (ICC), 2017.***

IEEE 802.15.4-2015: BLACKLISTING

- Blacklisting
  - Detecting *bad* channels
  - Channel Hopping without these bad channels
  - Global: certain channels should be globally blacklisted
  - Local: a radio channel should not be used by a pair of nodes

- Question: Is ***local*** Blacklisting relevant in Channel Hopping?
  - Different zones / links / nodes: different blacklisted channels?



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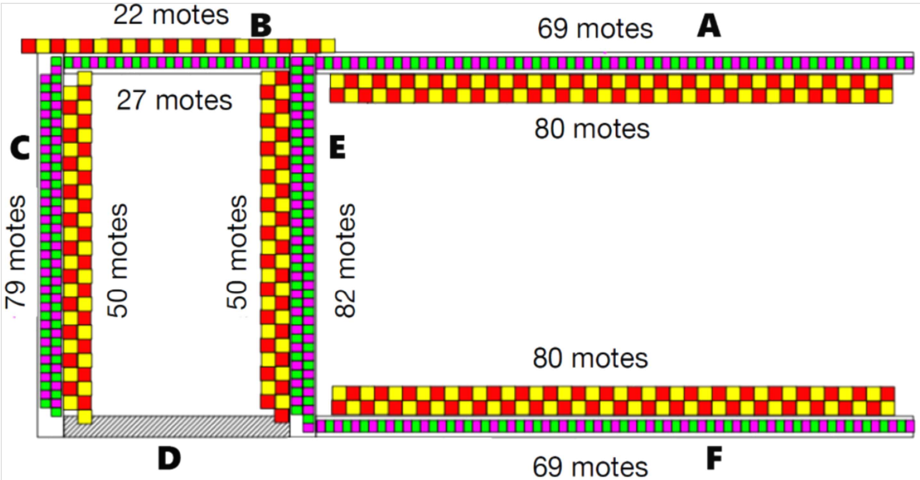
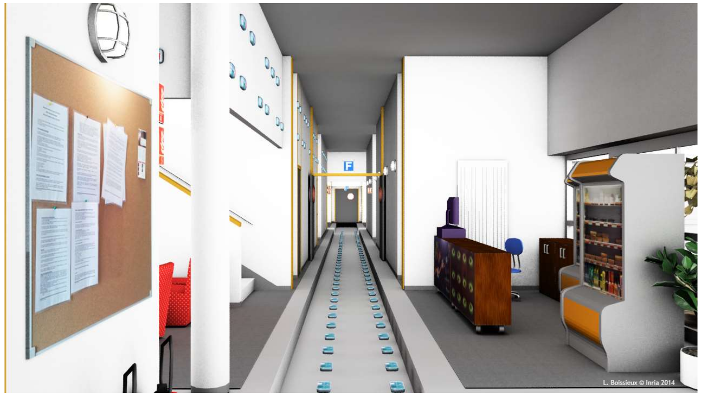
EXPERIMENTAL SETUP





FIT IoT-LAB Platform: *Grenoble's site*

Parameter	Value
# of nodes	2
Nodes spacing	0.6 - 17 *m*
Duration	90 *min*
# of experiments	*200*
Application model	1 *pkt / 3 sec*

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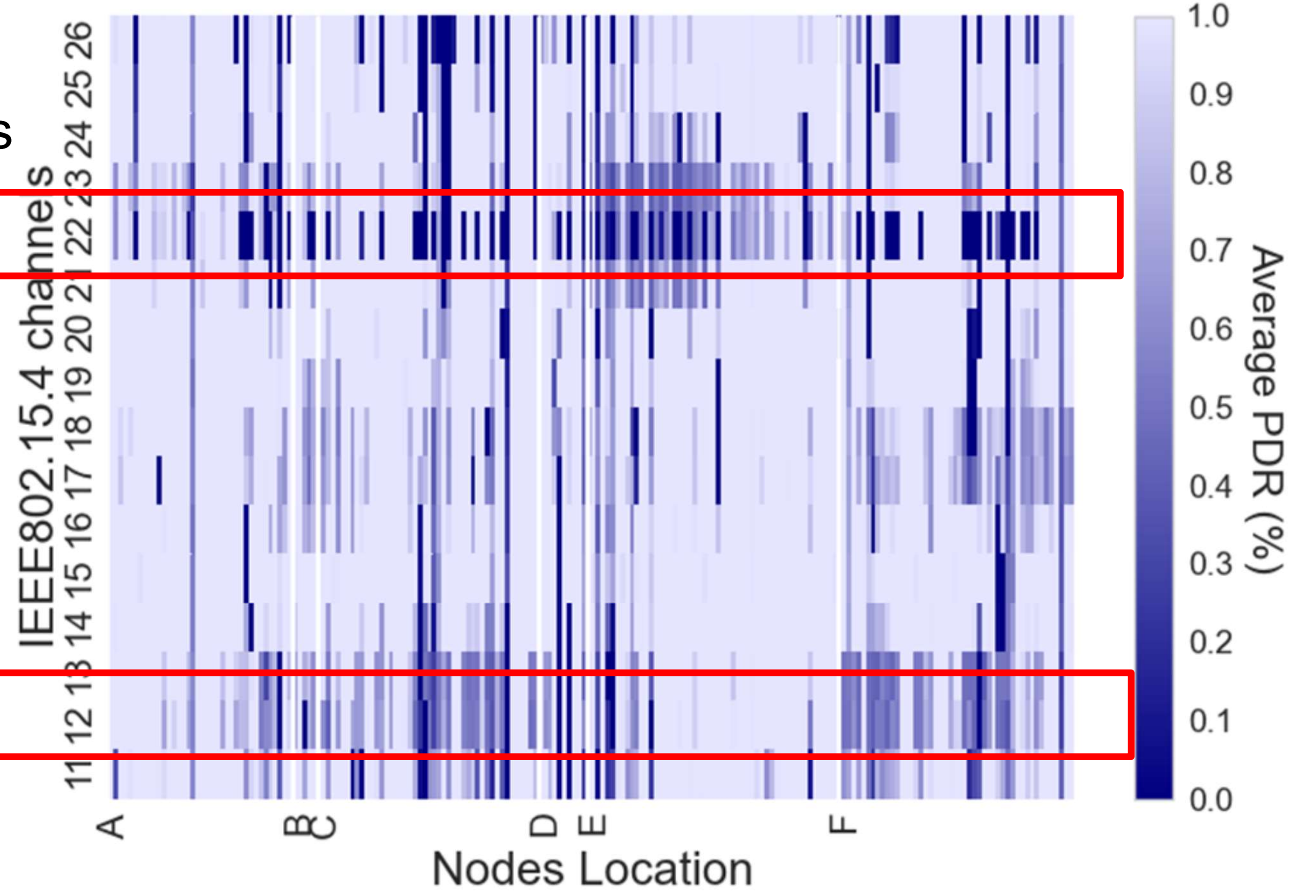
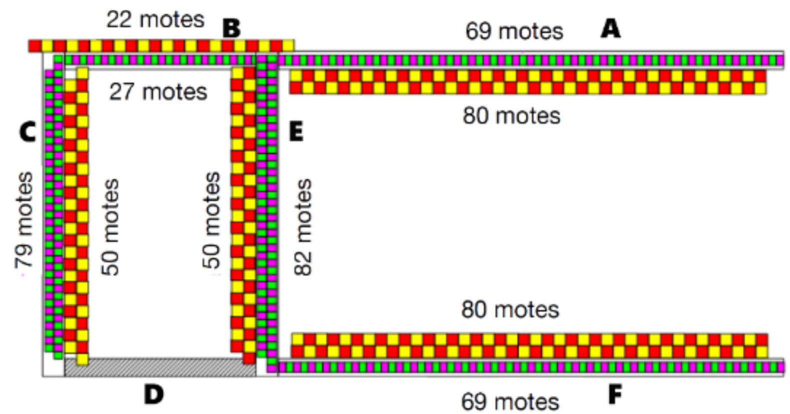
GEOGRAPHIC VARIABILITY

Bad channels for many links

Specific local properties
(corridors CF& AE)





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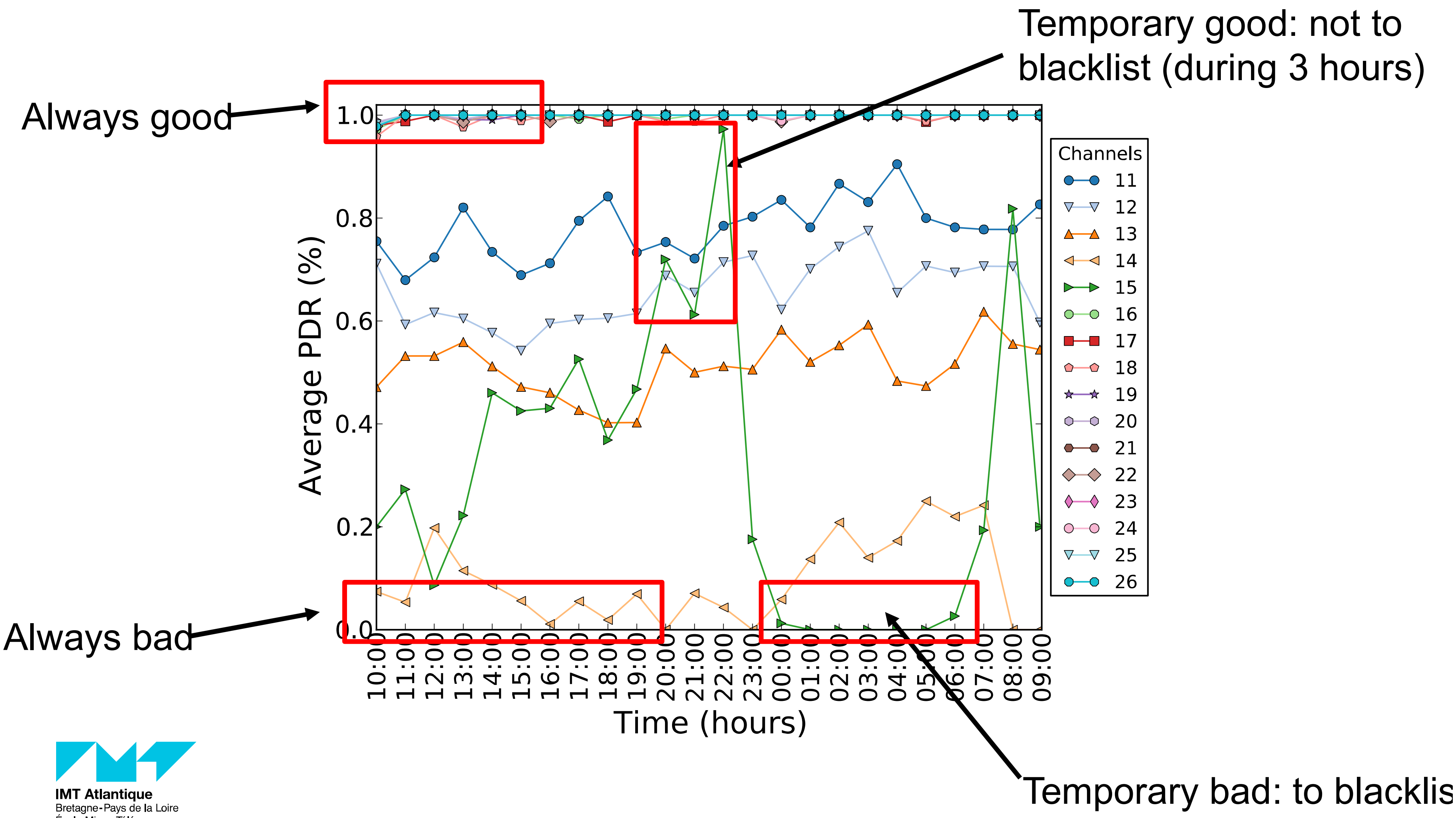
TIME VARIABILITY

RX/TX distance = 9m



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CHALLENGE

- Challenge: deterministic Channel Hopping
  - Different channel offsets → lead to collisions → detection and reconfiguration

COLLISION EXAMPLE 1

	A->B				**C->D**			
	Channel Offset	2			Channel Offset	1		
	Whitelist	1	5		Whitelist	5	7	
ASN	Radio Channel				Radio Channel			
0	1				7			
1	5				5			**Collision**
2	1				7			
3	5				5			**Collision**
4	1				7			
5	5				5			**Collision**
6	1				7			
7	5				5			**Collision**
8	1				7			
9	5				5			**Collision**
10	1				7			
11	5				5			**Collision**
12	1				7			
13	5				5			**Collision**

F() = good[Offset + ASN mod 2]

Collision in all even timeslots!

LINK-BASED ADAPTIVE BLACKLISTING TECHNIQUE

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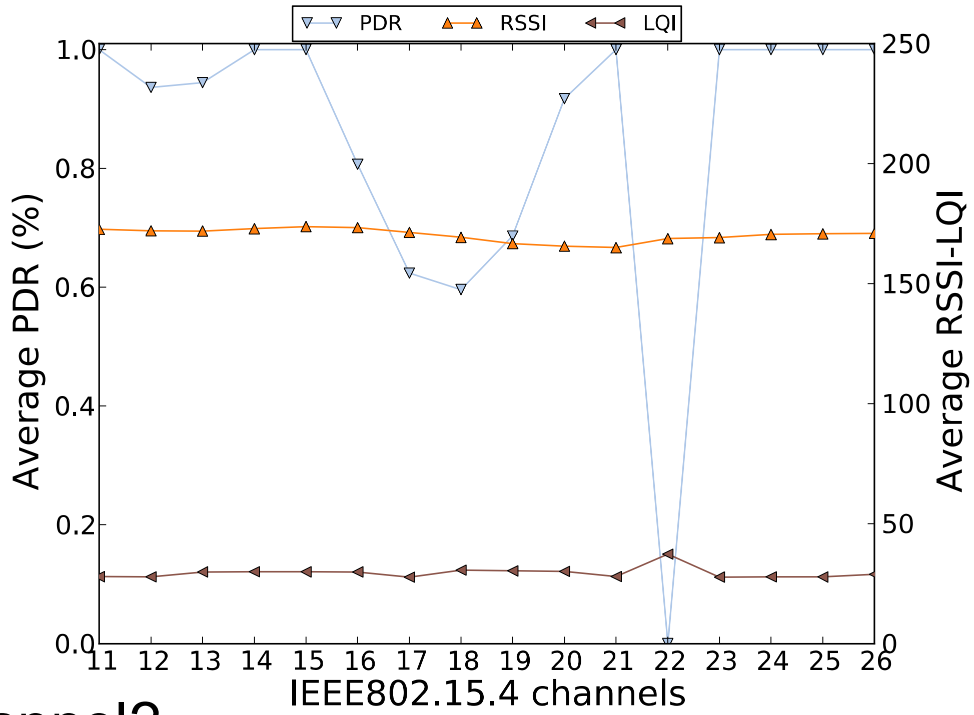
[2] **V. Kotsiou**, G. Z. Papadopoulos, P. Chatzimisios, and F. Theoleyre, "*LABeL: Link-based Adaptive BLacklisting Technique for 6TiSCH Wireless Industrial Networks*", ACM ***International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM)***, **2017.**

DECIDING WHICH CHANNELS TO BLACKLIST

- Which channel quality metric we use?
  - RSSI-LQI are not suitable: calculated for received data packets.
  - PDR is the most accurate indicator to detect bad channels.



- How to predict the quality of a channel?
  - We use Window Mean Exponential Weighted Moving Average (WMEWMA) estimator to smooth the above PDR values

$$PDR_{wmewma}[c] = aPDR_{wmewma}[c] + (1-\alpha)PDR_{last16}[\mathrm{c}]$$

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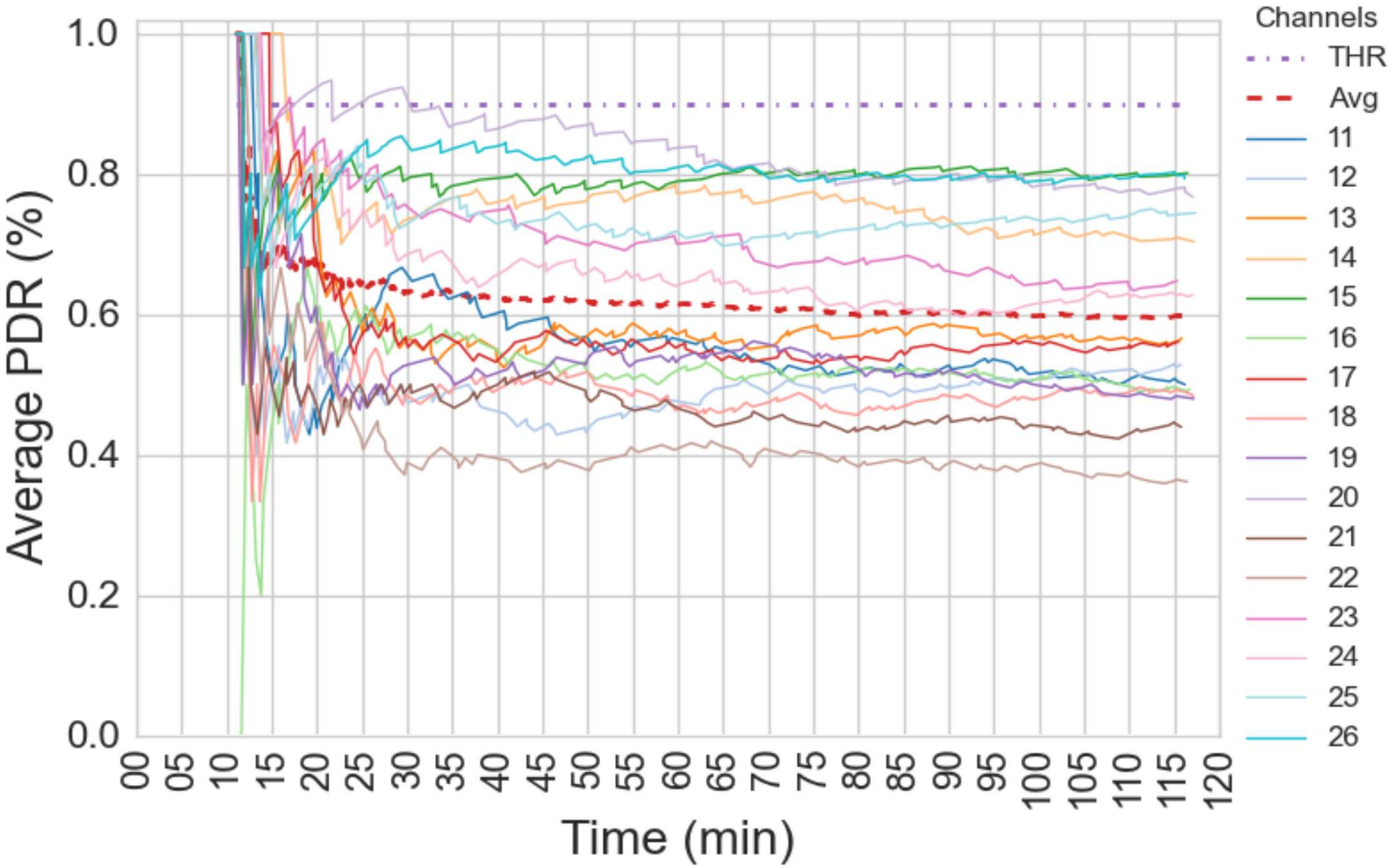
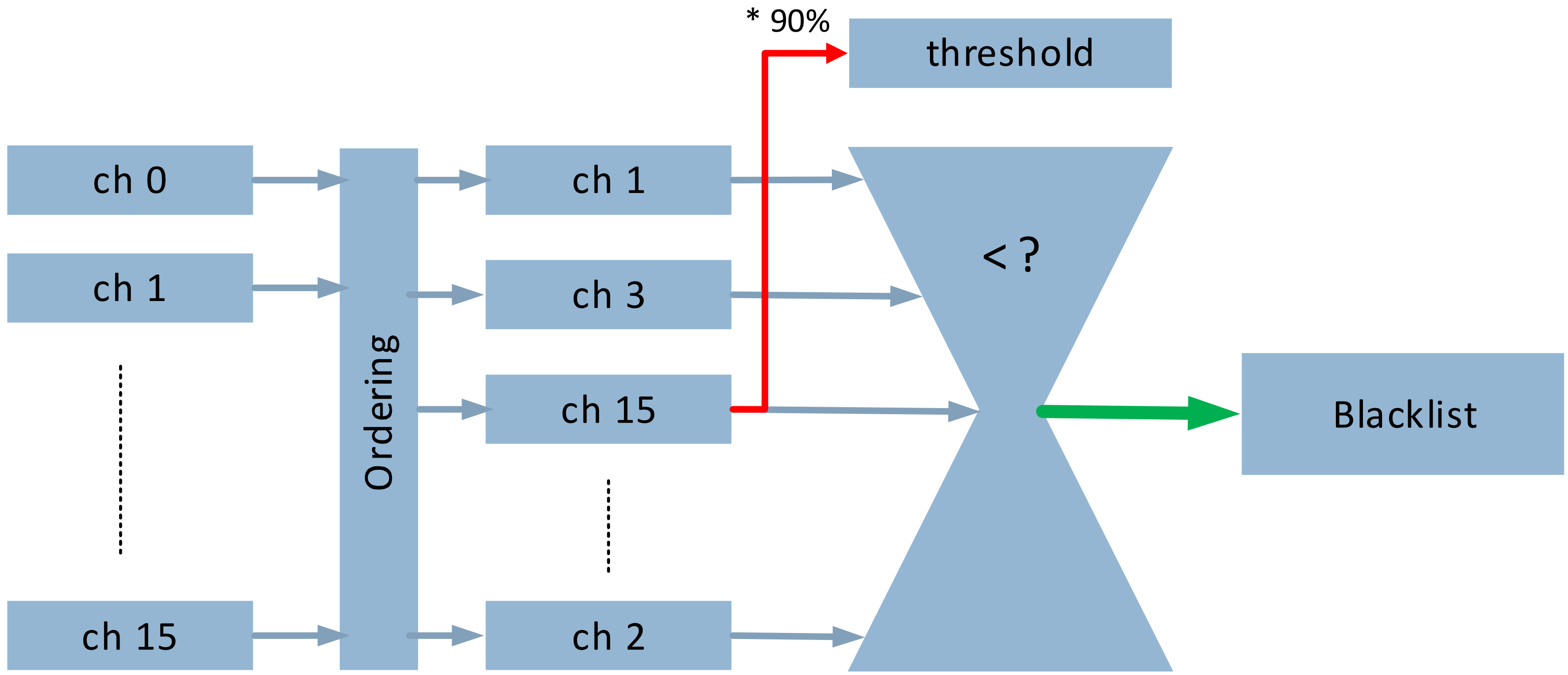
WHICH CRITERION SHOULD BE USED TO DECIDE WHICH CHANNELS TO EXCLUDE FROM THE CHS ?

- ► Fixed Threshold value.
  - In the case of a low-quality links, all channels maybe blacklisted.



WHICH CRITERION SHOULD BE USED TO DECIDE WHICH CHANNELS TO EXCLUDE FROM THE CHS ?

- Adaptive Threshold value.
  - depends on the link quality
- Blacklist Construction
  - Depends on the PDR of the ***k*th best radio channel**



MODIFYING THE CHANNEL HOPPING SEQUENCE

LookUp Table

Index	Channel
0	***16***
1	***17***
2	***23***
3	***18***
4	***26***
5	***15***
6	***25***
7	***22***
8	***19***
9	***11***
10	***12***
11	***13***
12	***24***
13	***14***
14	***20***
15	***21***

ASN	***chOffset***	***k***	***Index***	***Channel***
25	0	0	9	***11***

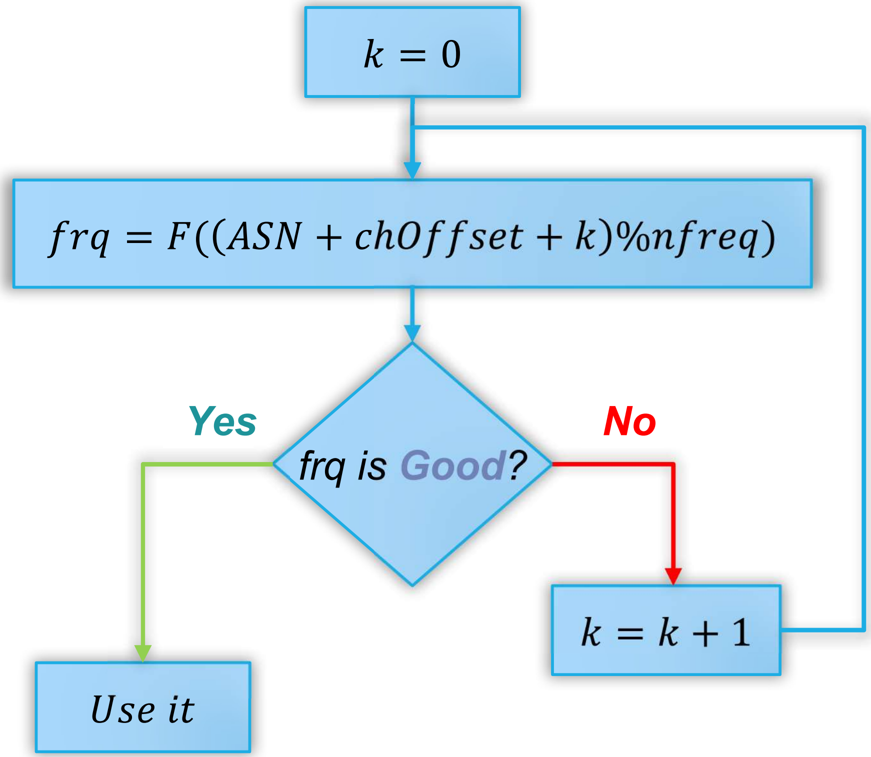
$$(ASN + chOffset + k)\%nfreq$$

$$(25 + 0 + 0)\%16$$

$$9$$

$$\mathrm{F}(9)$$

$$11$$



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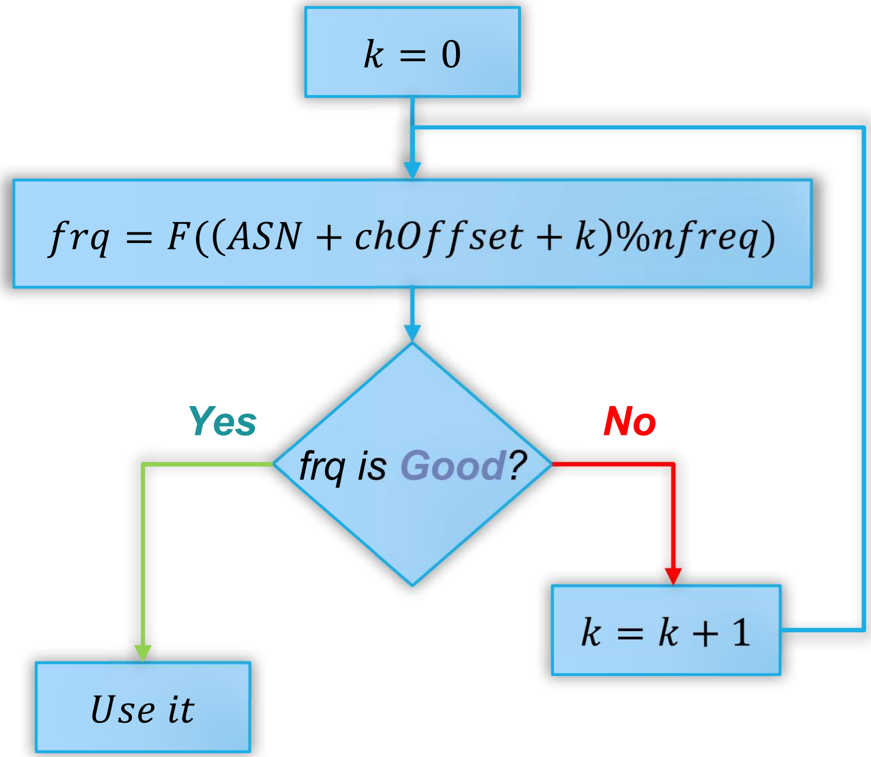
13	***14***
14	***20***
15	***21***

ASN	***chOffset***	***k***	***Index***	***Channel***
25	0	0	9	***11***
33	0	0	1	***17***
33	0	1	2	***23***
33	0	2	3	***18***



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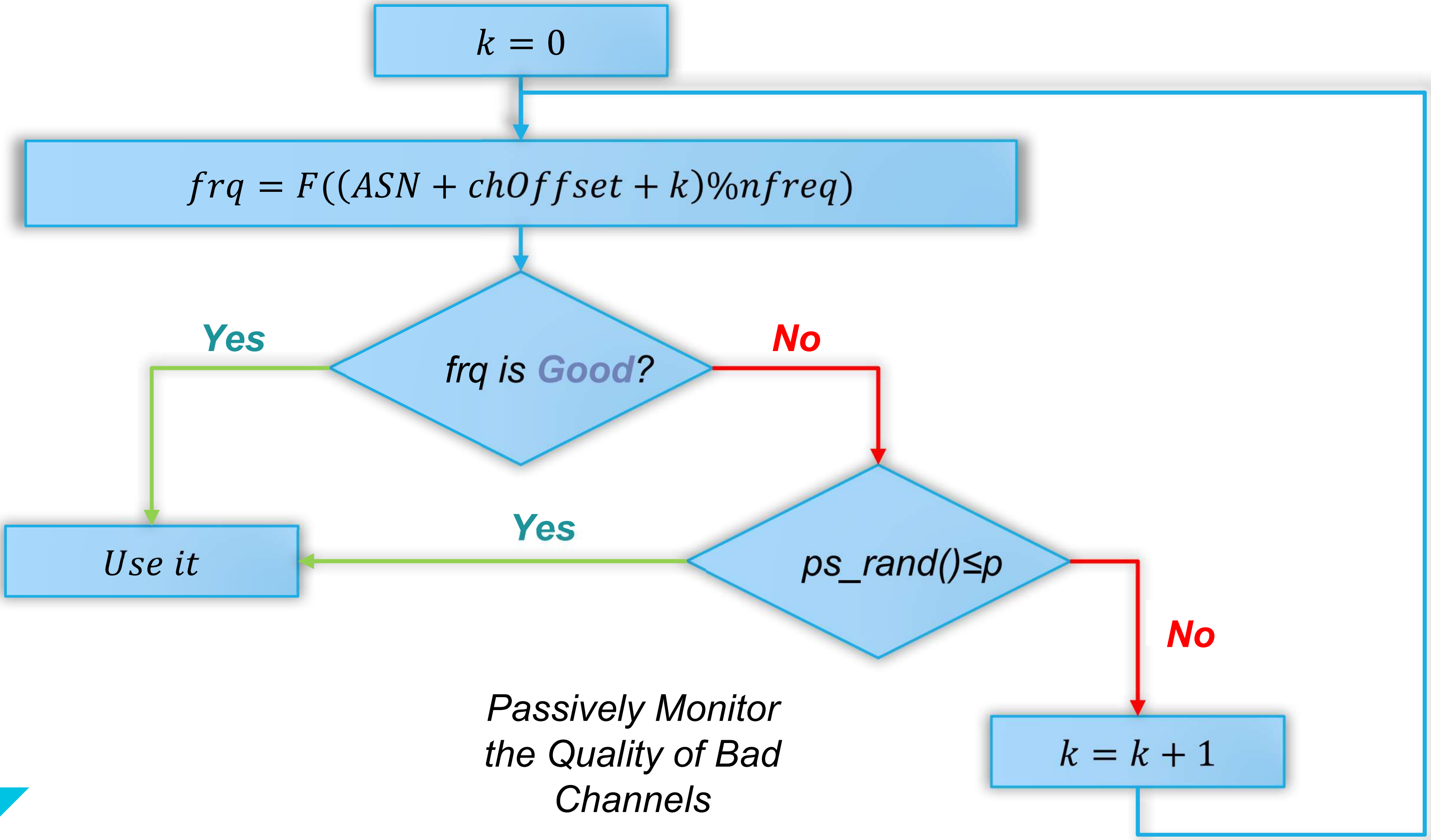
PASSIVELY MONITOR THE QUALITY OF BAD CHANNELS

- Probe – Control packets.
  - Produces unnecessary traffic
- Passively monitor the Quality of Bad Channels.



Passively Monitor the Quality of Bad Channels

SOME RESULTS

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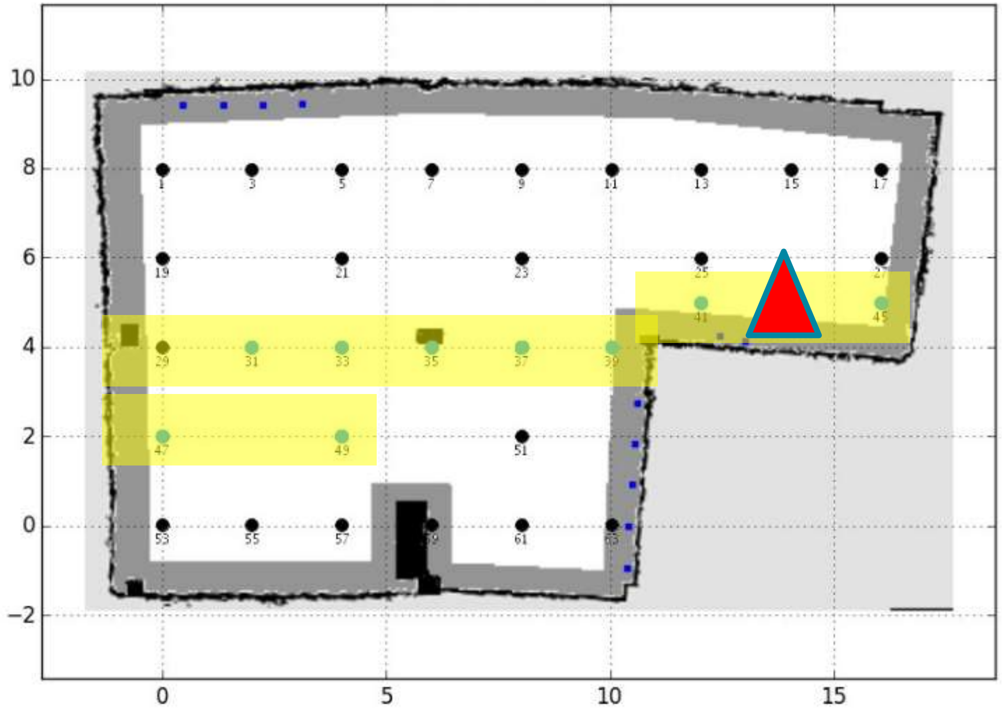
FIT IOT-LAB PLATFORM [STRASBOURG SITE]

Default: all the channels
Global Blacklisting: 3 worst channels
Local-Fixed: PDR < 90%
Local-Adaptive: LABeL: adaptive Blacklist

10 nodes
Star topology



Strasbourg Site Topology

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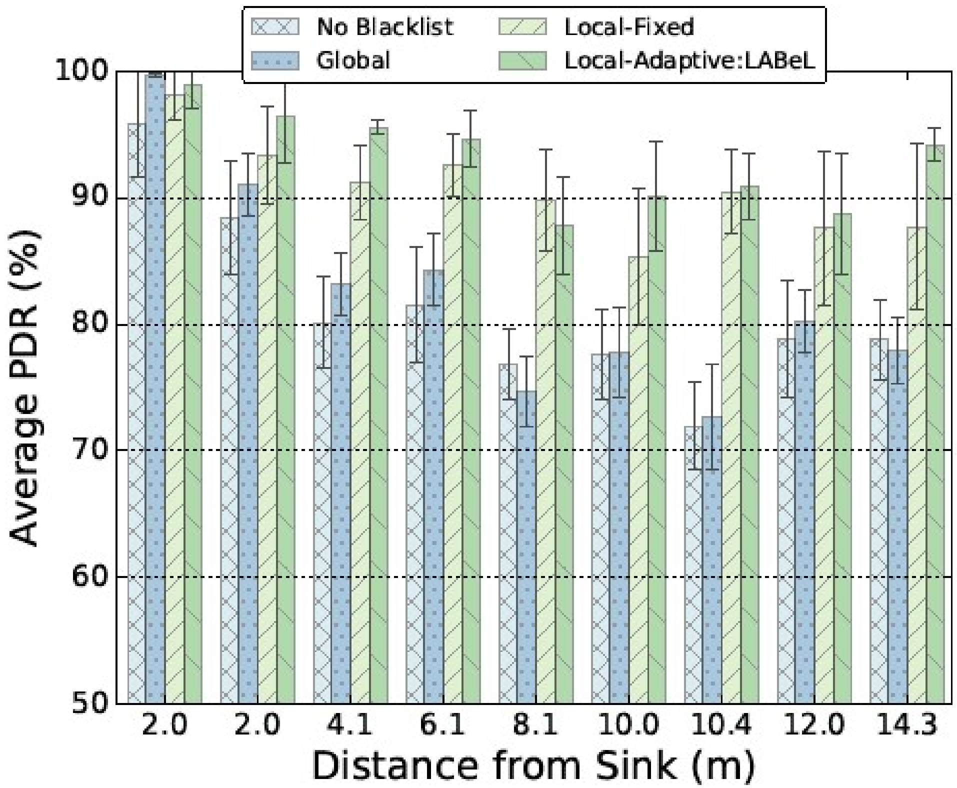
RELIABILITY (PDR)



All the blacklisting techniques improve in some extent the PDR

- Global: lowest improvement
- Local: Blacklisting: suboptimal
- LABeL: outperforms all other techniques.

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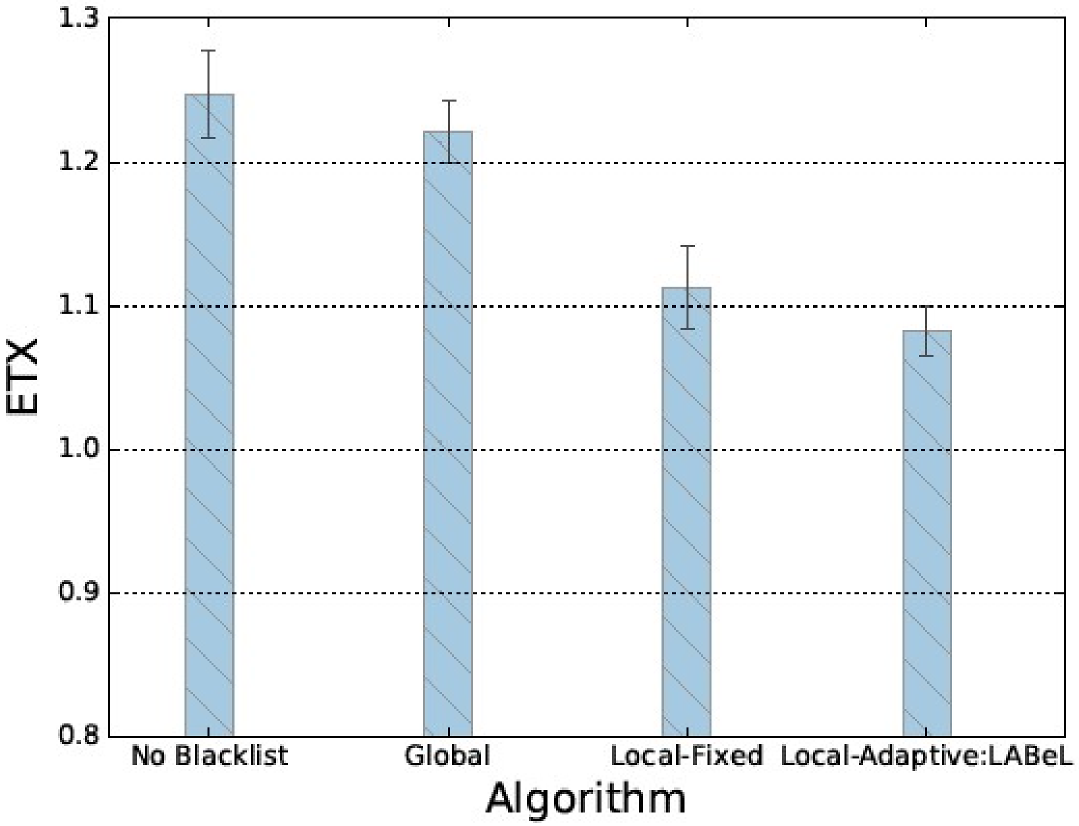
EXPECTED TRANSMISSION COUNT (ETX)



LABeL provides an ETX below 1.1, making on average links more robust (14% less transmissions compared to without backlisting).

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