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# 5G and context awareness for MAV communication

Sofie Pollin and Bertold Van den Bergh
Zurich, Nov 3, 2014
FLY.net workshop

# MAV communication: easy!?

# Outline

- The case for Wifi
  - Measured and analyzed
- 5G and MAV
  - Drivers for 5G and MAV
  - Full Duplex as an example
- Conclusions

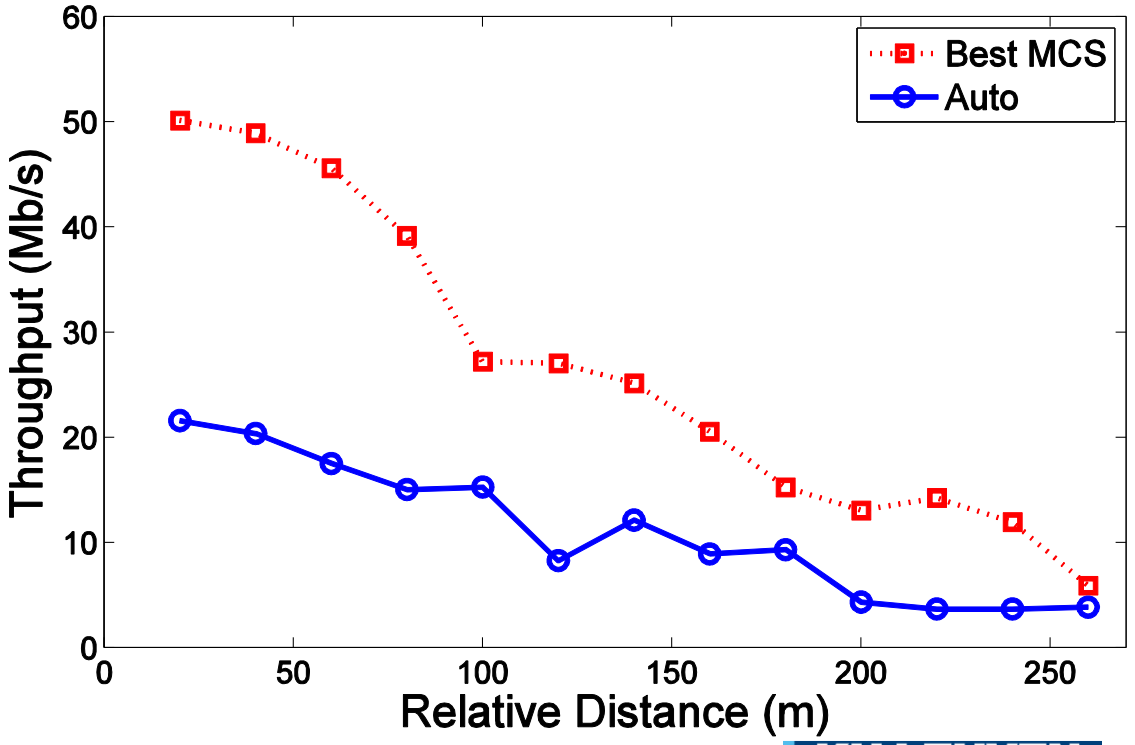
# Aerial measured performance order of magnitude worse than on the ground

On-the-ground measured maximum: 176 Mb/s

Bad control causes **loss of > factor 2**

**Total losses > factor 8!**

- **Impact of Frame?**
- **MIMO loss?**
- **Impact of Interference?**

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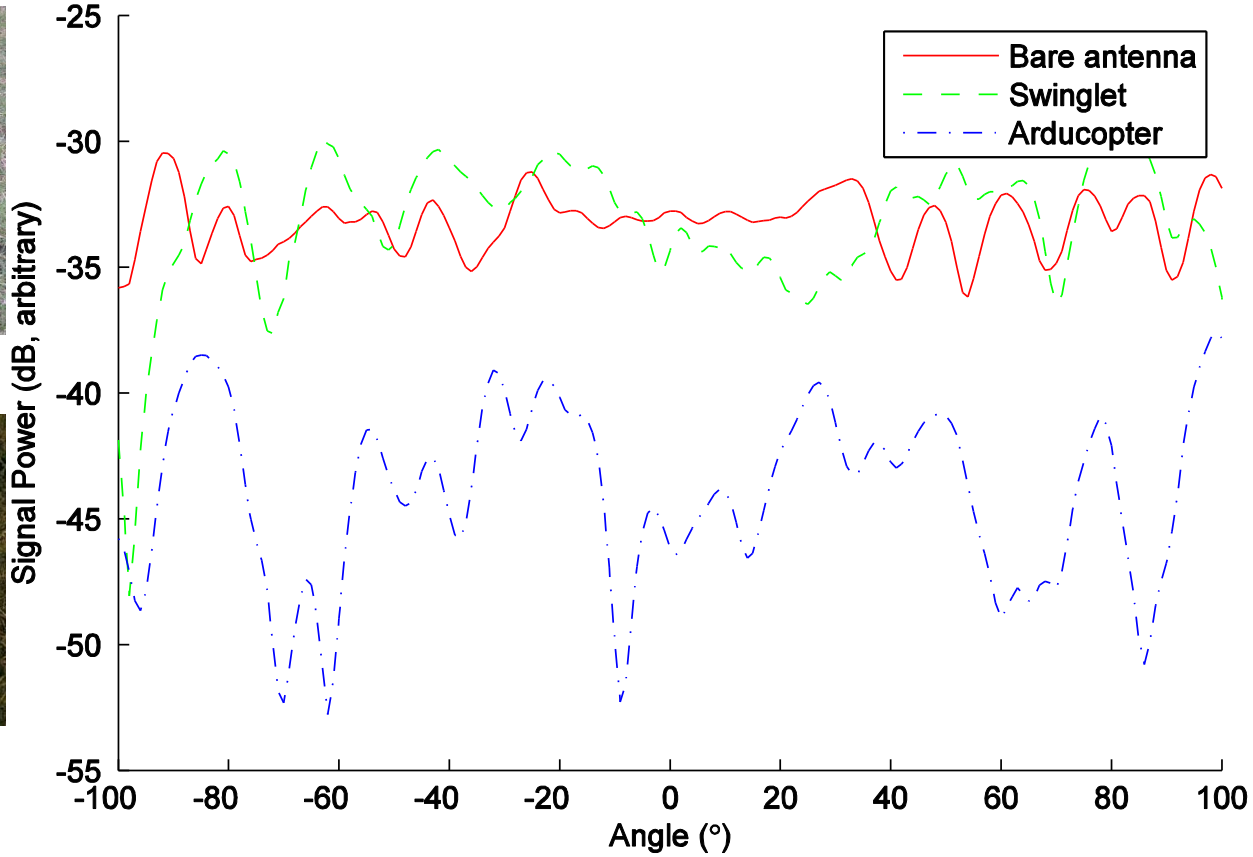
Mahdi Asadpour, Bertold Van den Bergh, Domenico Giustiniano, Karin Anna Hummel, Sofie Pollin, and Bernhard Plattner,
**Micro aerial vehicle networks: an experimental analysis of challenges and opportunities**,
IEEE Communications Magazine 52(7): 141-149, July 2014

# Impact of the frame: reflections



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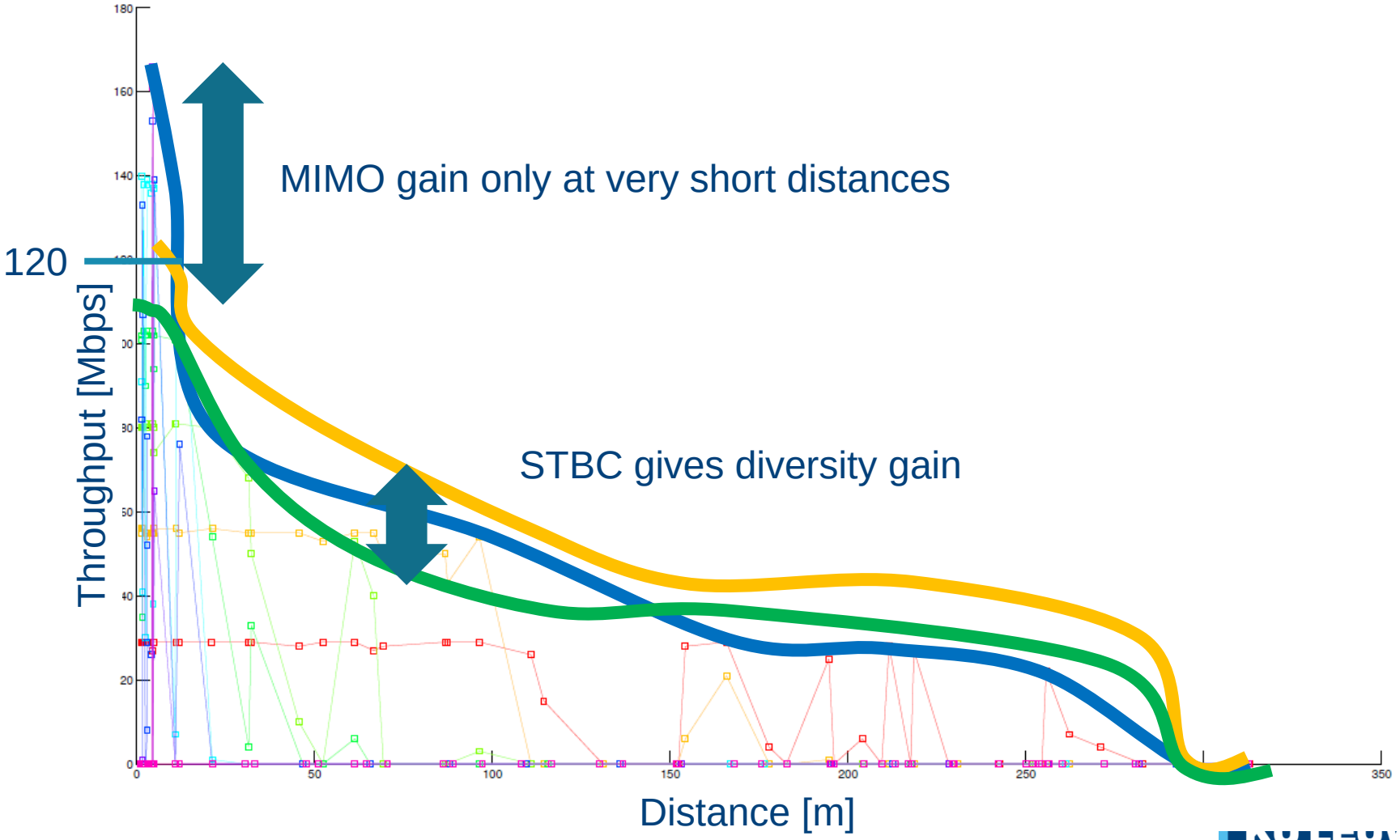
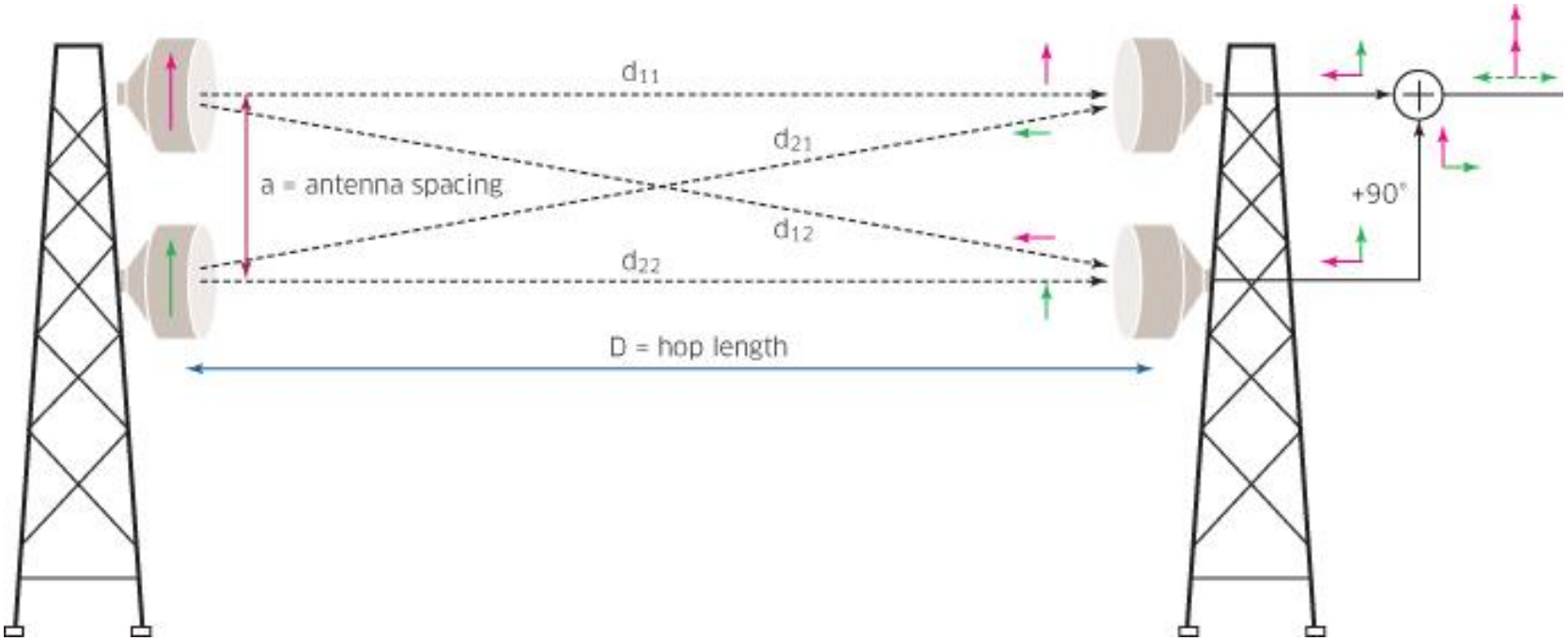
# Measurements without the frame: SISO case

# Gain of multiple antenna techniques



# LOS MIMO

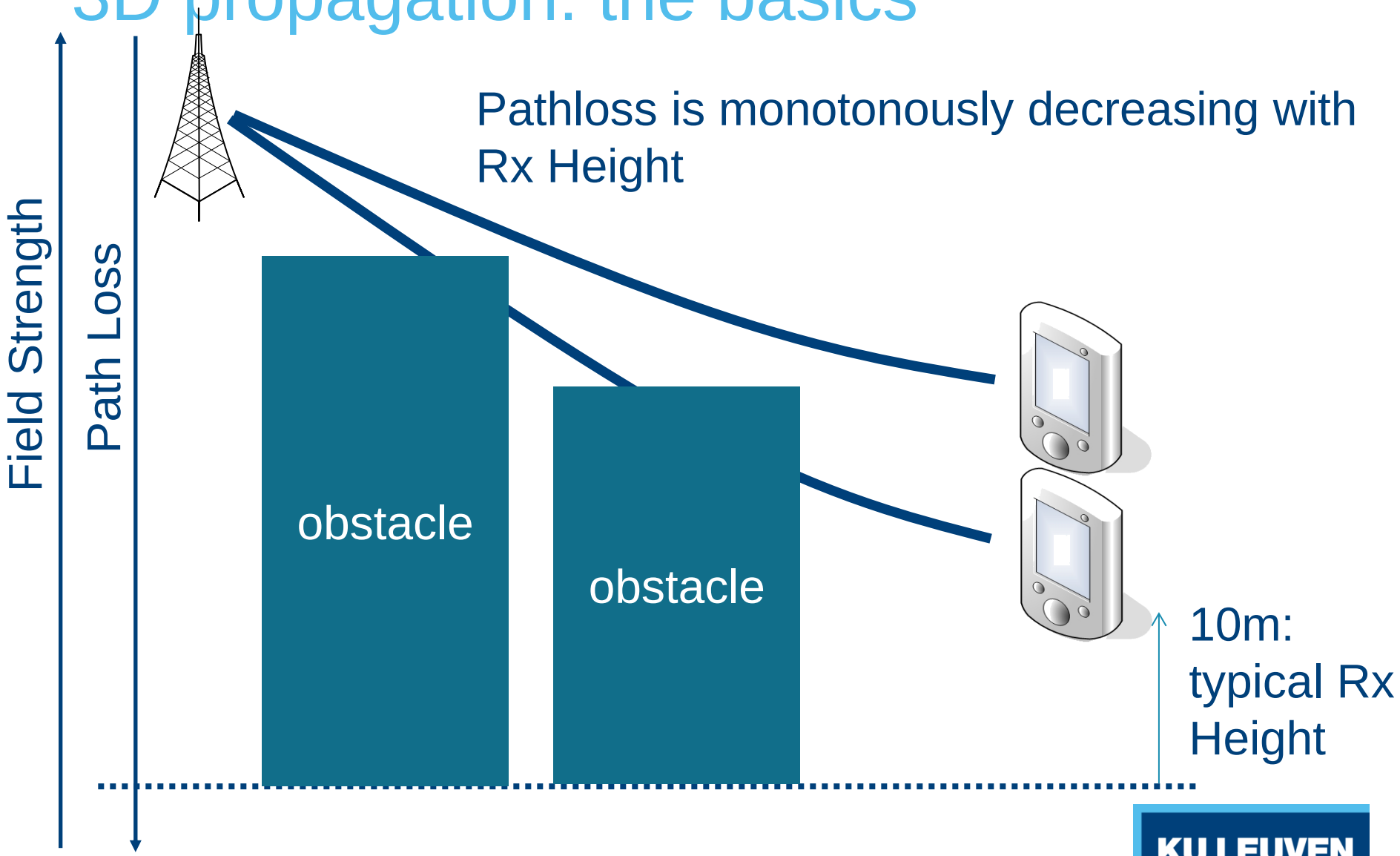



$d \approx \sqrt{\frac{\lambda R}{2}}$ gives **70 cm** at 10m, 2.4 GHz

Alternative: two polarizations

[Source: Alcatel Lucent]

# 3D propagation: the basics

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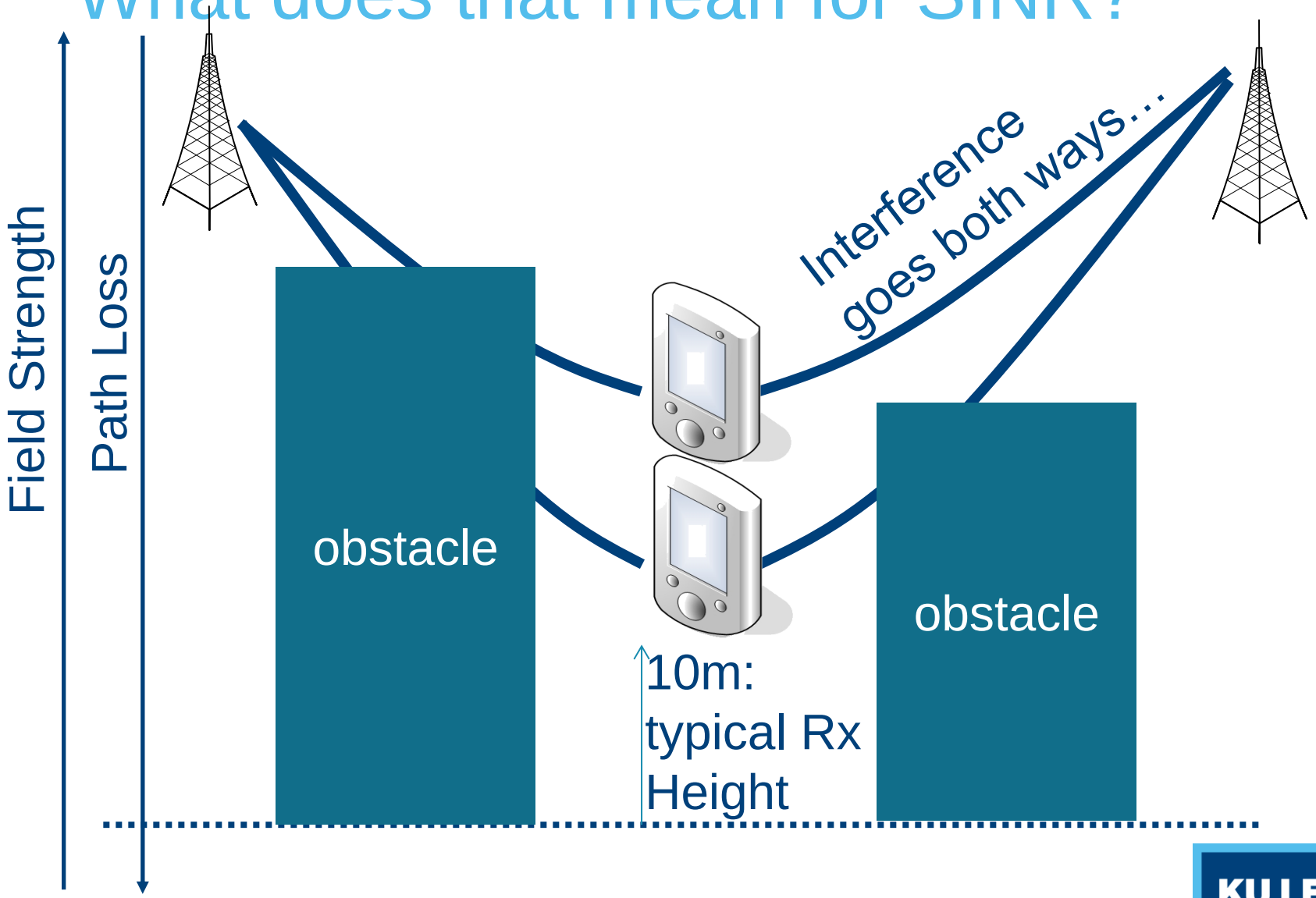
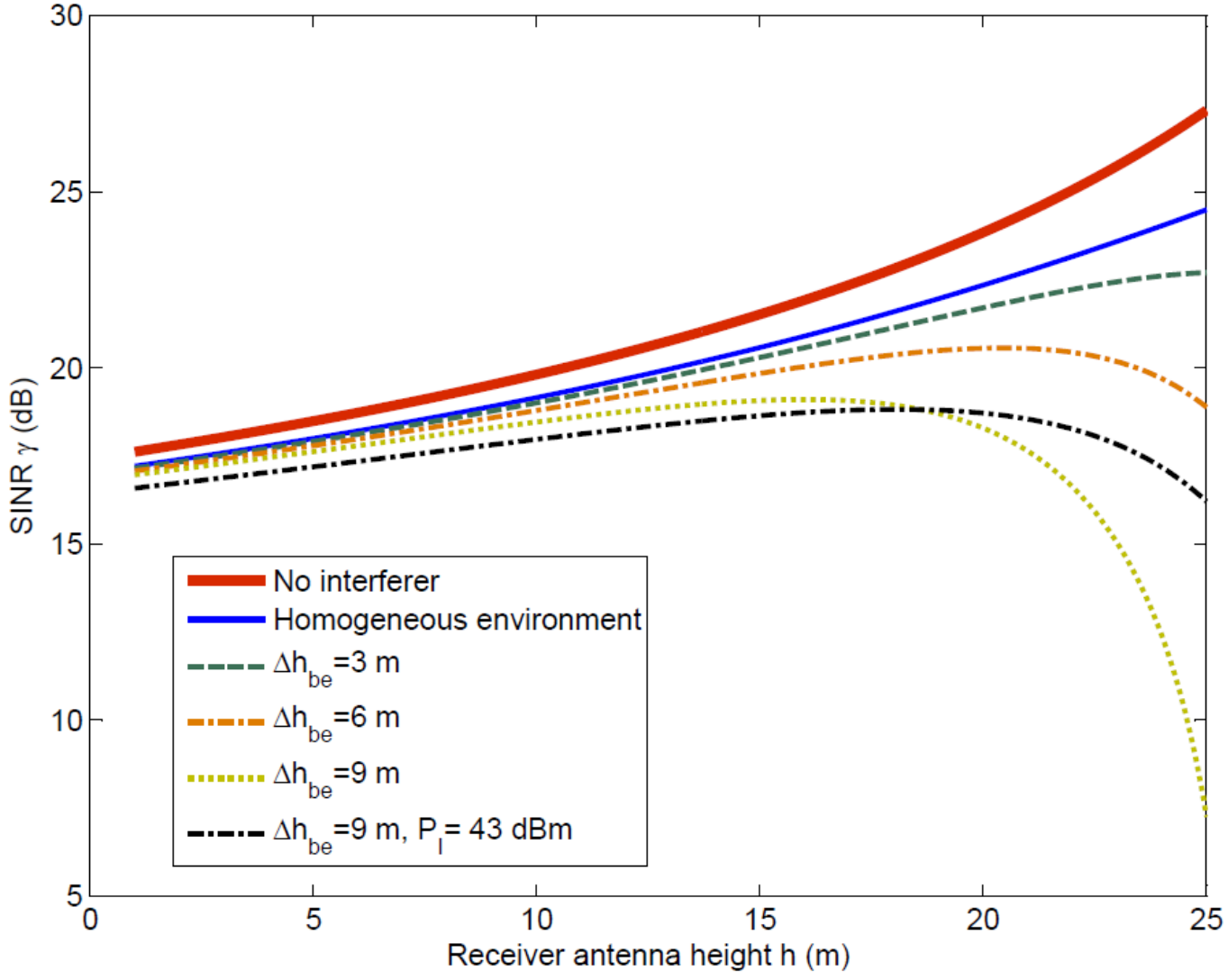
# What does that mean for SINR?



# SINR could be decreasing with Rx height



# 3D spectrum sharing

- FCC statement: **Drones seen driving spectrum sharing technologies**

… J. Knapp added that because unmanned aircraft "come in all shapes and sizes" depending on applications, "you have to be concerned about command and control," for example, and emerging capabilities like real-time video….

- MAVs have to share spectrum with incumbent (terrestrial) solutions

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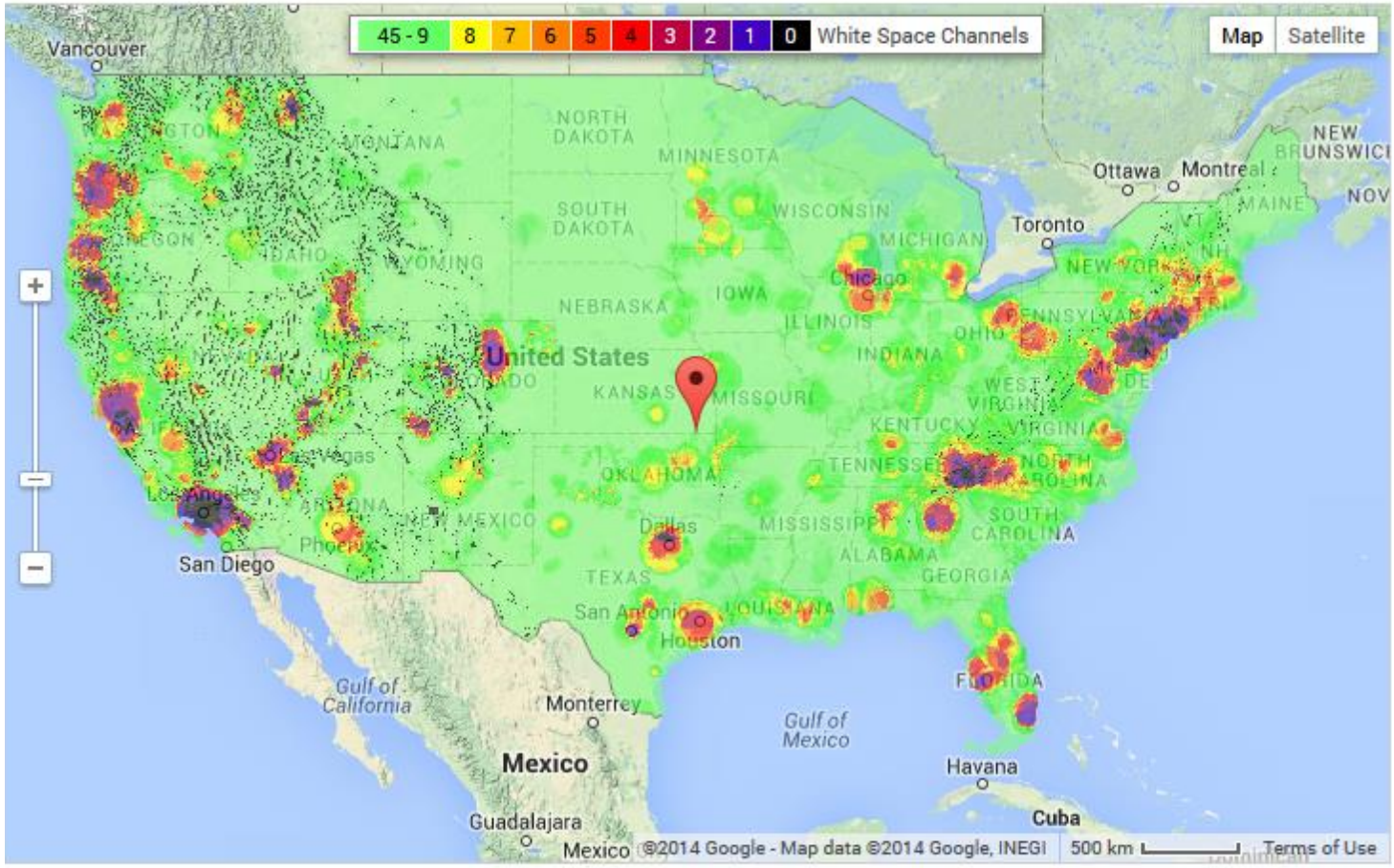
# Google TV White Spaces




Spectrum availability (as of October 31, 2014)

10m gives
21 channels

50m gives
no channels

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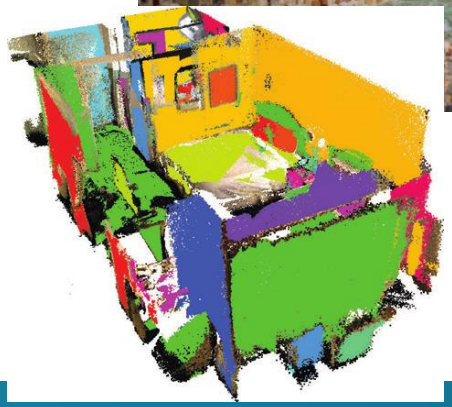
# Radio mapping limited by

- Compute power
  - Simple empirical models: high prediction errors at acceptable computational cost [1]:
  - More detailed models: computational cost & accuracy of terrain info
- Model input
  - City databases becoming available
  - Visual SLAM model



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[1] Phillips, C.; Sicker, D.; Grunwald, D., "Bounding the error of path loss models," *DySPAN 2011*

# 3D spectrum sharing

GPU

Cheaper compute power, accelerators

More terrain info available

3D world

City databases

Scenarios for 3D spectrum sharing

TV WS
LSA
UAV spectrum

**3D sharing Opportunity**

Cheap measurement hardware

Minimize Drive Test

Autonomous sensing

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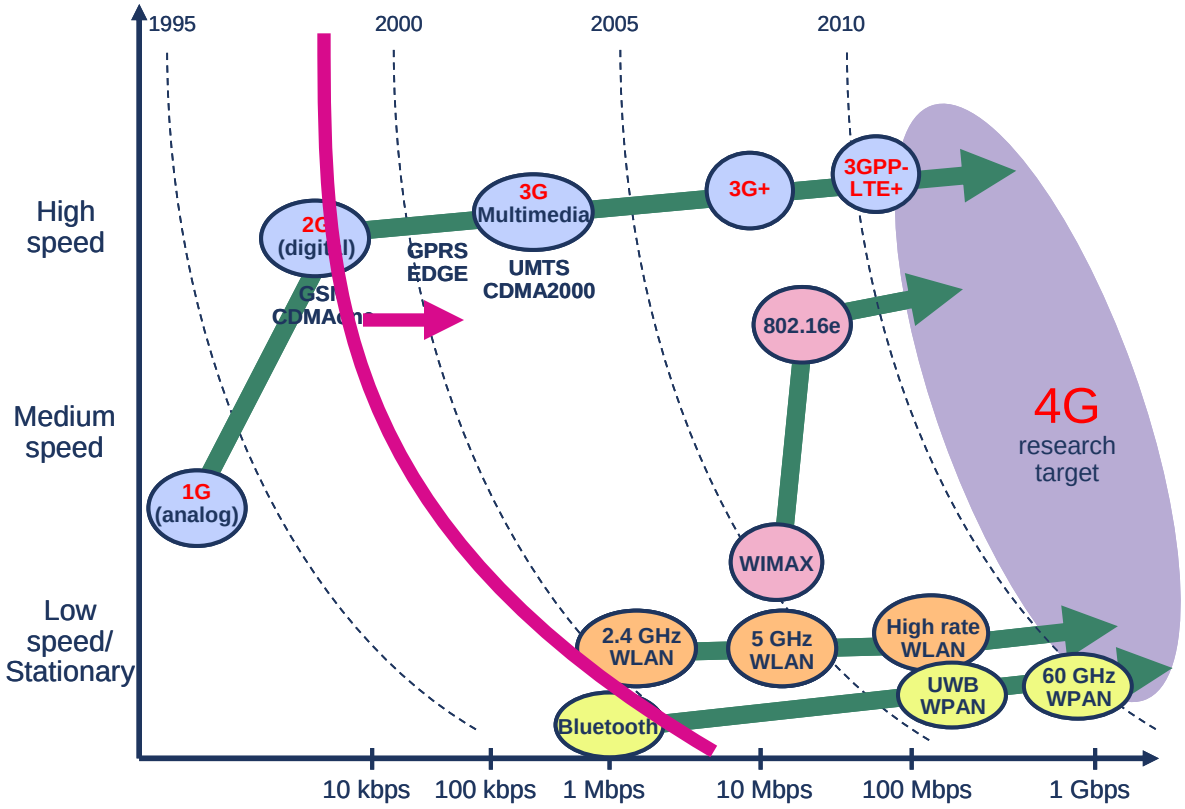
- Conclusions

# SDR: meet flexibility in and across standards at low cost




Functional flexibility wanted: within and across standards

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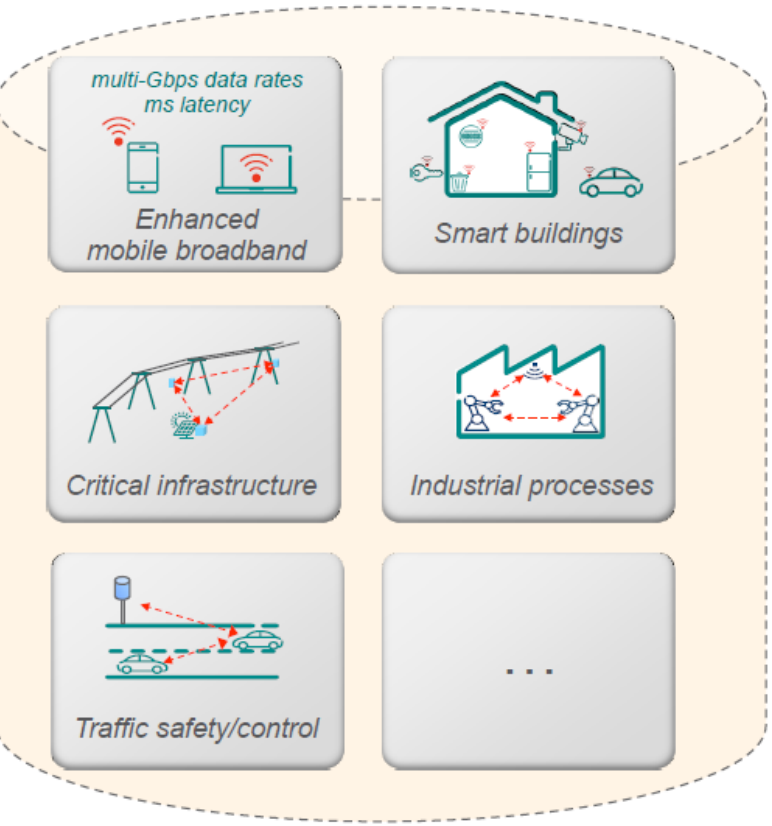
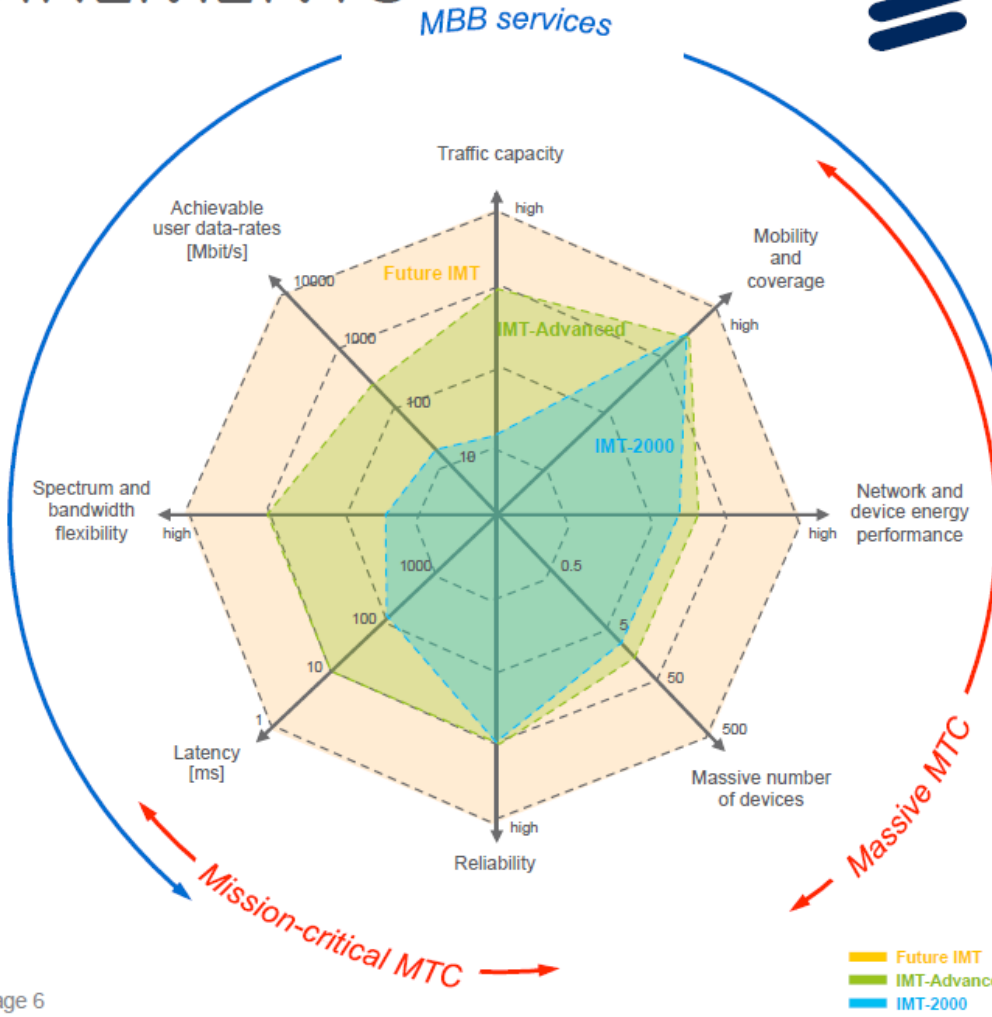
[L. Van der Perre - imec]

# 5G: SCENARIOS & REQUIREMENTS

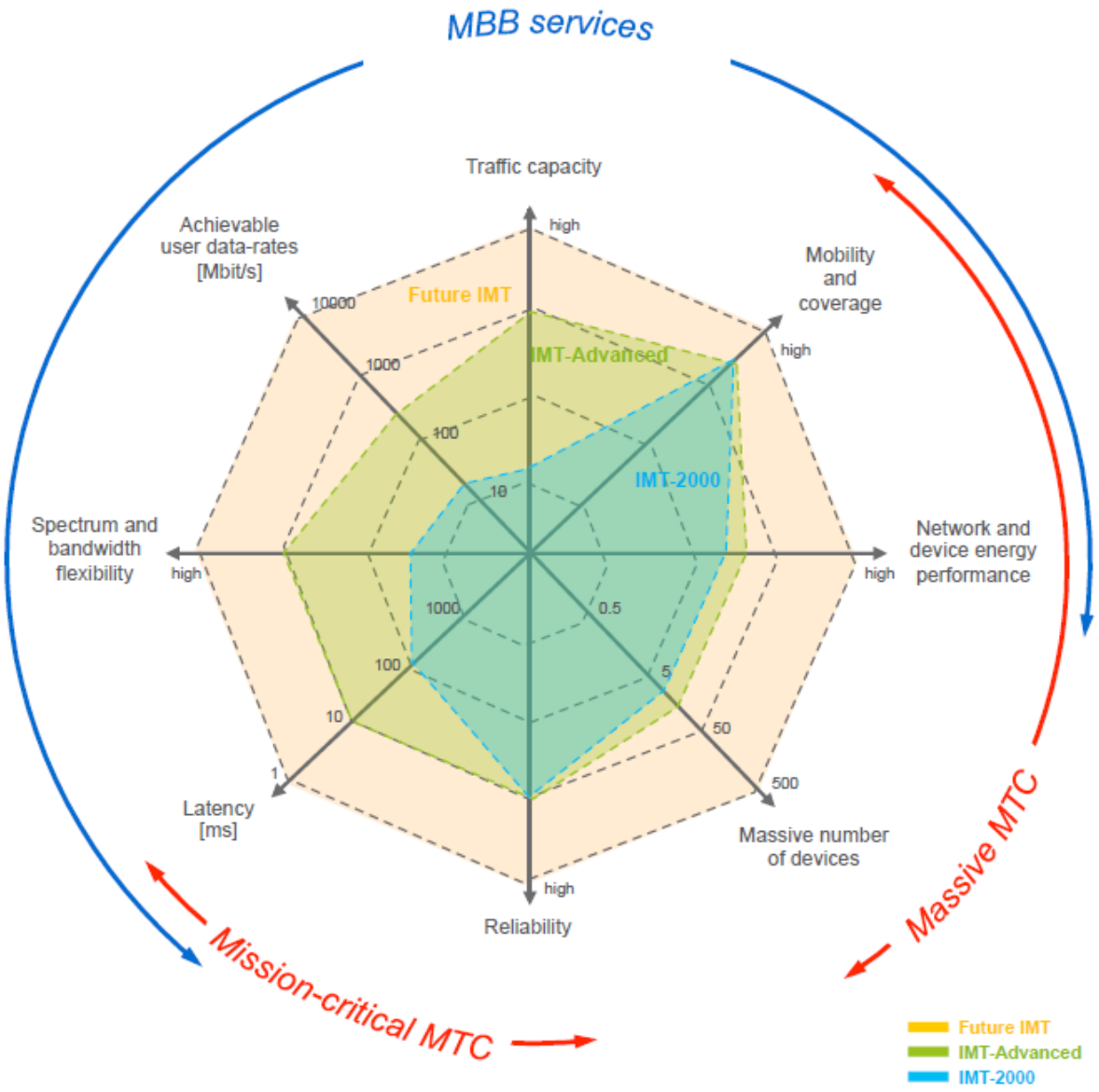





[Source: Afif Osseiran – Ericsson]

# MAV communication requirements




[Source: Afif Osseiran – Ericsson]

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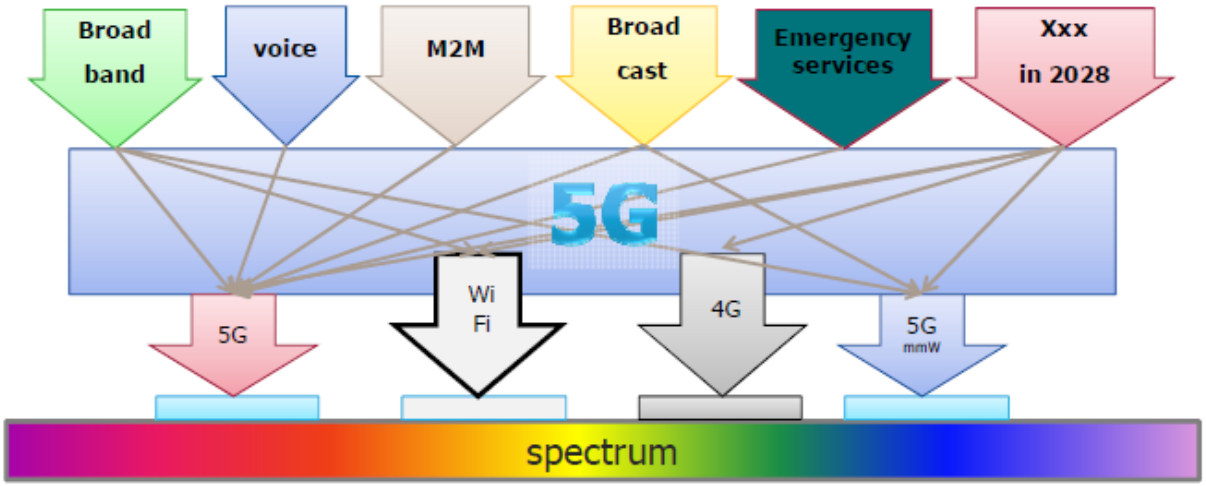
# FROM MULTI-RAT TO FUSION OF RAT'S




heterogeneous services

**Legacy RAT** to be integrated: service mapping, handover ..

**System sharing** instead of spectrum sharing

- Two levels of integration: 5G air interface and system: multi-RAT
- Sharing at system level: framework needed

Hans-Peter Mayer "H2020 Phases 2 and 3" – EC Consultation Workshop – 29.09.14 – Brussels
http://ec.europa.eu/digital-agenda/en/news/stakeholders-consultation-workshop-network-technologies-work-programme-2016-2017

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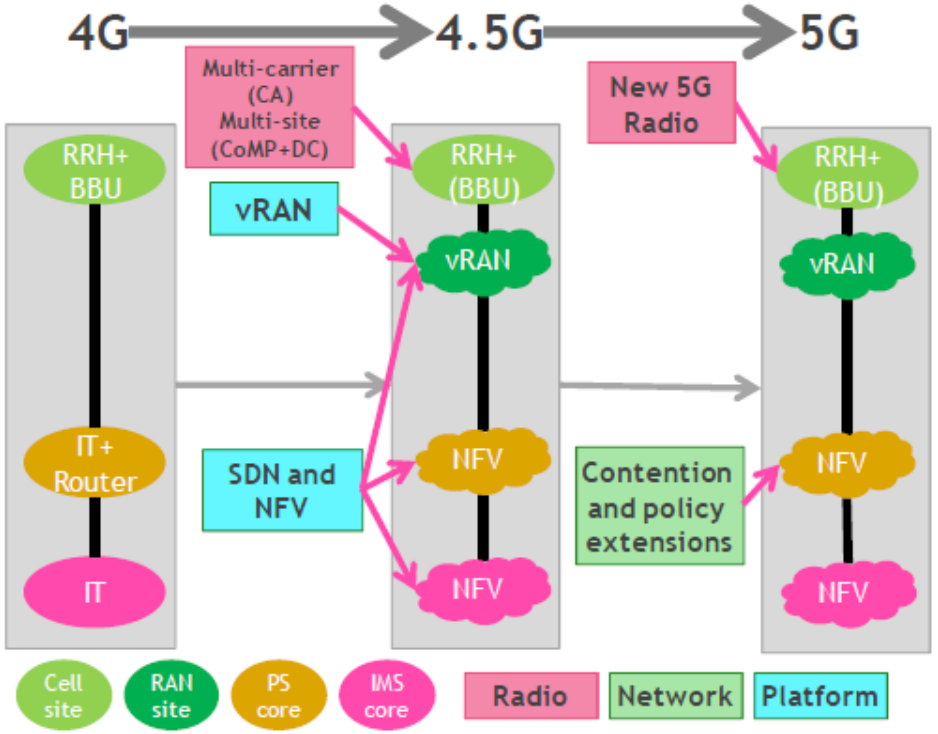
[Source: Alcatel-Lucent]

# 4G = SDR
# 5G = SDR + SDN

- Radio features
  - Combining carriers: Carrier Aggregation:
  - Combining sites: Dual-Connectivity and CoMP
  - Combining cellular and WLAN: RAN based interworking
- Network features
  - Voice and multimedia with VoLTE and WebRTC
  - Combining cellular and WLAN: SaMOG/ePDG
  - Policy based networking: ANDSF and PCRF
- Platform features
  - Virtualizing cell site processing: vRAN
  - Virtualizing network: NFV and SDNs




**4.5G HAS ALREADY STARTED AND IS LAYING DOWN THE FOUNDATION TECHNOLOGIES FOR 5G**

Alistair Urie – 5G Huddle Conference – 22-23.09.14 – London
https://eu-ems.com/summary.asp?event_id=219&page_id=1884

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[Source: Alcatel-Lucent]

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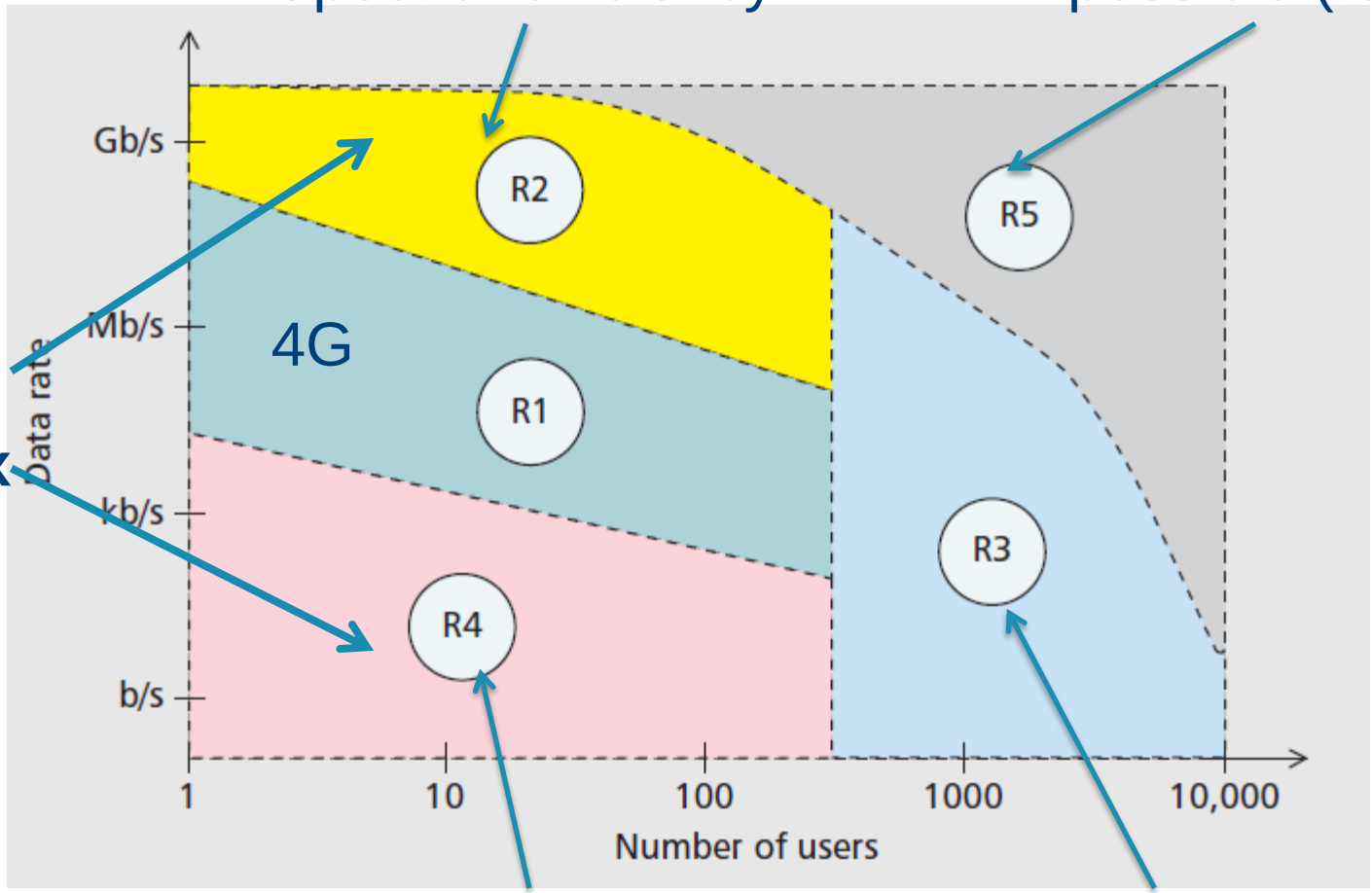
# The 5G communication landscape

Spectral efficiency

Impossible (today)




**Full Duplex**

high reliability / low latency

Massive M2M

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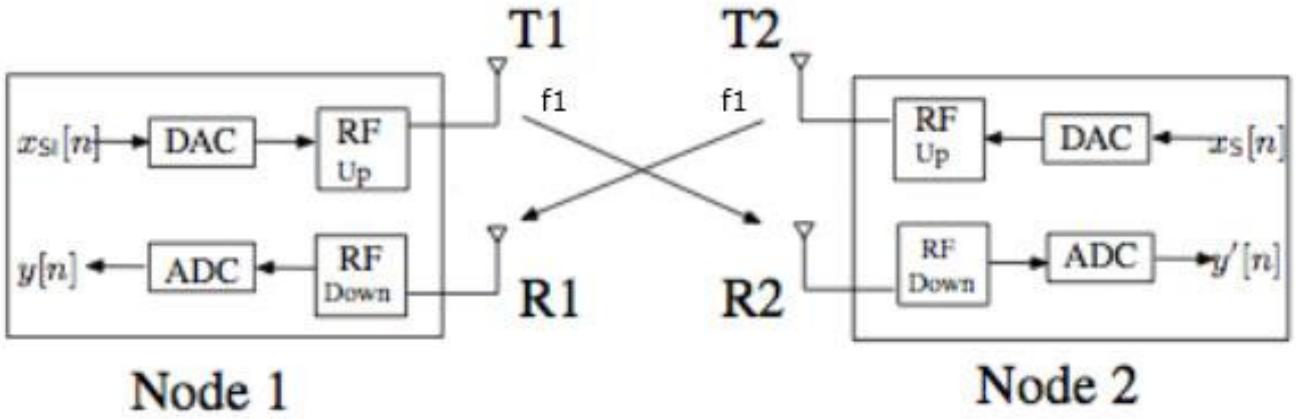
[Boccardi, F; Heath, R.W.; Lozano, A.; Marzetta, T.L.; Popovski, P., "Five disruptive technology directions for 5G," *Communications Magazine, IEEE* , vol.52, no.2, pp.74,80, February 2014]

# What do we mean with full duplex?

- Simultaneous transmission and reception
- Same time- and frequencyslot



# What do we mean with full duplex?

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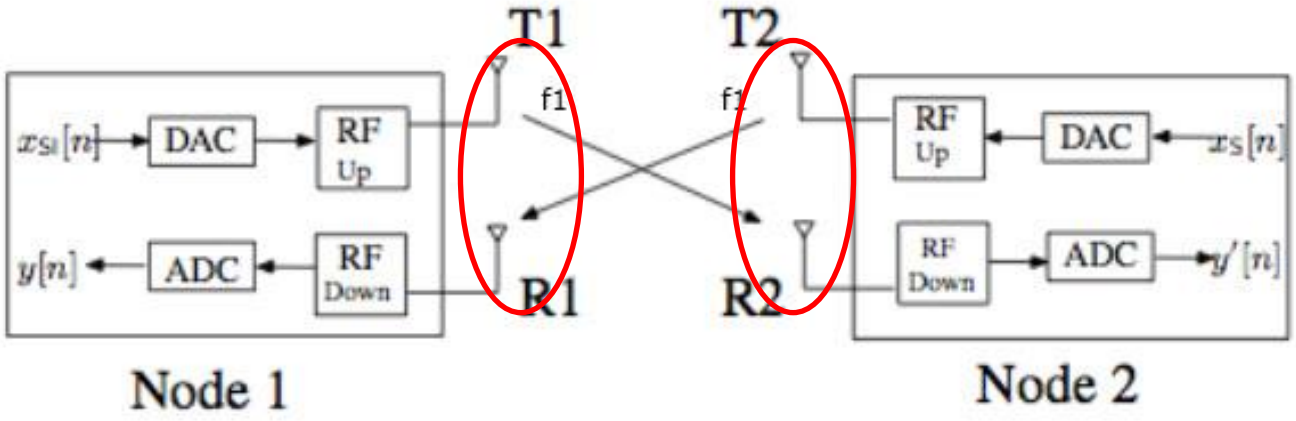
Problem:




- Self-interference can be up to 110dB for wifi

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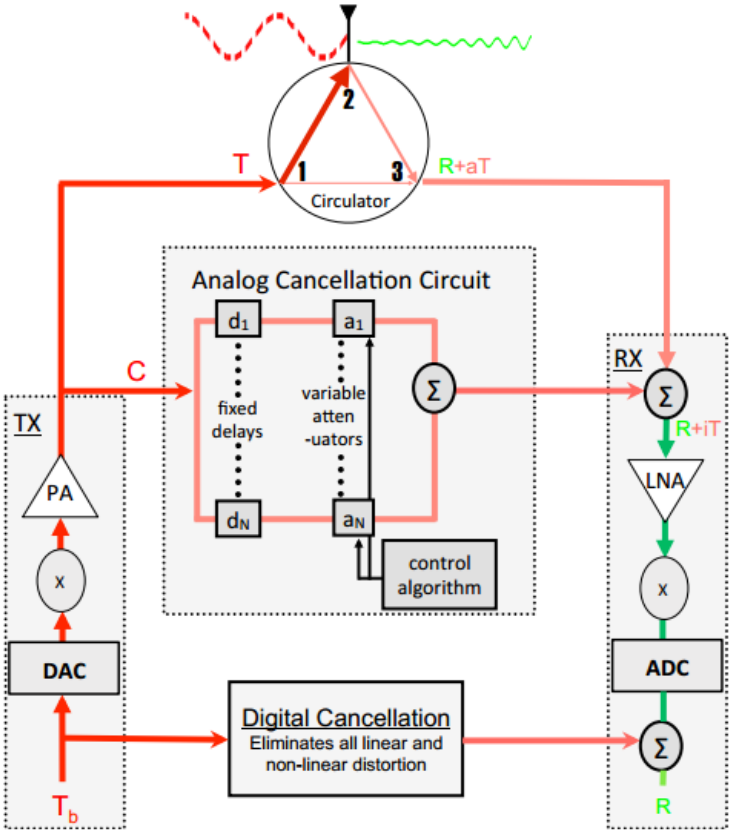
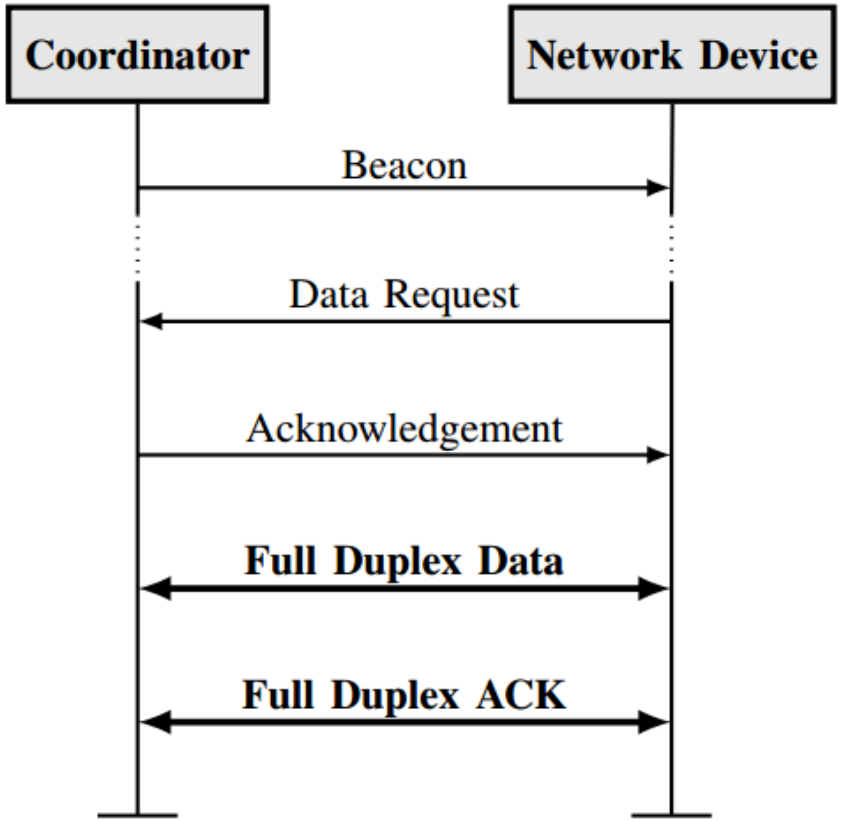
# Solution to full duplex problem



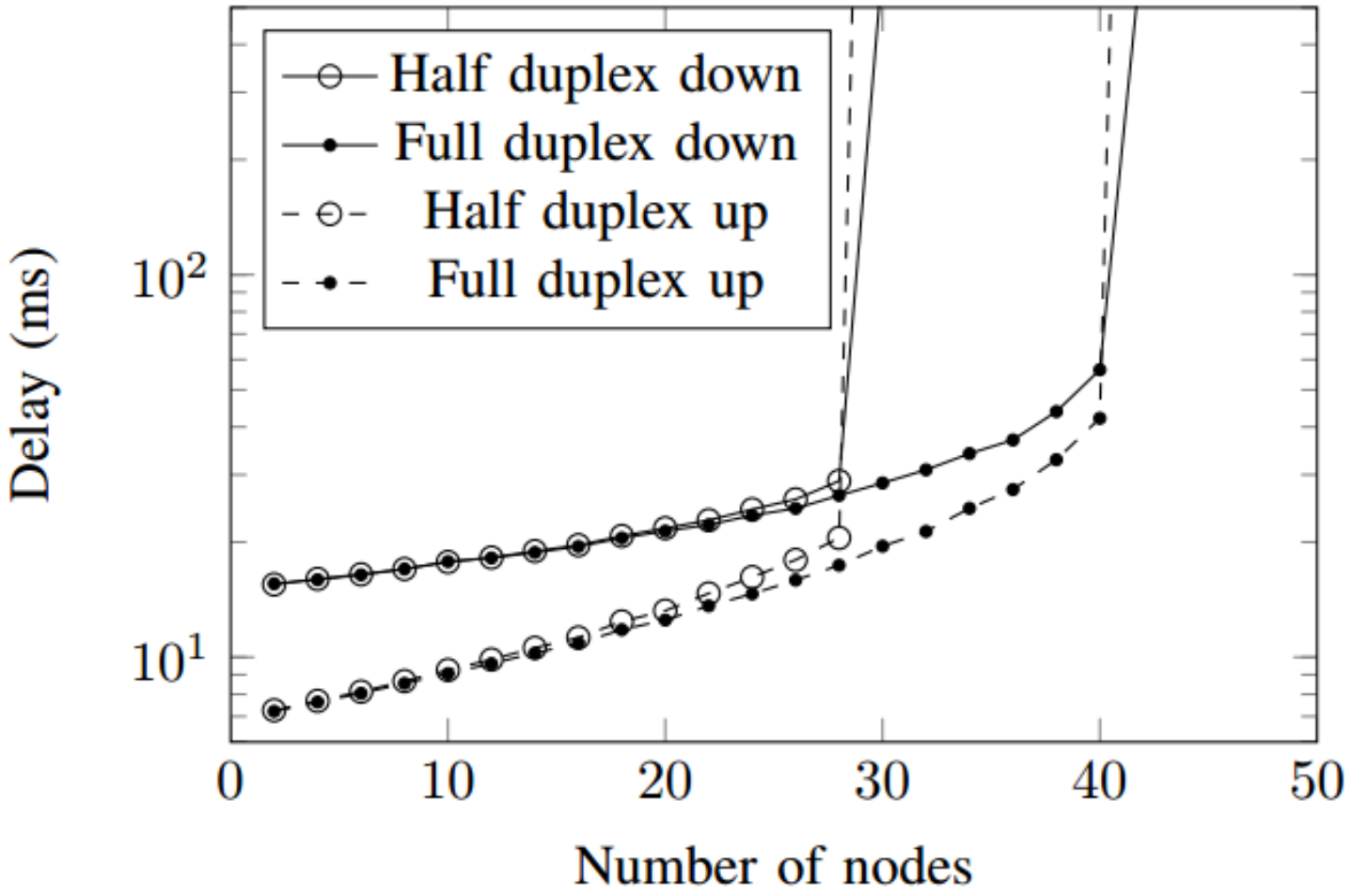




Recently proven feasible using commodity hardware

Protocol design feasible

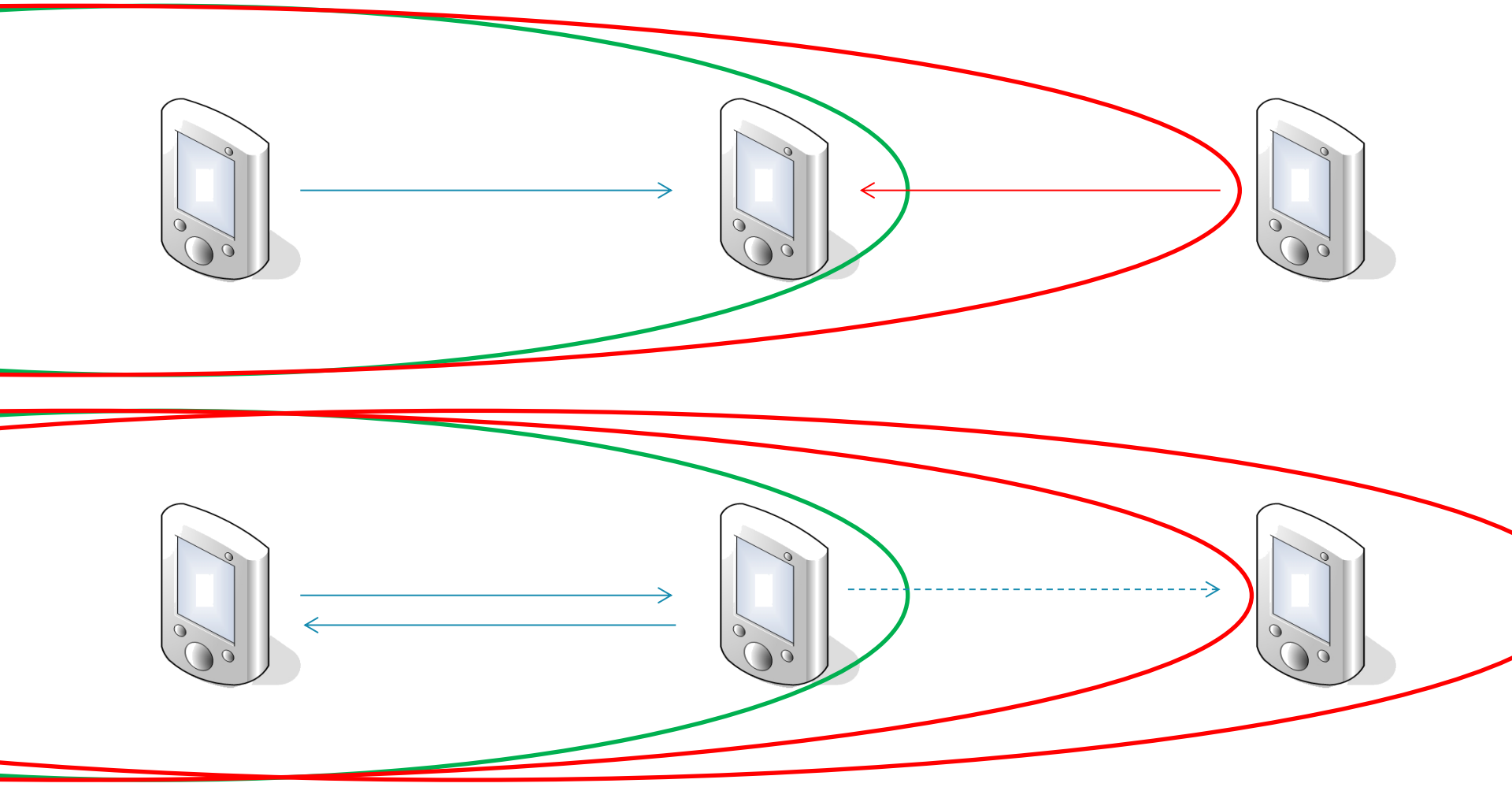
[Source: Bharadia et al, Full Duplex Radios]

# Network collapse takes 50% longer




Parameters: 3 packets/s of 100 bytes, 10% of all traffic is downlink

# Full duplex solves exposed and hidden node problems



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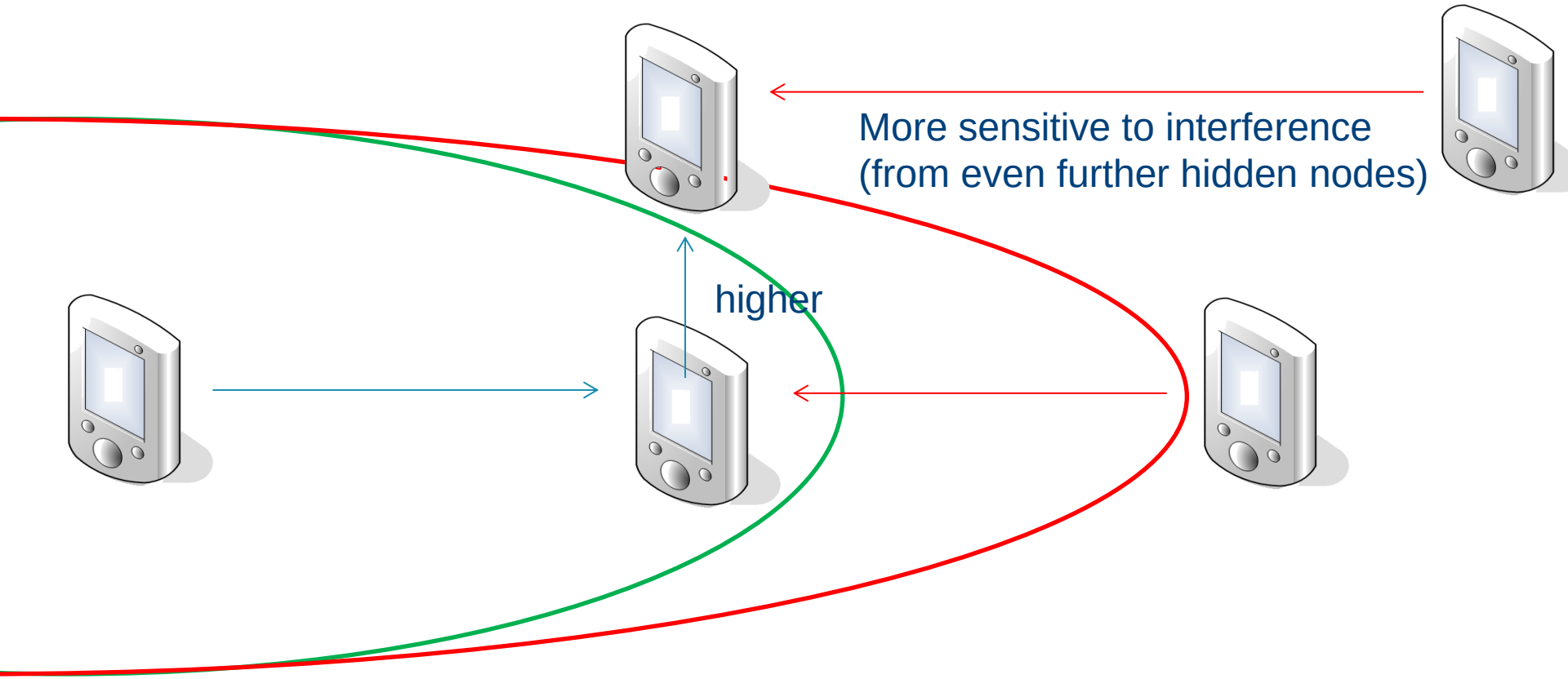
# 5G solutions even more relevant for MAVs?




Can we prove this!?

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# Experiments in the age of 4G…

Networking test beds:
Little control of PHY



**Many Nodes**

Radio test beds:
Not real-time


**Spectral Efficiency**

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# CLAWS: Cross-Layer Adaptable Wireless System

Day 2

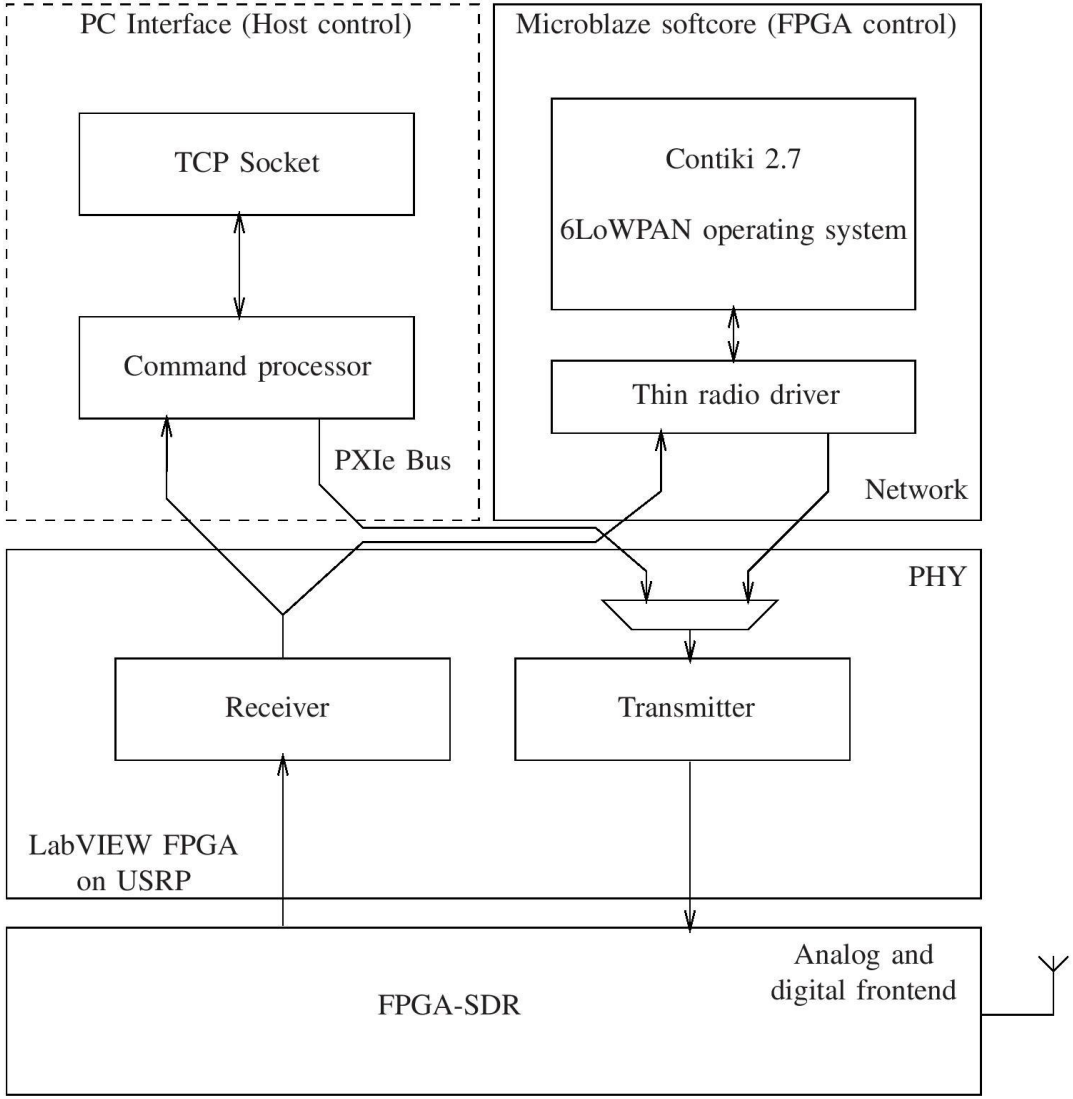
Day 4

Day 3

1Month later:

Full software defined implementation of the 802.15.4 PHY, MAC and network layer as baseline for Full Duplex

# CLAWS architecture



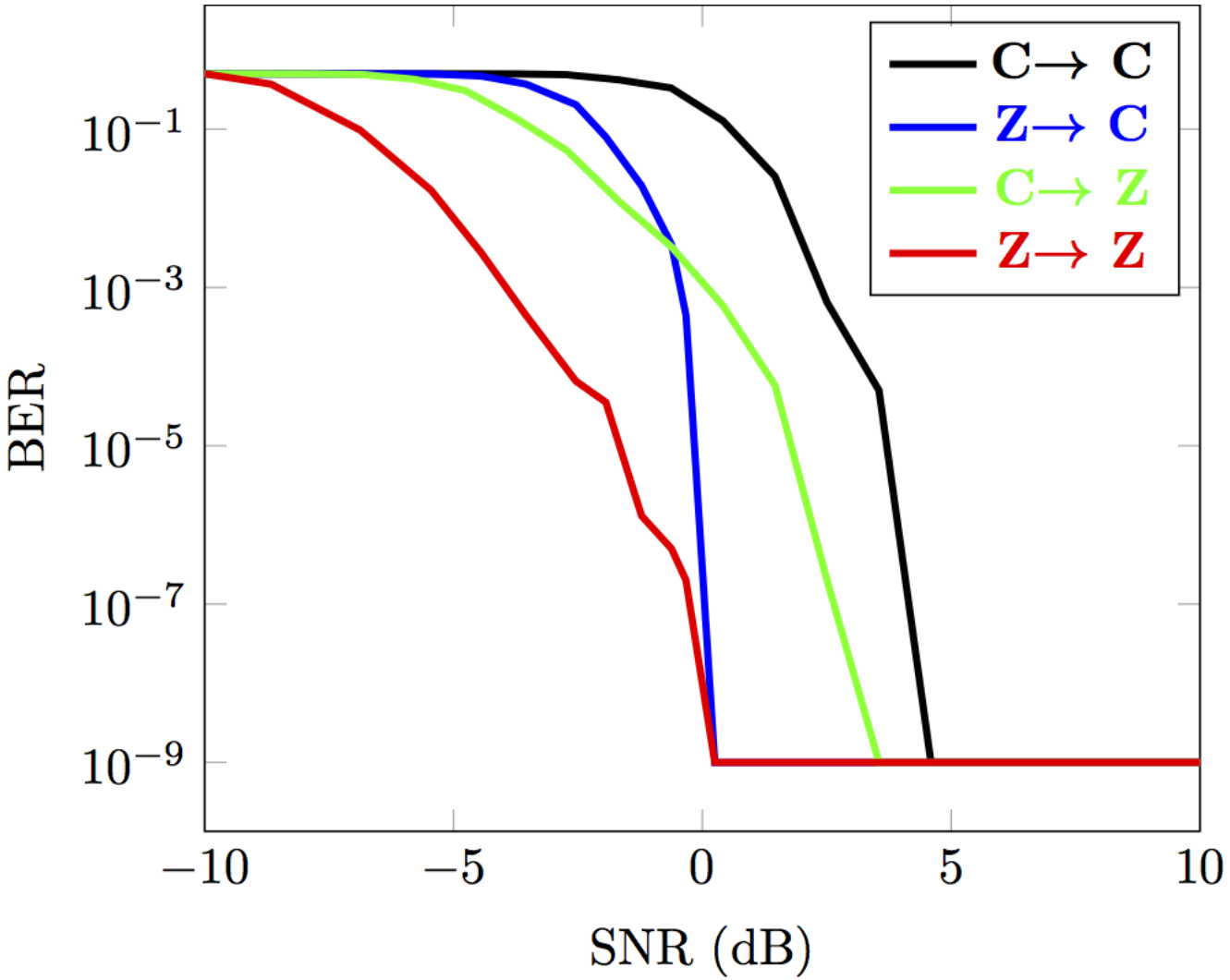

Host control:
LabVIEW VI

FPGA control:
Contiki OS running
on softcore

Baseband PHY:
LabVIEW FPGA

NI PXIe-7966R and
NI 5791 RF FAM

# CLAWS PHY performance

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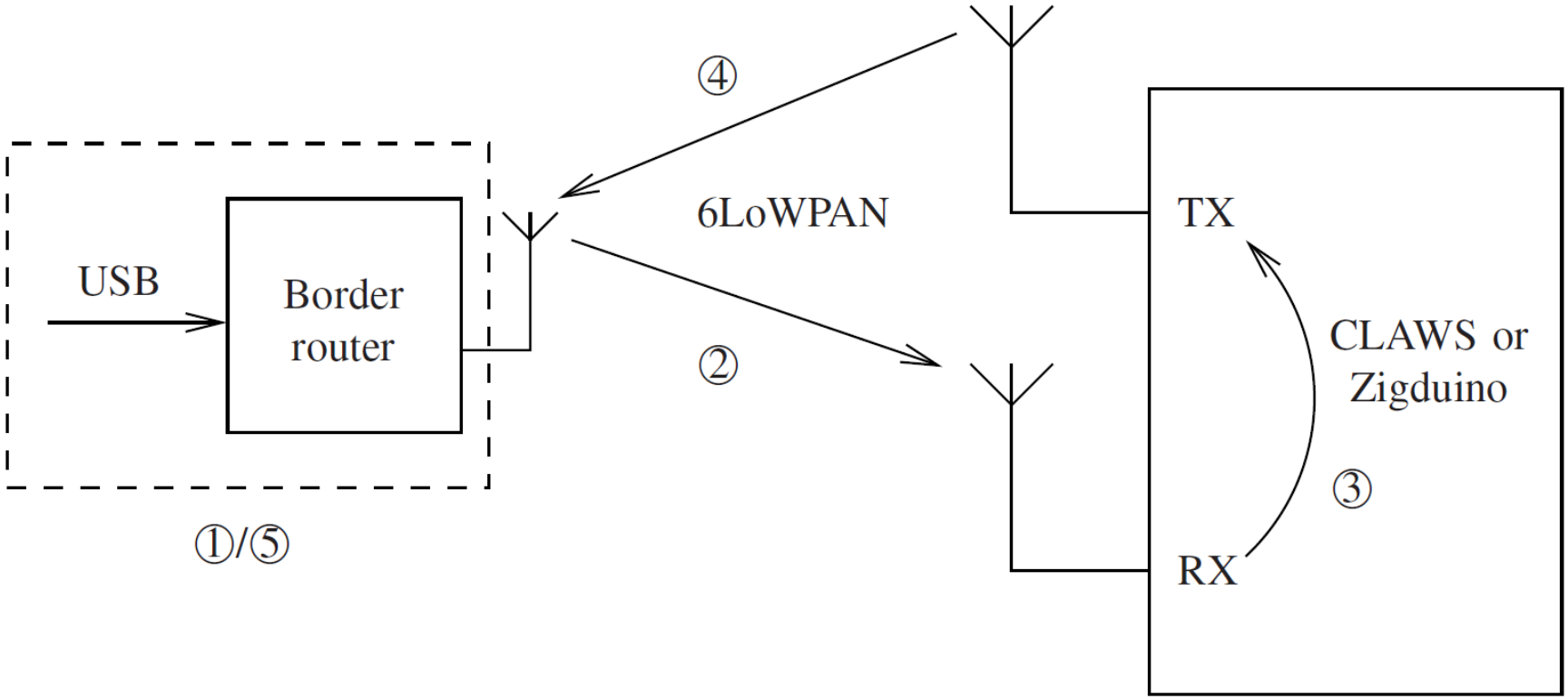
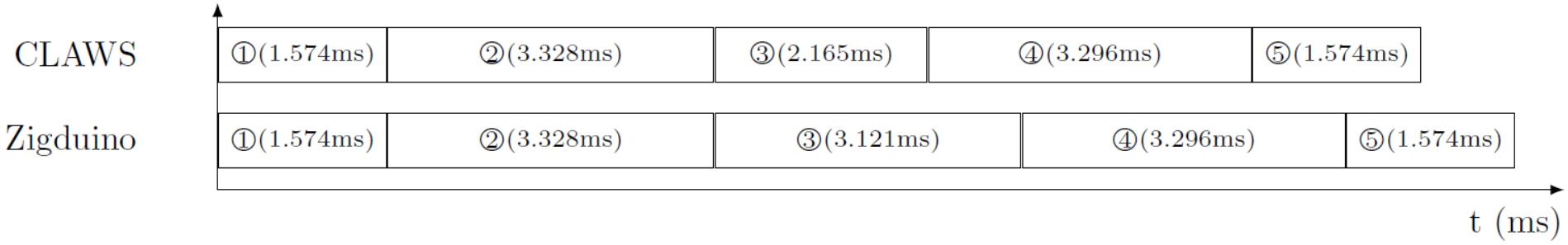
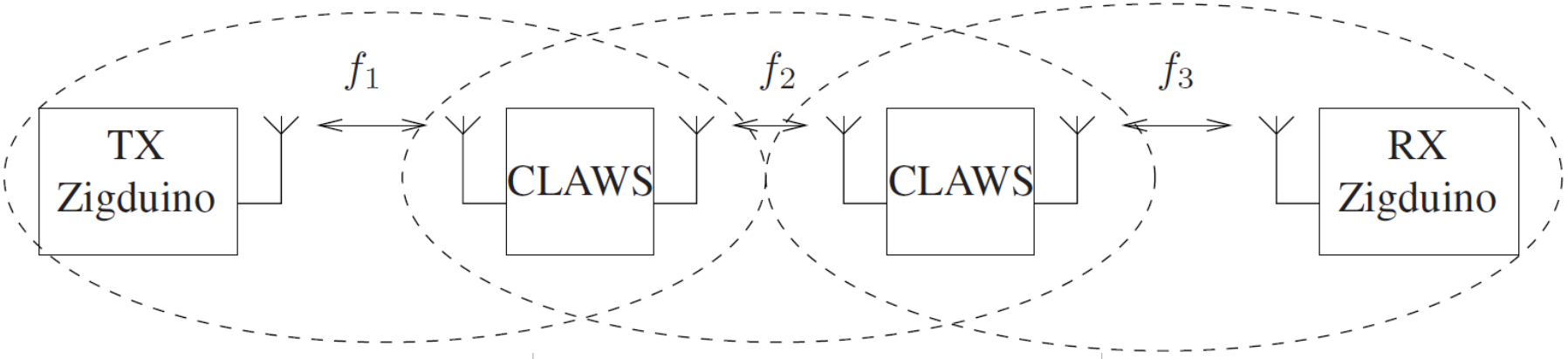
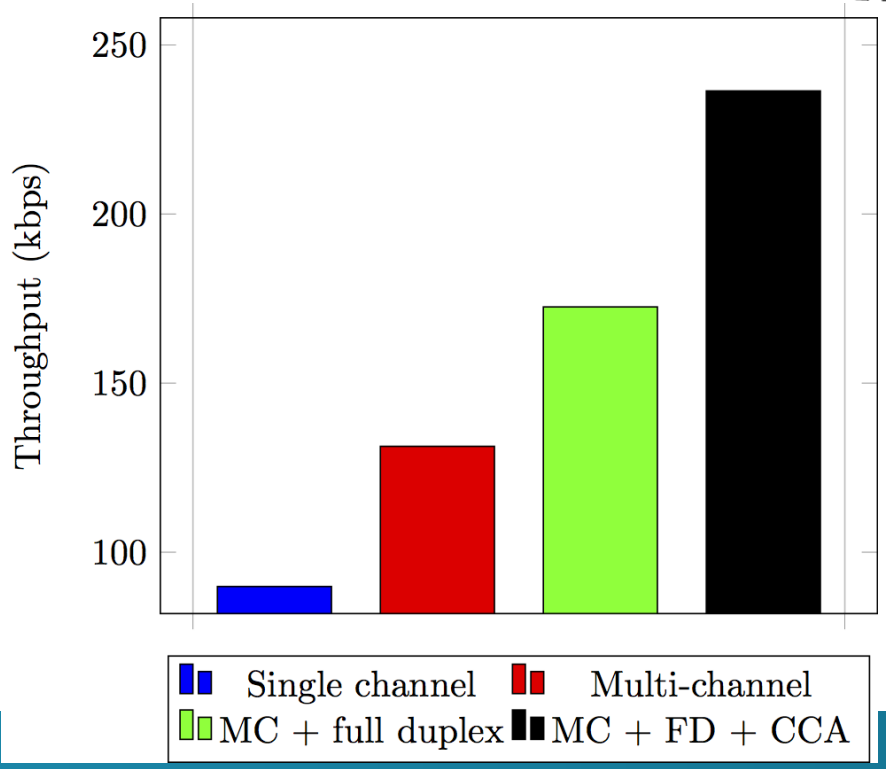
# CLAWS timing breakdown



# A simple cross-layer design and experiment

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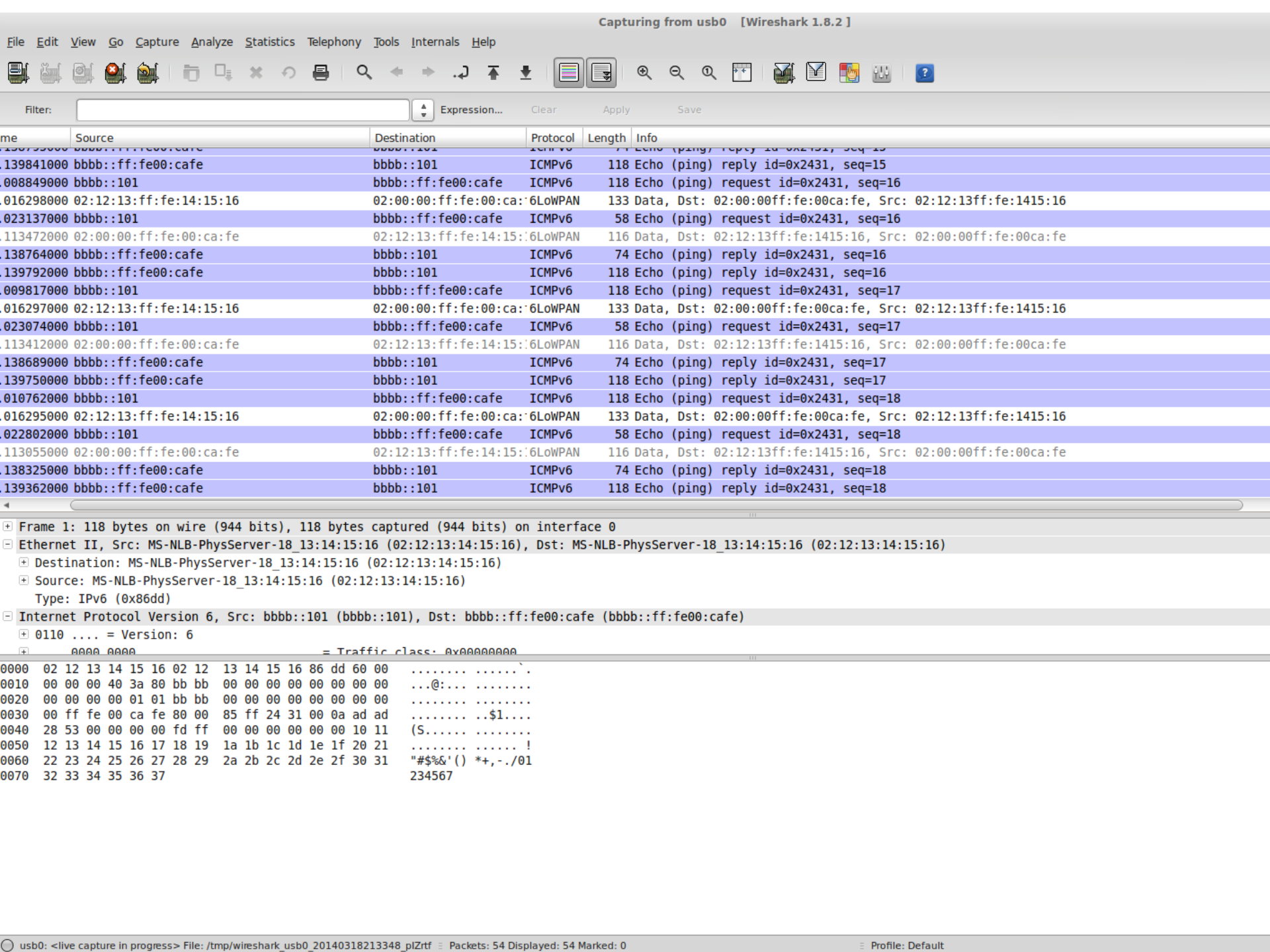
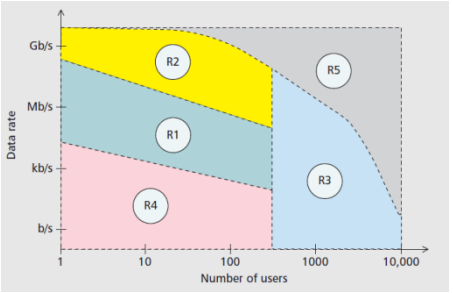

Capturing from usb0 [Wireshark 1.8.2 ]
File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help
Filter:
Expression...
Clear
Apply
Save
me Source Destination Protocol Length Info
.139841000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 118 Echo (ping) reply id=0x2431, seq=15
.008849000 bbbb::101 bbbb::ff:fe00:cafe ICMPv6 118 Echo (ping) request id=0x2431, seq=16
.016298000 02:12:13:ff:fe:14:15:16 02:00:00:ff:fe:00:ca: 6LoWPAN 133 Data, Dst: 02:00:00ff:fe:00ca:fe, Src: 02:12:13ff:fe:1415:16
.023137000 bbbb::101 bbbb::ff:fe00:cafe ICMPv6 58 Echo (ping) request id=0x2431, seq=16
.113472000 02:00:00:ff:fe:00:ca:fe 02:12:13:ff:fe:14:15: 6LoWPAN 116 Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:00:00ff:fe:00ca:fe
.138764000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 74 Echo (ping) reply id=0x2431, seq=16
.139792000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 118 Echo (ping) reply id=0x2431, seq=16
.009817000 bbbb::101 bbbb::ff:fe00:cafe ICMPv6 118 Echo (ping) request id=0x2431, seq=17
.016297000 02:12:13:ff:fe:14:15:16 02:00:00:ff:fe:00:ca: 6LoWPAN 133 Data, Dst: 02:00:00ff:fe:00ca:fe, Src: 02:12:13ff:fe:1415:16
.023074000 bbbb::101 bbbb::ff:fe00:cafe ICMPv6 58 Echo (ping) request id=0x2431, seq=17
.113412000 02:00:00:ff:fe:00:ca:fe 02:12:13:ff:fe:14:15: 6LoWPAN 116 Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:00:00ff:fe:00ca:fe
.138689000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 74 Echo (ping) reply id=0x2431, seq=17
.139750000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 118 Echo (ping) reply id=0x2431, seq=17
.010762000 bbbb::101 bbbb::ff:fe00:cafe ICMPv6 118 Echo (ping) request id=0x2431, seq=18
.016295000 02:12:13:ff:fe:14:15:16 02:00:00:ff:fe:00:ca: 6LoWPAN 133 Data, Dst: 02:00:00ff:fe:00ca:fe, Src: 02:12:13ff:fe:1415:16
.022802000 bbbb::101 bbbb::ff:fe00:cafe ICMPv6 58 Echo (ping) request id=0x2431, seq=18
.113055000 02:00:00:ff:fe:00:ca:fe 02:12:13:ff:fe:14:15: 6LoWPAN 116 Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:00:00ff:fe:00ca:fe
.138325000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 74 Echo (ping) reply id=0x2431, seq=18
.139362000 bbbb::ff:fe00:cafe bbbb::101 ICMPv6 118 Echo (ping) reply id=0x2431, seq=18
Frame 1: 118 bytes on wire (944 bits), 118 bytes captured (944 bits) on interface 0
Ethernet II, Src: MS-NLB-PhysServer-18_13:14:15:16 (02:12:13:14:15:16), Dst: MS-NLB-PhysServer-18_13:14:15:16 (02:12:13:14:15:16)
Destination: MS-NLB-PhysServer-18_13:14:15:16 (02:12:13:14:15:16)
Source: MS-NLB-PhysServer-18_13:14:15:16 (02:12:13:14:15:16)
Type: IPv6 (0x86dd)
Internet Protocol Version 6, Src: bbbb::101 (bbbb::101), Dst: bbbb::ff:fe00:cafe (bbbb::ff:fe00:cafe)
0110 .... = Version: 6
0000 0000 = Traffic class: 0x00000000
0000 02 12 13 14 15 16 02 12 13 14 15 16 86 dd 60 00 ..... .....`.
0010 00 00 00 40 3a 80 bb bb 00 00 00 00 00 00 00 00 ...@:... .....
0020 00 00 00 00 01 01 bb bb 00 00 00 00 00 00 00 00 ..... .....
0030 00 ff fe 00 ca fe 80 00 85 ff 24 31 00 0a ad ad ..... ..$1....
0040 28 53 00 00 00 00 fd ff 00 00 00 00 00 00 10 11 (S..... .....
0050 12 13 14 15 16 17 18 19 1a 1b 1c 1d 1e 1f 20 21 ..... ..... !
0060 22 23 24 25 26 27 28 29 2a 2b 2c 2d 2e 2f 30 31 "#$%&'() *+,-./01
0070 32 33 34 35 36 37 234567
usb0: <live capture in progress> File: /tmp/wireshark_usb0_20140318213348_plZrtf Packets: 54 Displayed: 54 Marked: 0 Profile: Default

# Conclusions

- MAV communication: not just ‘4G in the air’

- 5G promises range of novel technologies:
  - Higher throughput, lower latency, …
  - More controllability (at PHY and Network!)




- Key: 3D context awareness to exploit this

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# Questions?


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