WIRELESS EXPERIMENTATION WITH SDR: THE WAY TO DRIVE INNOVATION

INGRID MOERMAN

WIRELESS INNOVATION

- HOW?
- SDR IS KEY
- FUTURE VISION

WIRELESS INNOVATION – HOW?

WIRELESS INNOVATION - HOW?

THEORETICAL ANALYSIS

☺ Link level models & analysis
- PHY design
- Channel models

☺ (Best case) system capacity models

☺ Static & deterministic systems

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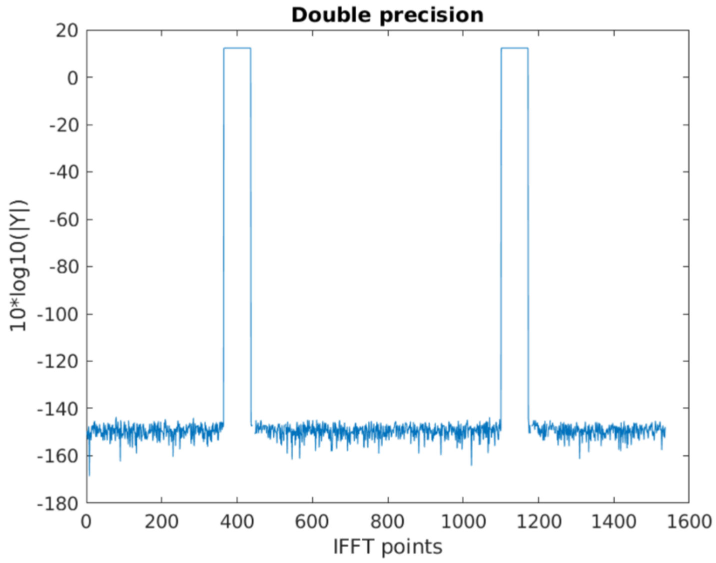
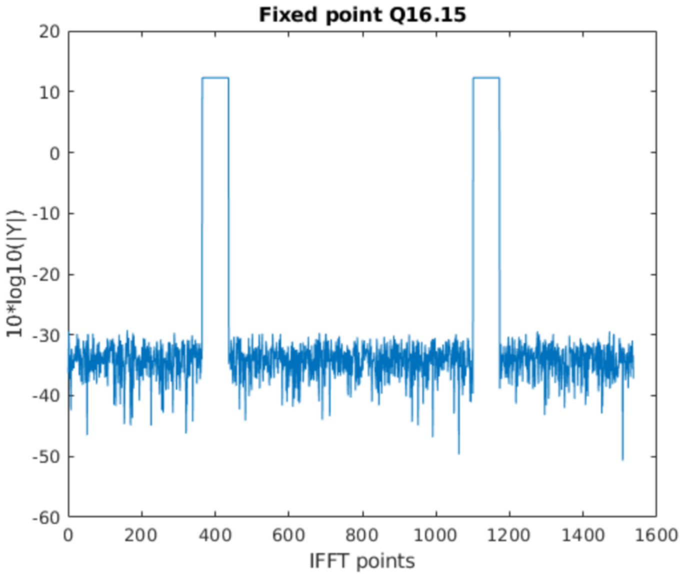
☹ Hard to model realistic environments and wireless impairments: interference, multi-path, fading, shadowing…

☹ Hard to take into account hardware/implementation related constraints

HARDWARE/IMPLEMENTATION RELATED CONSTRAINTS

- Example: Signal-to-Noise Ratio (SNR)
  - Double precision is not supported on ASIC/FPGA → noise floor elevation due to quantization





HARDWARE/IMPLEMENTATION RELATED CONSTRAINTS

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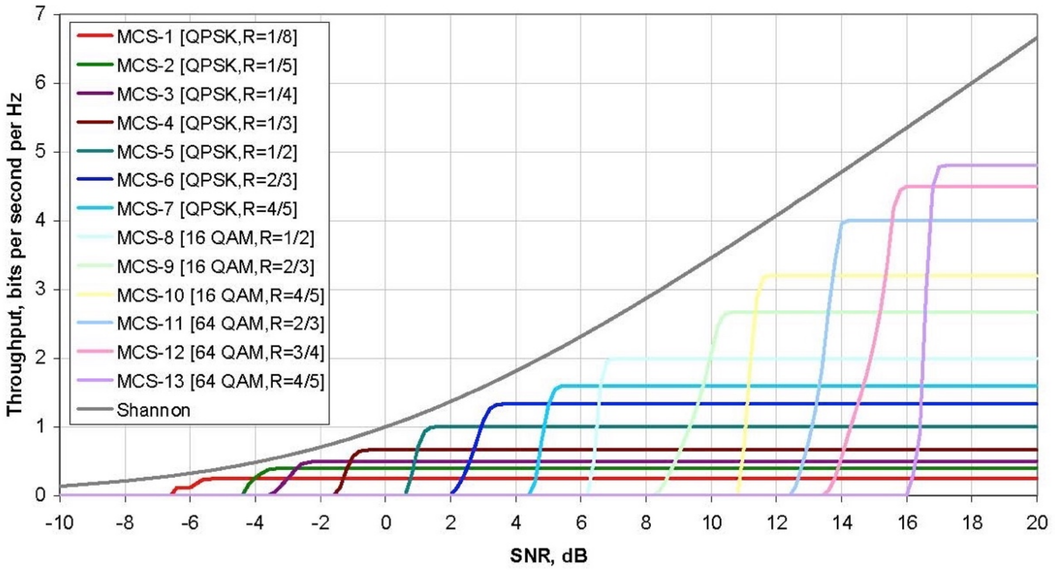

Theoretical analysis may lead to WRONG coverage and capacity estimations

WIRELESS INNOVATION - HOW?

THEORETICAL ANALYSIS	SIMULATION
☺ Link level models & analysis • PHY design • Channel models	☺ Network level analysis
☺ (Best case) system capacity models	☺ Easy implementation
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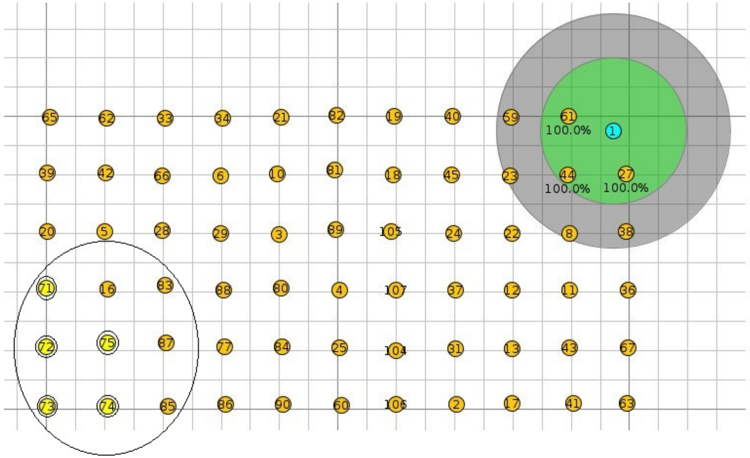
LIMITED REALISM OF SIMULATORS

Unrealistic grid topologies

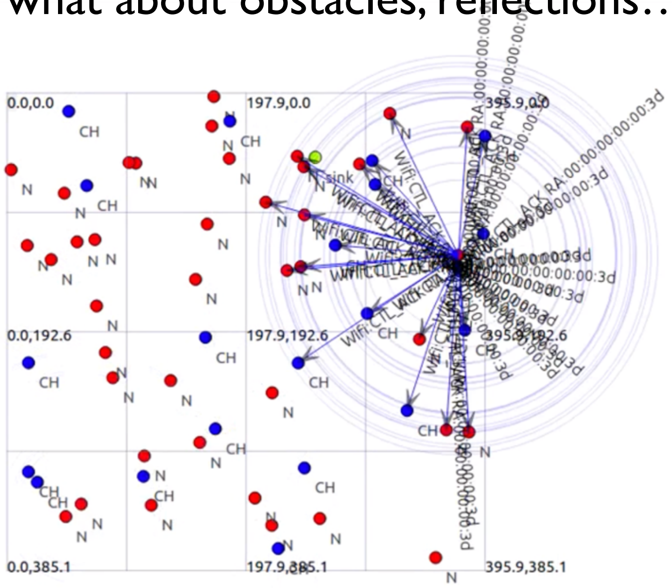
artificial multi-hop domain



M Ali Lodhi et al., KSII Transactions on Internet and Information Systems, Vol. 11, No. 4, Apr. 2017

Oversimplified channel models

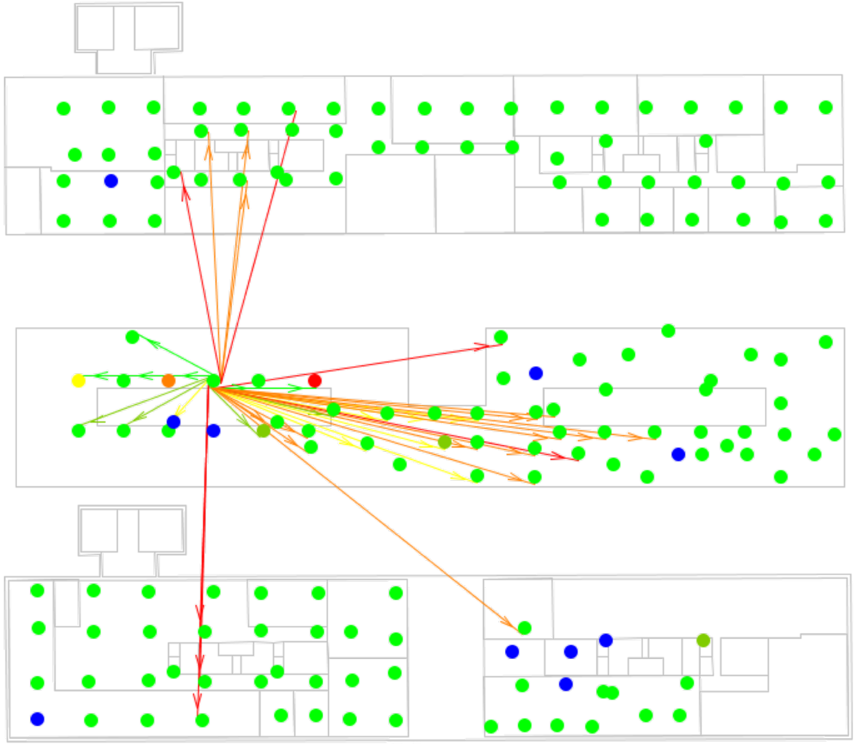
what about obstacles, reflections…?



https://youtu.be/8Vm2J1g8faU

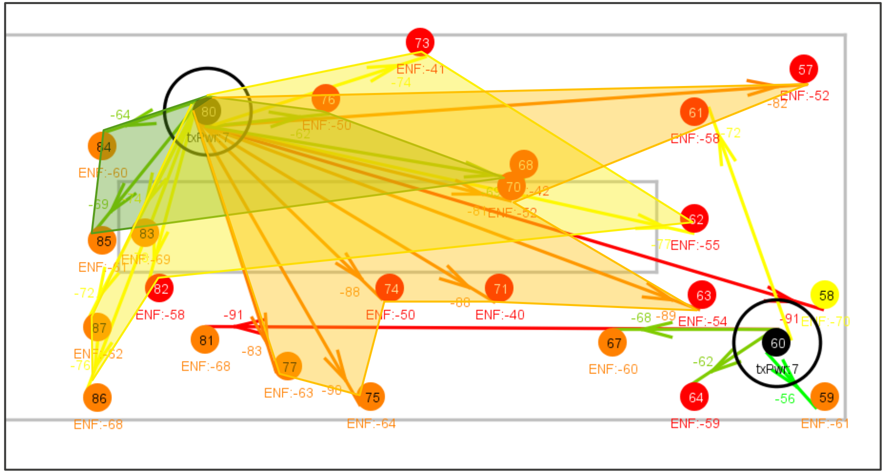
LIMITED REALISM OF SIMULATORS

- Example: real-life collision domain
  - Influenced by obstacles, wall & ceilings, antenna



3 floors

18 x 90 m^2

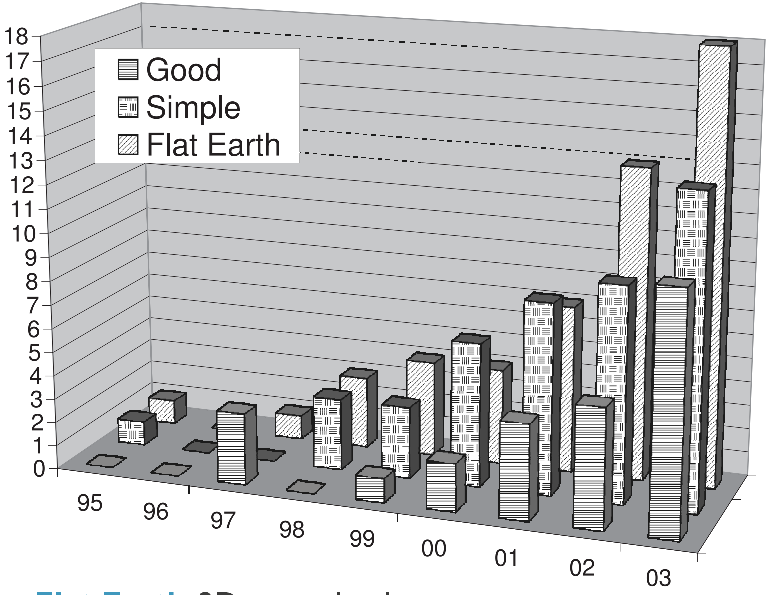


SIMULATION WRONG ASSUMPTIONS

- The world is flat
- There are only line-of-sight transmissions
- The transmission area of a radio is circular (perfect omnidirectional antennas)
- All radios have equal range
- Radio links are perfectly symmetrical
- Signal strength is a simple function of distance
- Transmit power range is identical for all devices
- Events are uniformly distributed in sensor networks and every event is independent of other events
- …

STILL MANY "SIMPLE" & "FLAT EARTH" SIMULATIONS TODAY!

Number of papers in each year of Mobicom and MobiHoc



Flat Earth: 2D, no packet loss
Simple: simple "more realistic" model, includes delay & packet losses
Good: empirical models based on extensive experimental data

Newport, C., Kotz, D., Yuan, Y., Gray, R. S., Liu, J., & Elliott, C. (2007). Experimental Evaluation of Wireless Simulation Assumptions, SIMULATION, 2007, 83(9), 643–661.

SIMULATION

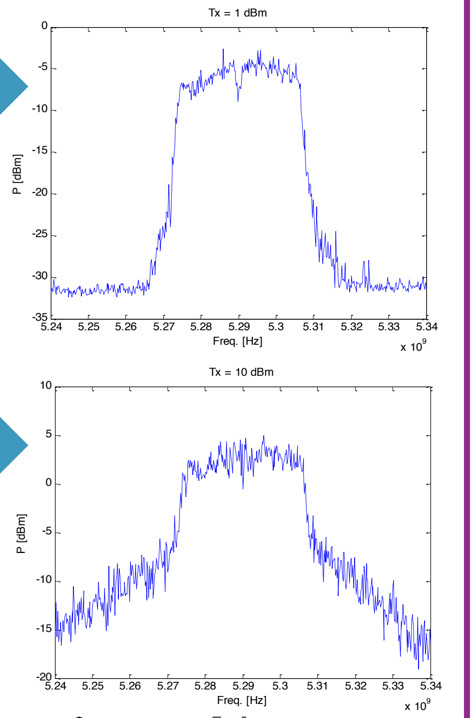
HARDWARE/IMPLEMENTATION RELATED CONSTRAINTS

- Example: hardware limitations of off-the-shelf Wi-Fi cards

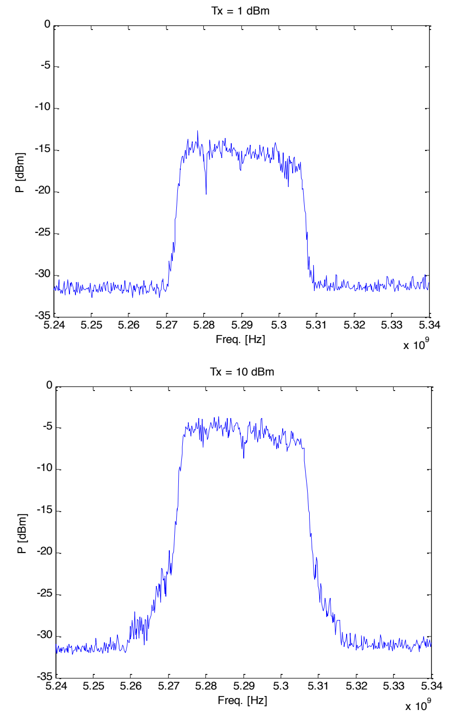
Low Tx power (1dBm)

High Tx power (10 dBm)

Vendor 1



Vendor 2



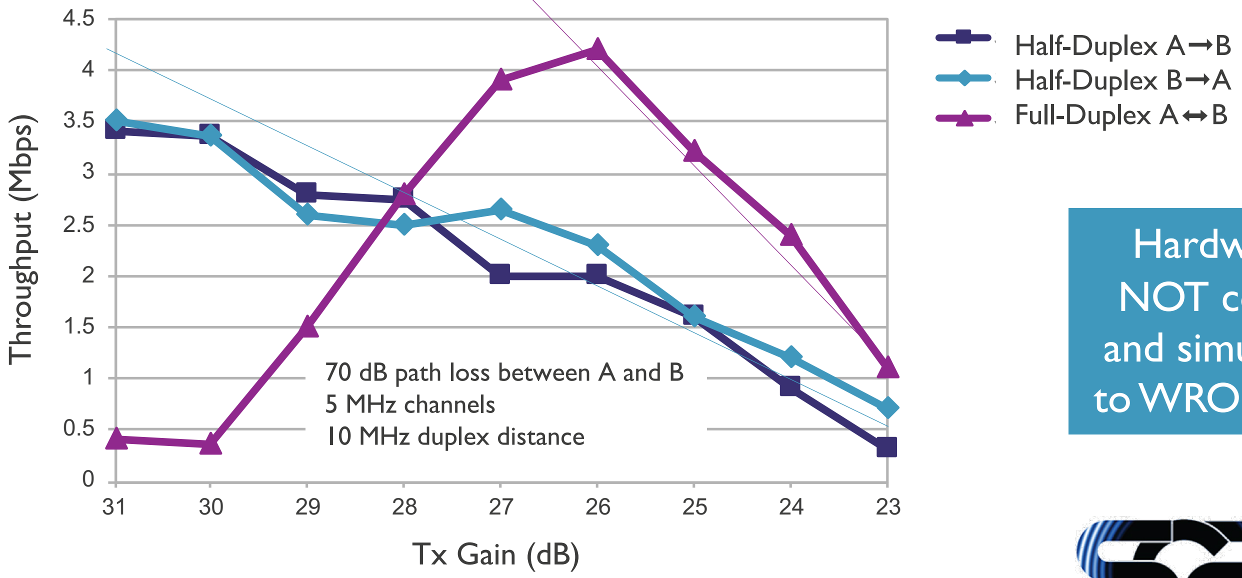
Different Wi-Fi cards have different behavior in terms of Tx power and out-of-band emission

Simulations do not consider interference between "non-overlapping" channels

THEORETICAL ANALYSIS
SIMULATION

HARDWARE/IMPLEMENTATION RELATED CONSTRAINTS

- Example: full duplex operation and/or multi-radio operation
  - Non-linear gain + self-interference effects → distortion & noise floor elevation



Hardware constraints are NOT considered in models and simulations and may lead to WRONG operation modes

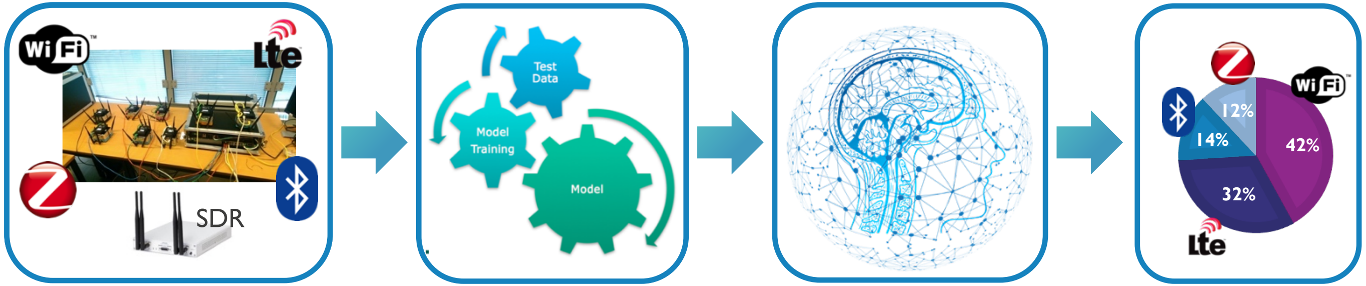
Spectrum Collaboration Challenge

SIMULATION

LIMITED REALISM OF SIMULATORS

- Example: simulator for creating data sets for machine learning

Generate I/Q signals in testbed | Train model for technology recognition | Trained model (classifier) | Get spectrum occupancy information



Capture real-time I/Q samples in real-life environment with SDR

Be careful with synthetic data!

SIMULATION

LIMITED REALISM OF SIMULATORS

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- ☺ Realistic wireless environments (e.g. collision domain, coexistence, (self)interference, mobility…)
- ☺ Real hardware
- ☺ Real applications

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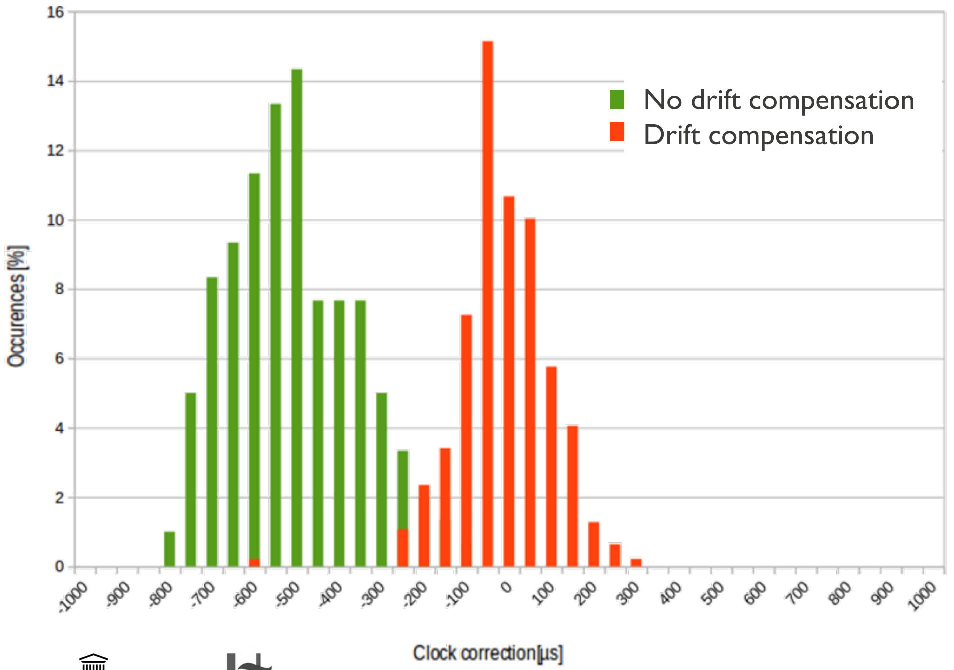
- ☹ More complex implementation
  - hardware dependent
  - often needs reverse engineering
- ☹ Small to medium scale experiments
- ☹ Reproducibility?

HARDWARE/IMPLEMENTATION RELATED CONSTRAINTS

- Example: time synchronization between nodes
  - A lot of clock drifts between different nodes ➜ need for guard spaces



Time synchronization between wireless devices is still a big issue limiting MAC efficiency

Experiments with real hardware cannot be avoided

WIRELESS INNOVATION - HOW?

THEORETICAL ANALYSIS | **SIMULATION** | **EXPERIMENTATION**

FUNDAMENTAL RESEARCH ↔ SMART ENGINEERING

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Each method has it merits, pitfalls & limitations

Experimentation with real hardware cannot be avoided

The devil is in the detail!

INNOVATION = MULTIDISCIPLINARY RESEARCH + SMART ENGINEERING

WIRELESS EXPERIMENTATION – SDR IS KEY

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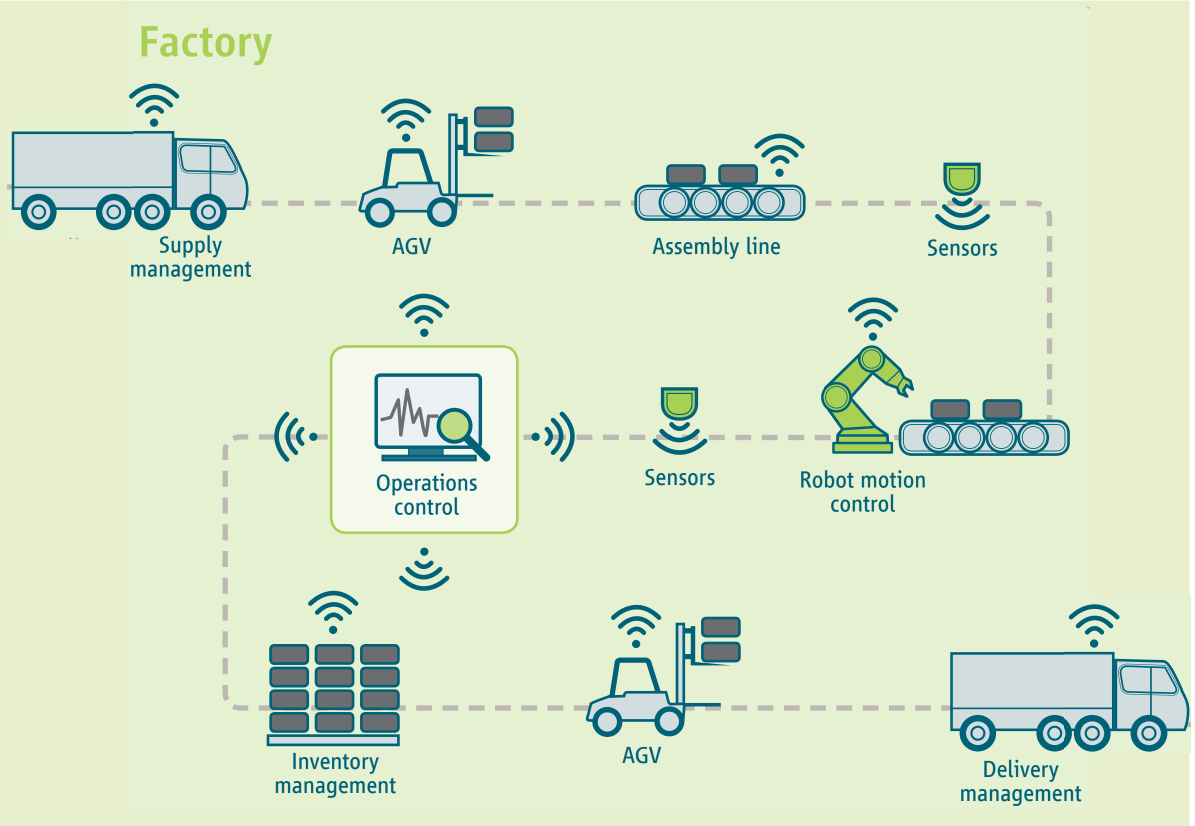
orca

DRIVING SHOWCASE: INDUSTRY 4.0



5G ACIA
5G Alliance for Connected Industries and Automation

https://www.5g-acia.org/fileadmin/5G-ACIA/Publikationen/Whitepaper_5G_for_Connected_Industries_and_Automation/WP_5G_for_Connected_Industries_and_Automation_Korrektur_Download.pdf

DRIVING SHOWCASE: INDUSTRY 4.0

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Use case (high level)		Availability	Cycle time	Typical payload size	# of devices	Typical service area
Motion control	Printing machine	>99.9999%	< 2 ms	20 bytes	>100	100 m x 100 m x 30 m
	Machine tool	>99.9999%	< 0.5 ms	50 bytes	~20	15 m x 15 m x 3 m
	Packaging machine	>99.9999%	< 1 ms	40 bytes	~50	10 m x 5 m x 3 m
Mobile robots	Cooperative motion control	>99.9999%	1 ms	40-250 bytes	100	< 1 km^2
	Video-operated remote control	>99.9999%	10 – 100 ms	15 – 150 kbytes	100	< 1 km^2
Mobile control panels with safety functions	Assembly robots or milling machines	>99.9999%	4-8 ms	40-250 bytes	4	10 m x 10 m
	Mobile cranes	>99.9999%	12 ms	40-250 bytes	2	40 m x 60 m
Process automation (process monitoring)		>99.99%	> 50 ms	Varies	10000 devices per km^2	

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HOW TO ACHIEVE DIVERSITY OF REQUIREMENTS

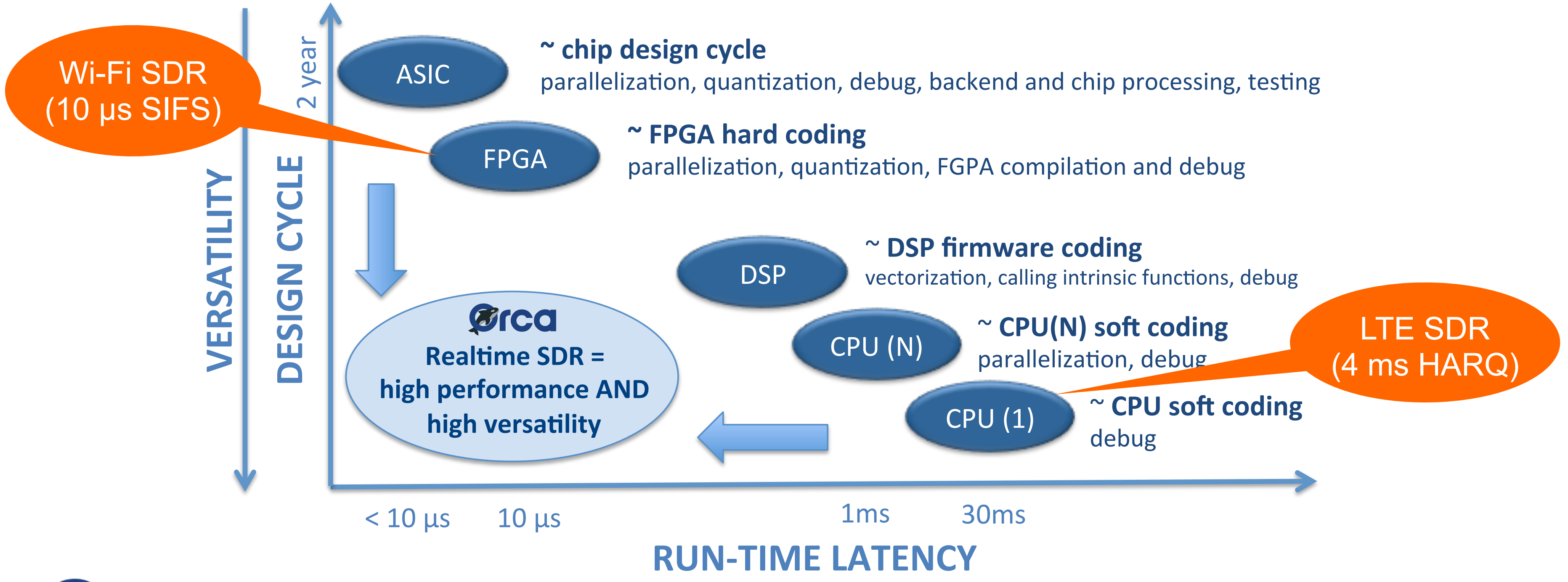
- WITH A SINGLE WIRELESS TECHNOLOGY?
- SHARING THE SAME SPECTRAL BANDS?

HOW DO WE CONTROL?

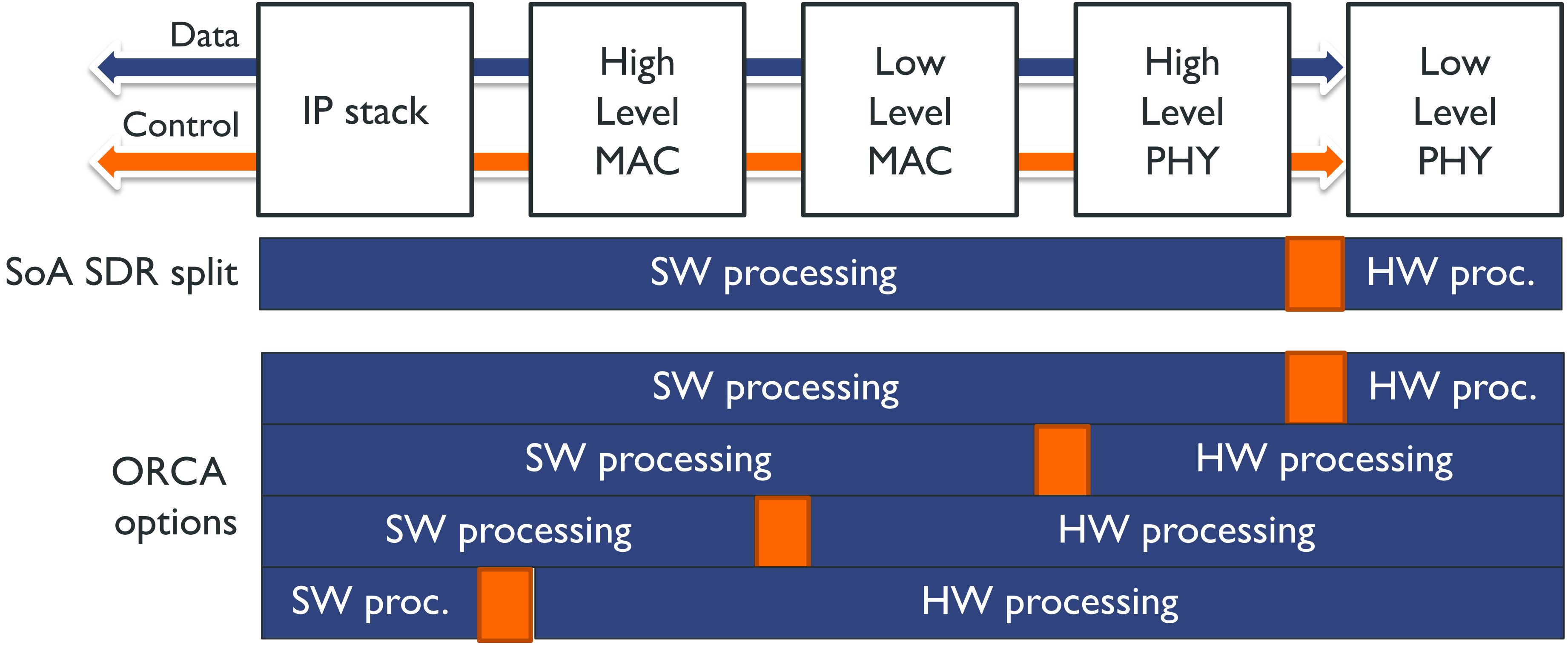
SCOPE

To offer mature, real-time and versatile SDR platforms in advanced wireless test facilities

Versatility = Flexibility + Reprogrammability

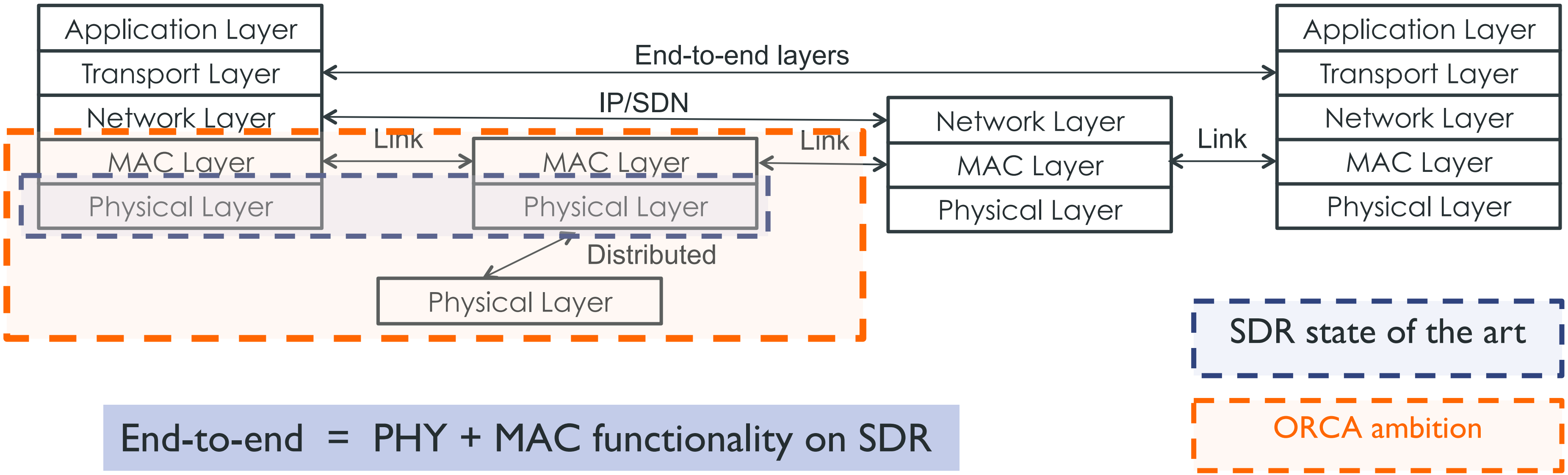


ORCA AMBITION: TOWARDS MORE REAL-TIME IMPLEMENTATION



SCOPE

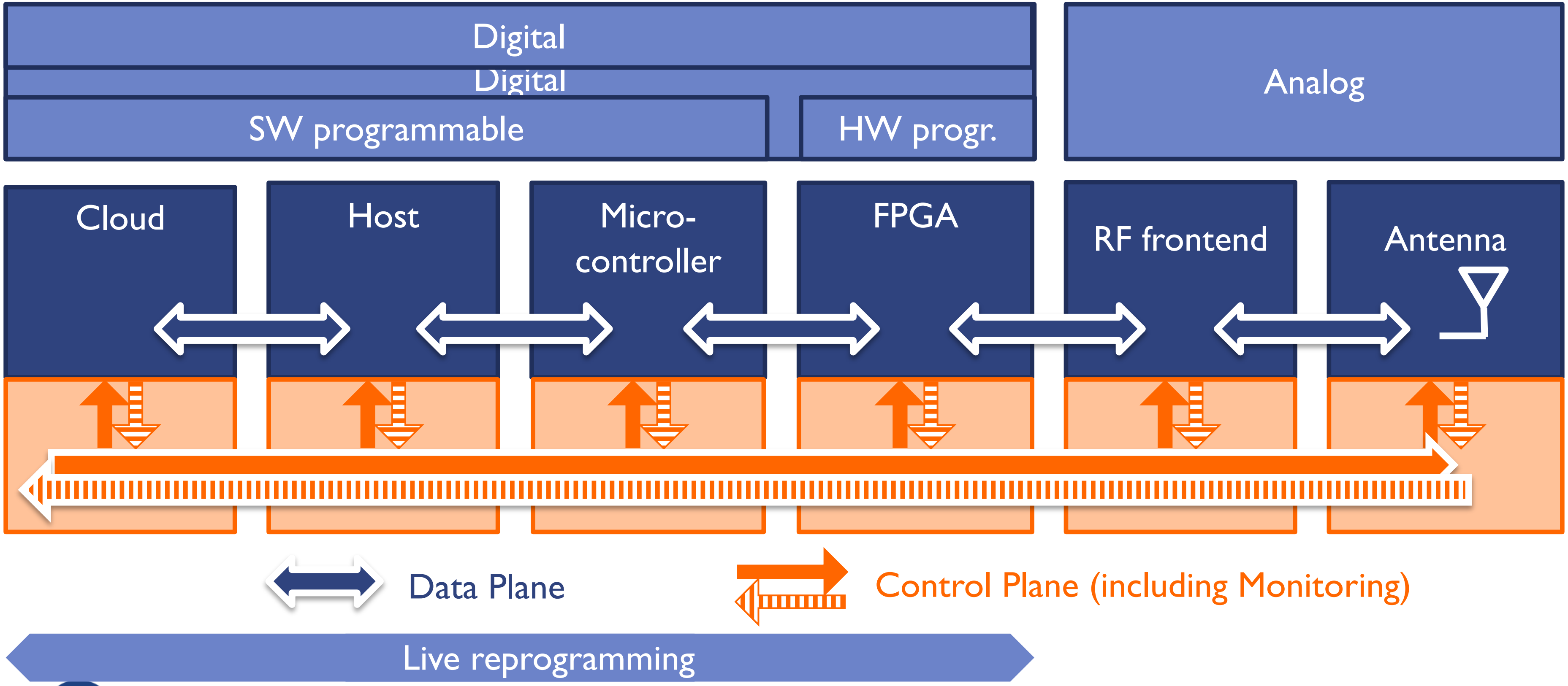
end-to-end networking experimentation



End-to-end = PHY + MAC functionality on SDR

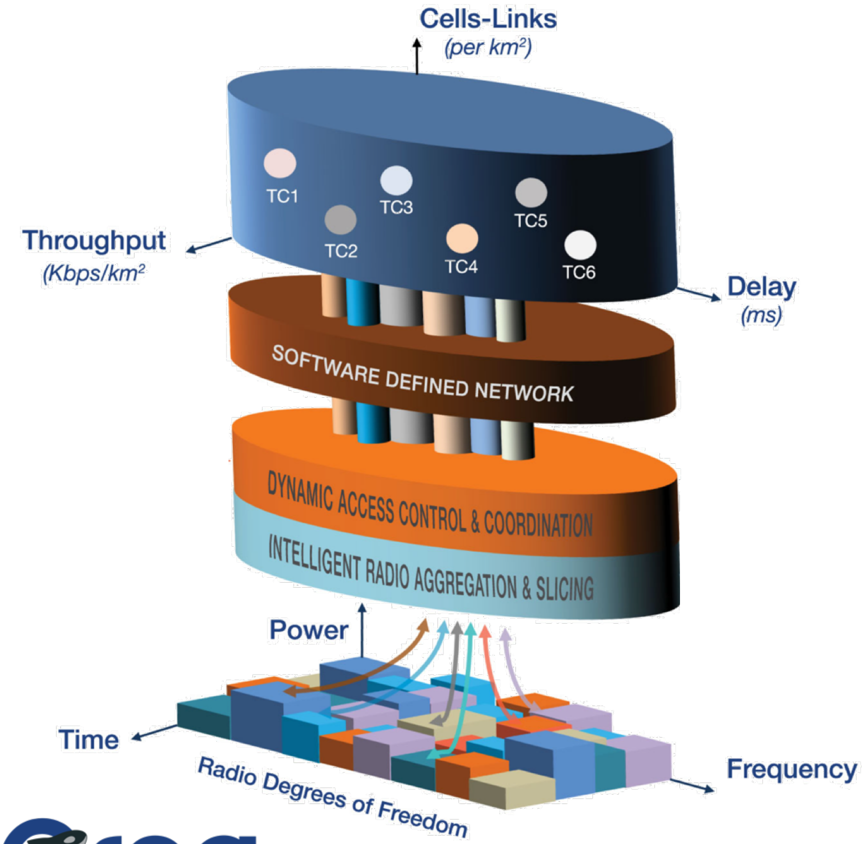
SCOPE

Compose, reconfigure and reprogram wireless devices at runtime



SCOPE

Bridging **SDR** and **SDN**



to drive end-to-end wireless network innovation by **bridging real-time SDR and SDN** exploiting maximum flexibility at radio level, medium access level and network level, to meet very diverse application requirements

MAPPING OF RADIO RESOURCE SLICES TO SDN FLOWS

SOME TECHNICAL HIGHLIGHTS

- makes SDR talk to commercial devices
- creates multiple radio interfaces on a single SDR for free
- enables infrastructure sharing
- makes real-time experimentation with SDR as easy as simulations
- offers flexible low-latency MAC-PHY architecture
- provides in-band full-duplex capable SDRs for high-throughput networking experimentation
- offers 5G mmWave system at 26 GHz with compact multi-beam antenna array
- offers hierarchical orchestration of end-to-end network slices through SDR-SDN integration

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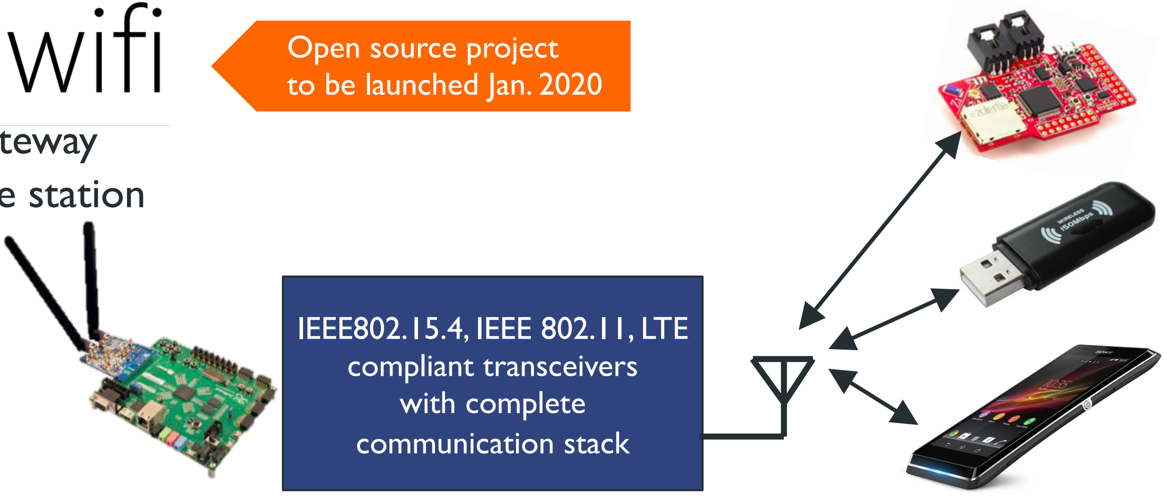
ORCA MAKES SDR TALK TO COMMERCIAL DEVICES

openwifi

Flexible IoT Gateway
Private LTE base station

Open source project
to be launched Jan. 2020

COMMERCIAL OFF THE SHELF NODES



IEEE 802.15.4 compliant IP core + TAISC flexible MAC platform can talk to commercial chips
IEEE 802.11 PHY/MAC + native Linux driver framework SDR behaves like a commercial Wi-Fi card
Private LTE base station talking with standard LTE devices

EASY CUSTOMIZATION ON TOP OF WELL-PROVEN WIRELESS STANDARDS

ORCA MAKES SDR TALK TO COMMERCIAL DEVICES

EASY CUSTOMIZATION ON TOP OF WELL-PROVEN WIRELESS STANDARDS

IEEE 802.15.4	CC2538 (commercial chip)	ORCA solution		
		Narrower BW	Standard	Wider BW
Data Rate (kbps)	250	31.25	250	2000
Bandwidth (MHz)	2	0.25	2	16
RTT (ms) [20 bytes in the air]	1.79	14.08	1.39	0.213
Sensitivity (dBm)	-97	-107	-98	-90
Range (m)	110	347	123	49

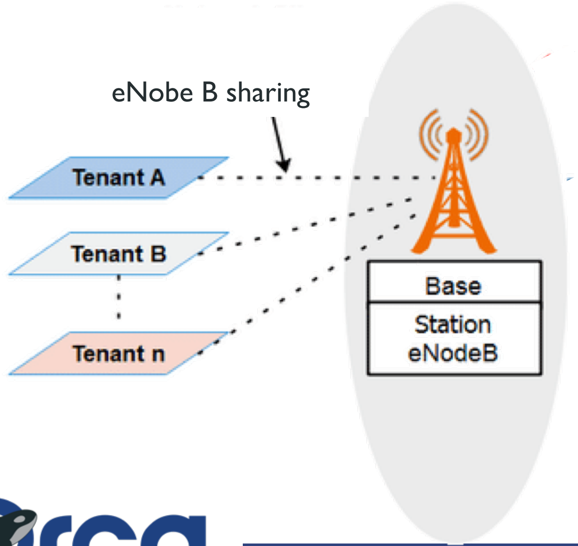
Low latency

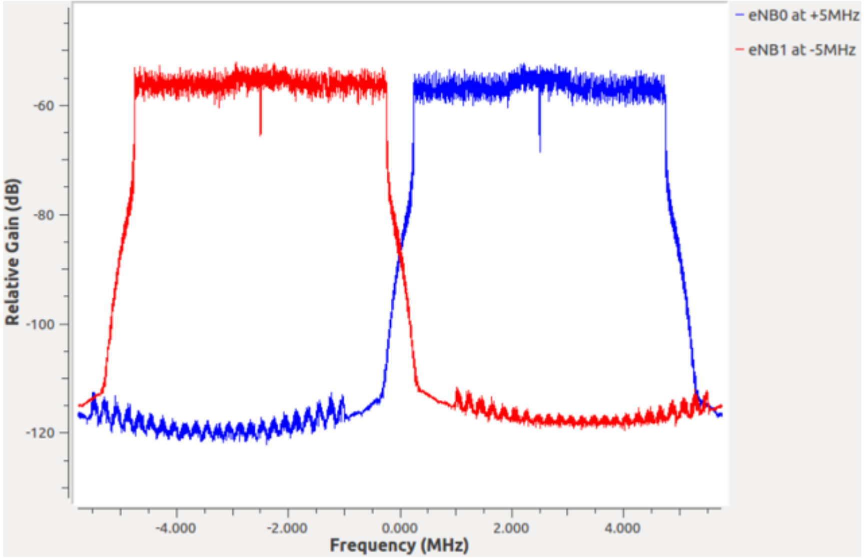
High reliability

ORCA ENABLES INFRASTRUCTURE SHARING

Virtualization: eNodeB infrastructure sharing

- Each operator uses its own spectrum
- Maximum 20MHz bandwidth achieved in total
- maximum 3 eNBs
  - 10+10MHz, 5+5+10MHz: 72Mbps
  - 5+5+5MHz: 54Mbps

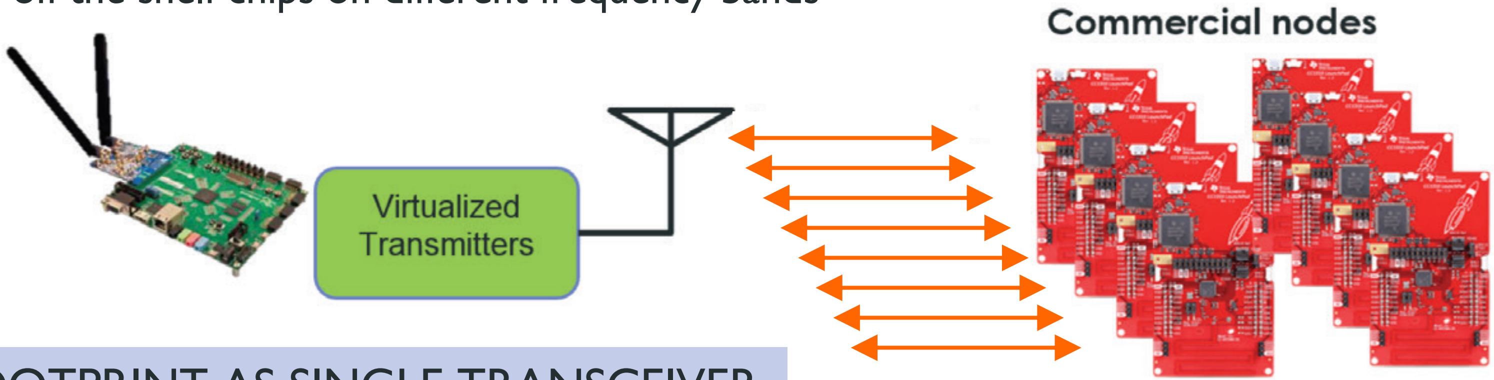




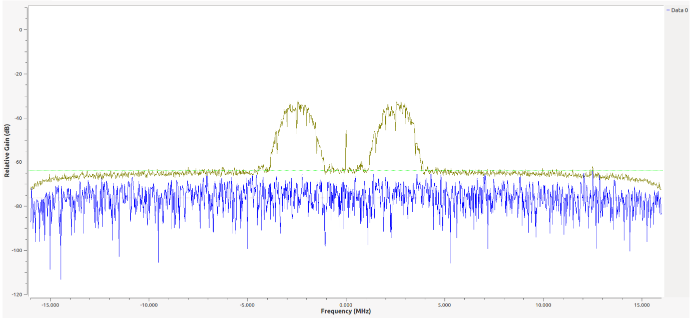
Runner up of best paper competition WiNTECH 2017

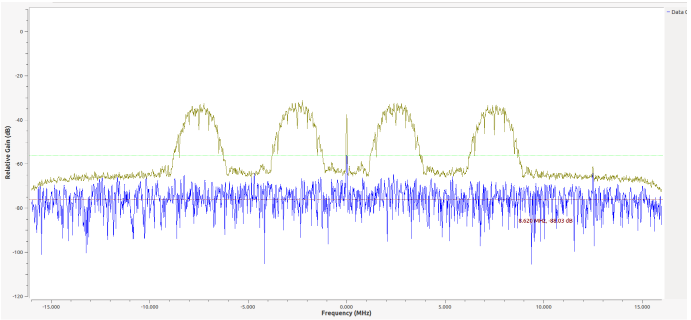
ORCA CREATES MULTIPLE RADIO INTERFACES ON A SINGLE SDR FOR FREE

An SDR based hardware virtualized TRANSCEIVER communicates concurrently with up to 8 commercial off the shelf chips on different frequency bands



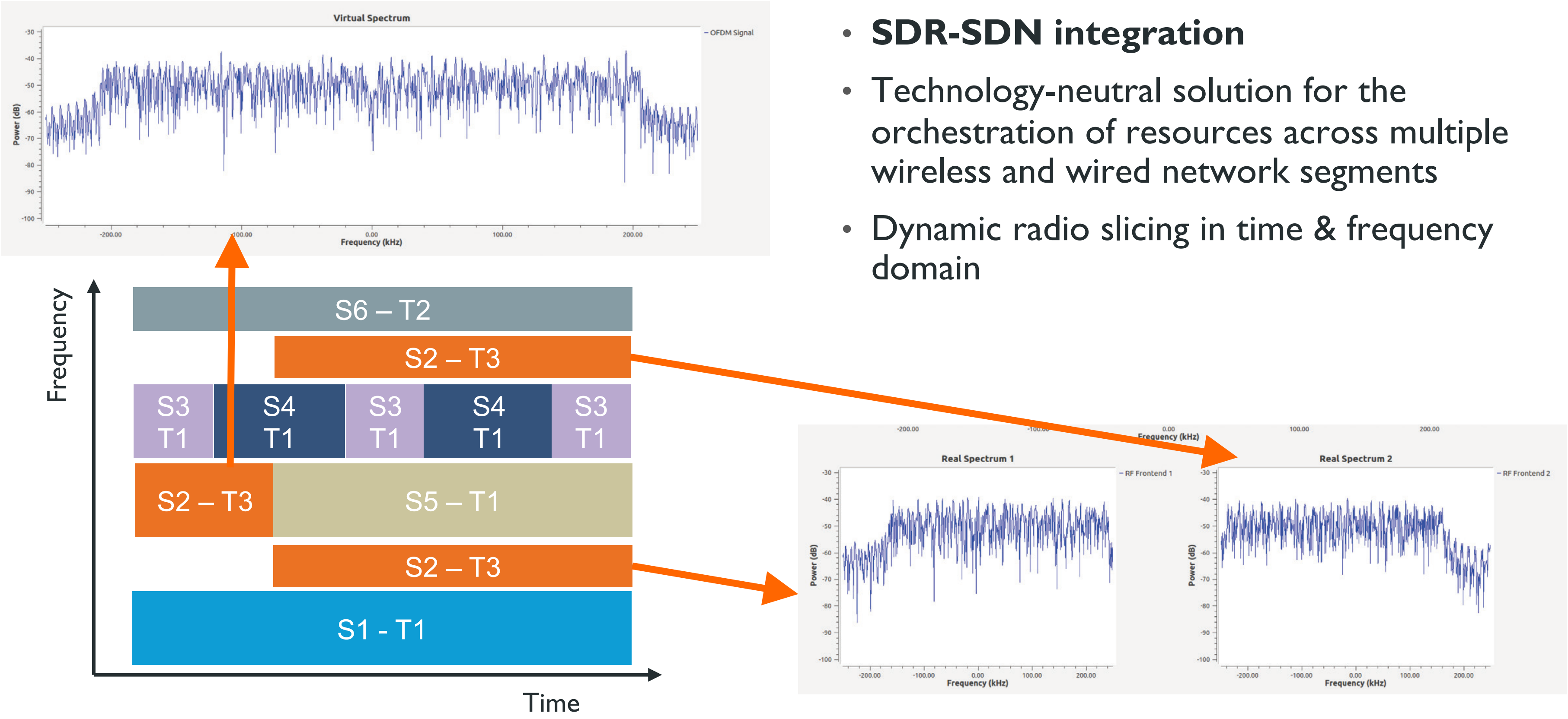
SAME FOOTPRINT AS SINGLE TRANSCEIVER





HIERARCHICAL ORCHESTRATION OF E2E NETWORK SLICES

- **SDR-SDN integration**
- Technology-neutral solution for the orchestration of resources across multiple wireless and wired network segments
- Dynamic radio slicing in time & frequency domain



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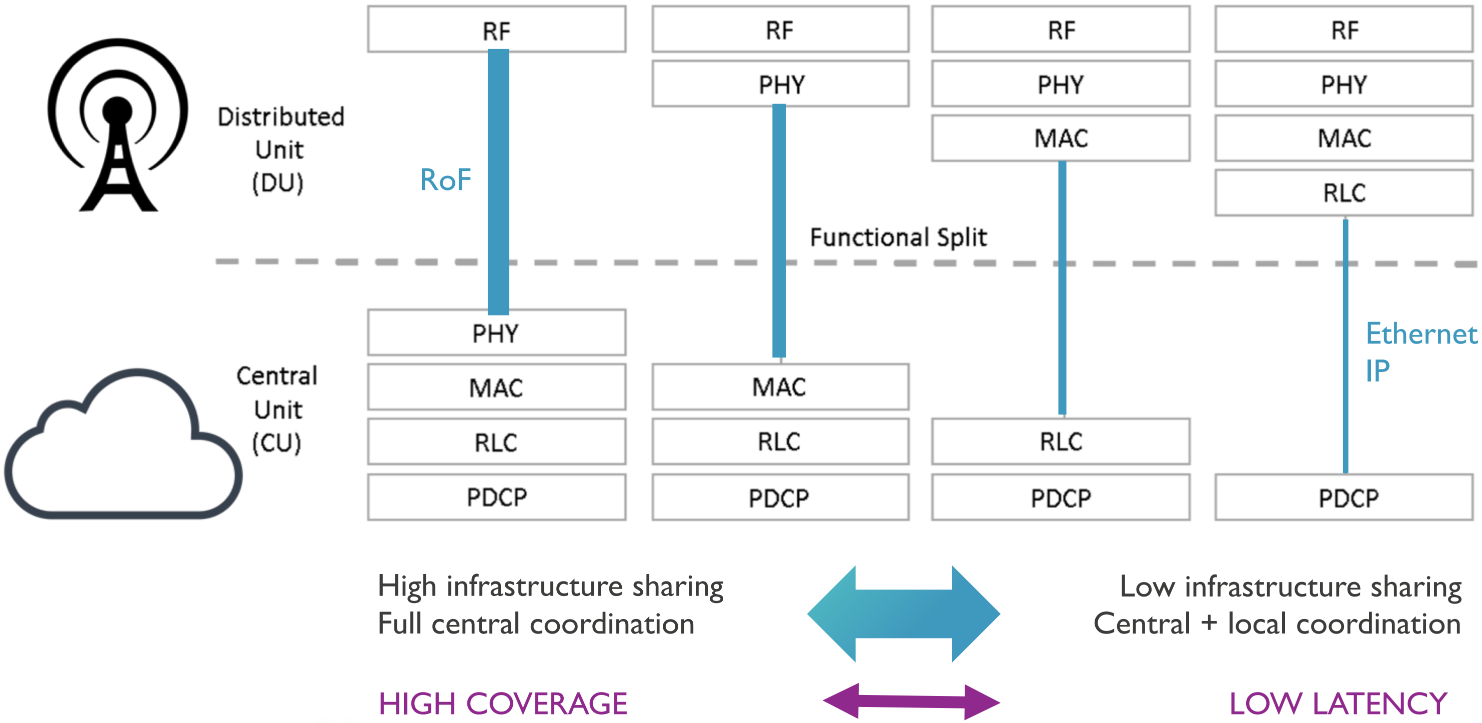
PUBLIC

FUTURE VISION – 5G IS GREAT

5G - SOFTWARIZATION

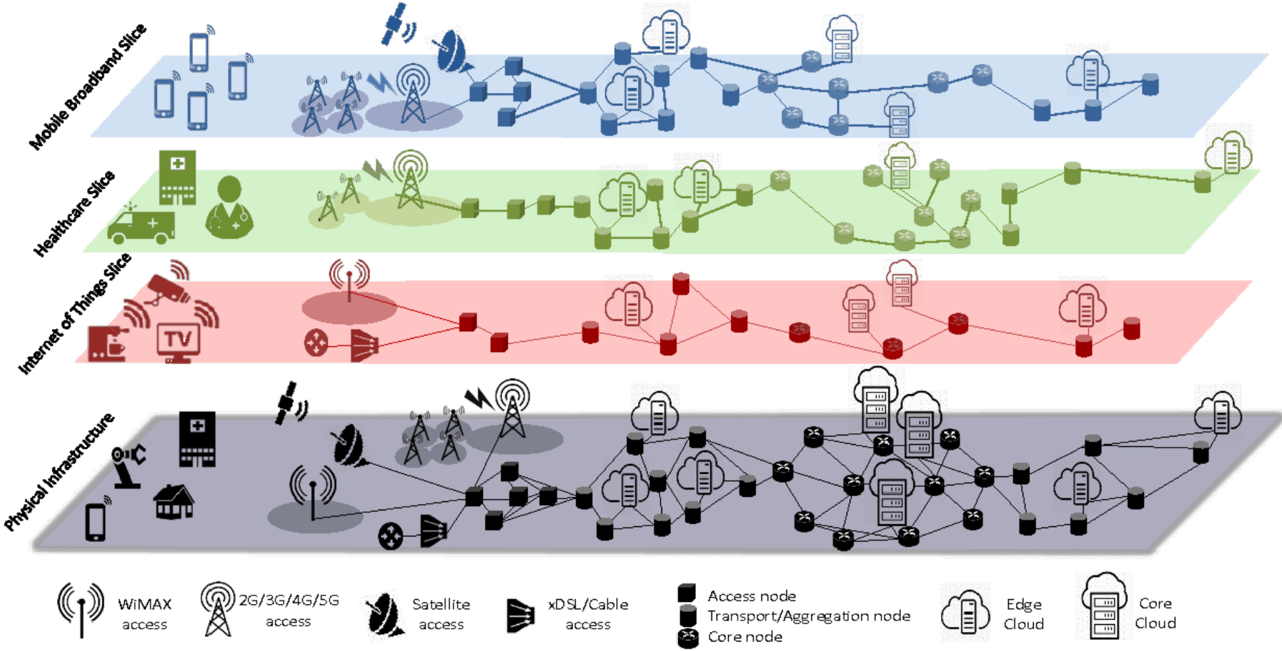
- Using software rather than hardware to perform the processing of radio and network functions
- Great for non real-time (NRT) services, but RT services need hardware acceleration close to antenna



https://www-file.huawei.com/-/media/CORPORATE/PDF/mbb/cloud-ran-the-next-generation-mobile-network-architecture.pdf?la=en

5G - NETWORK VIRTUALIZATION

- Sharing of physical network resources by creation of isolated virtual networks (network slices)
- Each network slice can be individually configured to serve a particular purpose (vertical), guaranteeing a particular set of performance characteristics
- SDN centralized control of network slices



https://www.onug.net/blog/5g-network-slicing-and-enterprise-networking/

FUTURE VISION – 5G IS GREAT, BUT…

5G IS GREAT, BUT… SOME OBSERVATIONS

- **Trade-off between high coverage & spectrum efficiency**
  - new 5G spectrum allocation in sub 6 GHz band (in addition to 2G/3G/4G spectrum)
  - sub 6 GHz band is the most popular spectral band because of its favorable propagation properties
    - very attractive for low cost, low-power end devices
    - BUT spectrum in sub 6 GHz band is scarce and does not scale with increasing application needs
    - exclusive spectrum leads to waste (overprovisioning, as allocation is based on maximum load conditions)
  - MORE EFFICIENT SPECTRUM SHARING NEEDED RATHER THAN MORE EXCLUSIVE USE
- **Trade-off between central and local coordination**

  - Network slicing is led by NFV/SDN communities promoting central coordination
  - Spectrum sharing and radio slicing requires fine-grained local control in wireless domain
  - ORCHESTRATION OF E2E SLICING WOULD BENEFIT FROM DOMAIN-SPECIFIC EXPERTISE
- **Holistic approach** with a "one system fits all" philosophy for supporting different verticals
  - complex and dynamic system with centralized control in the cloud
  - complex and time-consuming standardization process dominated by a few big mobile stakeholders
  - NEW AND SMALLER PLAYERS WOULD BRING INNOVATION

5G IS GREAT, BUT… SOME MORE OBSERVATIONS

- Softwarization is great, but **low latency** will require
  - less soft coding, more hard coding (hardware acceleration)
  - shift of functionality closer to antenna
- Embedded hardware is also **reprogrammable** (soft code as well as hard code)
- Some smaller, local, indoor deployments, dynamic environments and niche markets may require more **simple**, more **flexible**, **low-cost** (deployment and maintenance), solutions than 5G
- Do not ignore the power of **end devices**

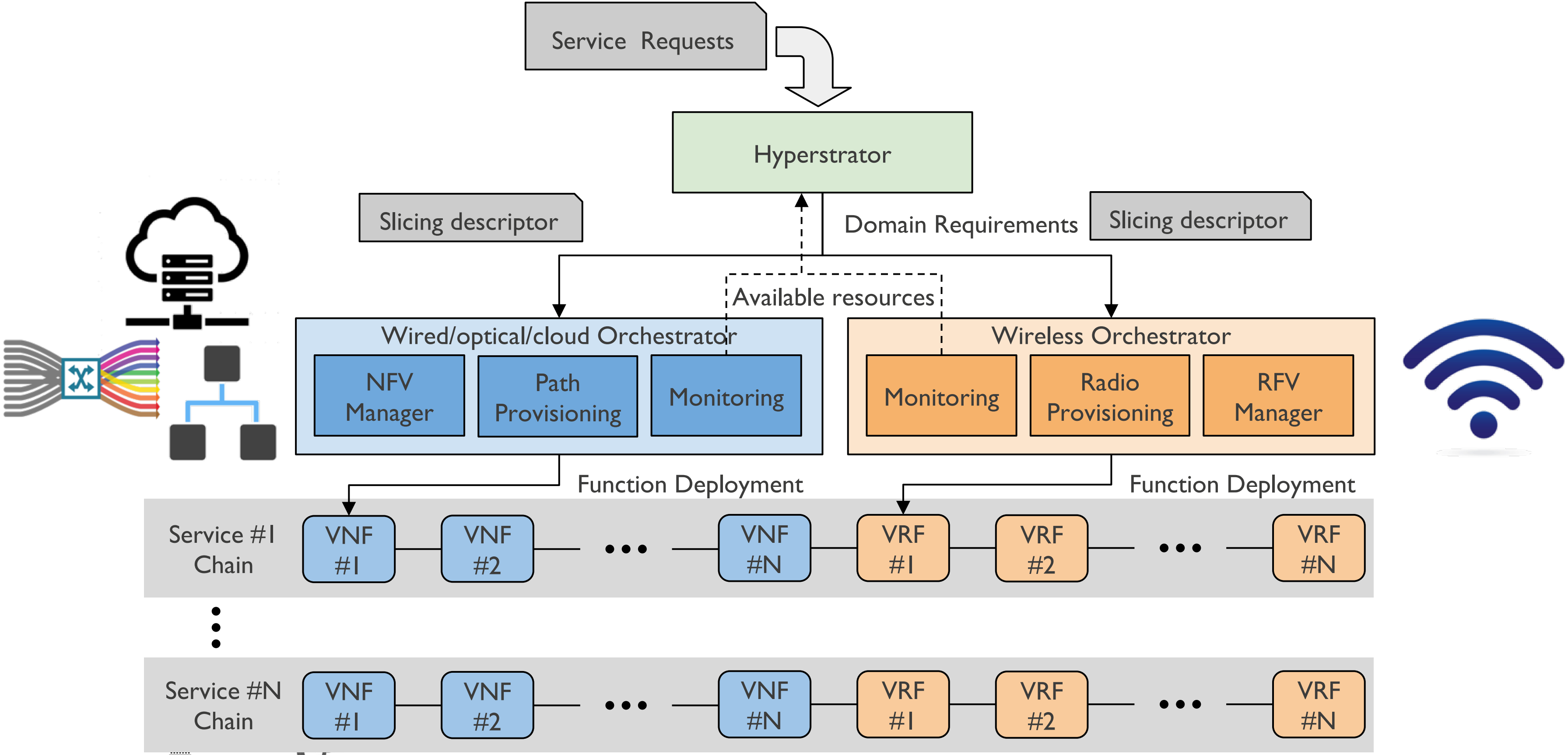
FUTURE VISION – THERE IS MORE THAN 5G

Orca END-TO-END VISION: MOTIVATION

- DIFFERENT NETWORK SEGMENTS
  - built for different purposes
  - different media (optical fibre, copper cables, and wireless) with different technologies & protocols
  - HOW TO COMBINE INTO END-TO-END SLICE?
  - HOW TO GUARANTEE SUFFICIENT FINE-GRAINED RESOURCE CONTROL IN DIFFERENT SEGMENTS?

- WIRED VERSUS WIRELESS
  - wired: predictable and known capacity
  - wireless: variable capacity
    - due to the inherent stochastic nature of the wireless medium
    - due to interference (broadcast nature of wireless links)
    - due to mobility
  - DIFFERENT ABSTRACTIONS AND MODELS!

Orca END-TO-END VISION: HIERARCHICAL ORCHESTRATION



ORCA END-TO-END VISION: BENEFITS

- MODULAR: specialized segment orchestrator designed by domain experts
- ROBUST: less vulnerable to single point of failure
- UPGRADABLE: easy and independent changes or upgrades
- EXTENSIBLE: easy integration of orchestrators that manage additional/future types of network segments
- TECHNOLOGY NEUTRAL: not restricted to 5G technologies & specific spectral bands
- SIMPLIFIED STANDARDISATION
  - focus on open interfaces (1) expressing service requirements to hyperstrator and (2) expressing high-level functional description of slices between hyperstrator and underlying segments orchestrators
  - yields more freedom for solutions within segments
  - minimize risks of dependencies and lock in

ORCA WHITE PAPER

https://orca-project.eu/wp-content/uploads/sites/4/2018/10/orchestrating_e2e_network_slices_Final.pdf

ORCHESTRATING NEXT-GENERATION SERVICES THROUGH END-TO-END NETWORK SLICING

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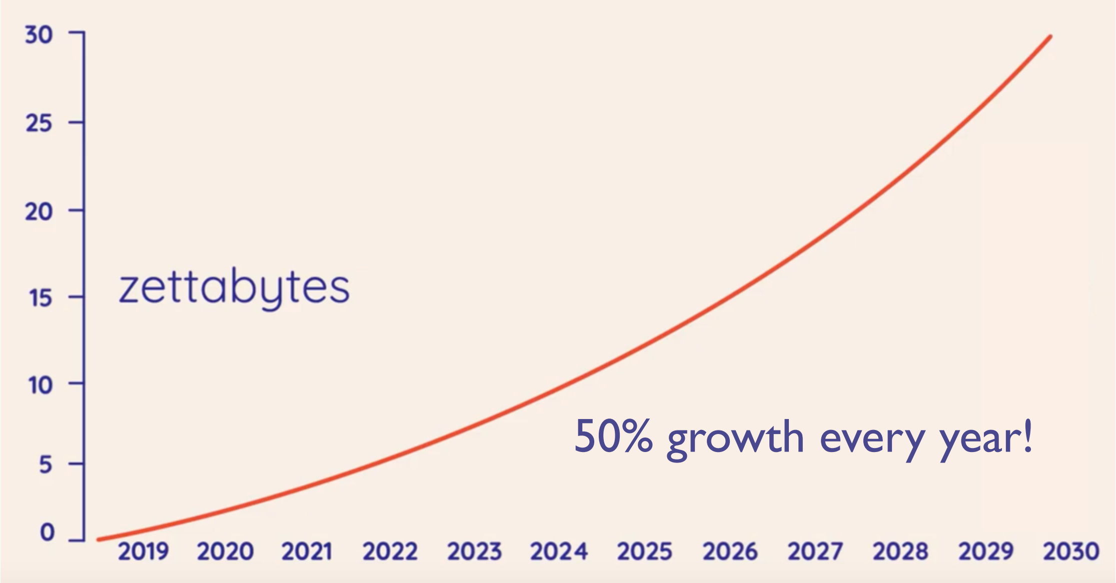
FUTURE VISION – DARPA SPECTRUM COLLABORATION CHALLENGE

WHY SPECTRUM SHARING

GROWING DEMAND OF WIRELESS TRAFFIC



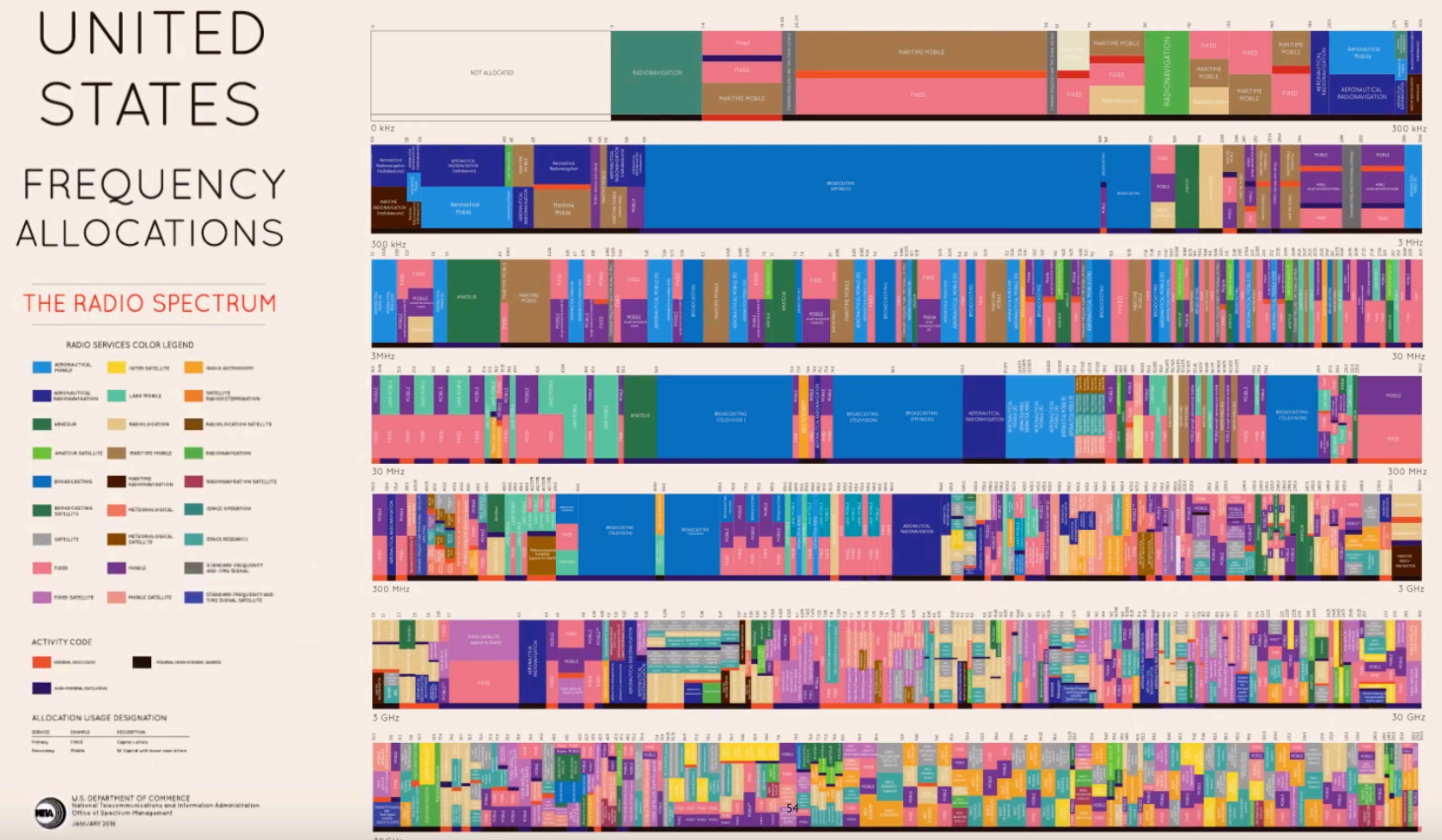
Source: Darpa SC2, https://youtu.be/cd3kCPvaXOw

< 6 GHz spectrum cannot grow!

WHY SPECTRUM SHARING?

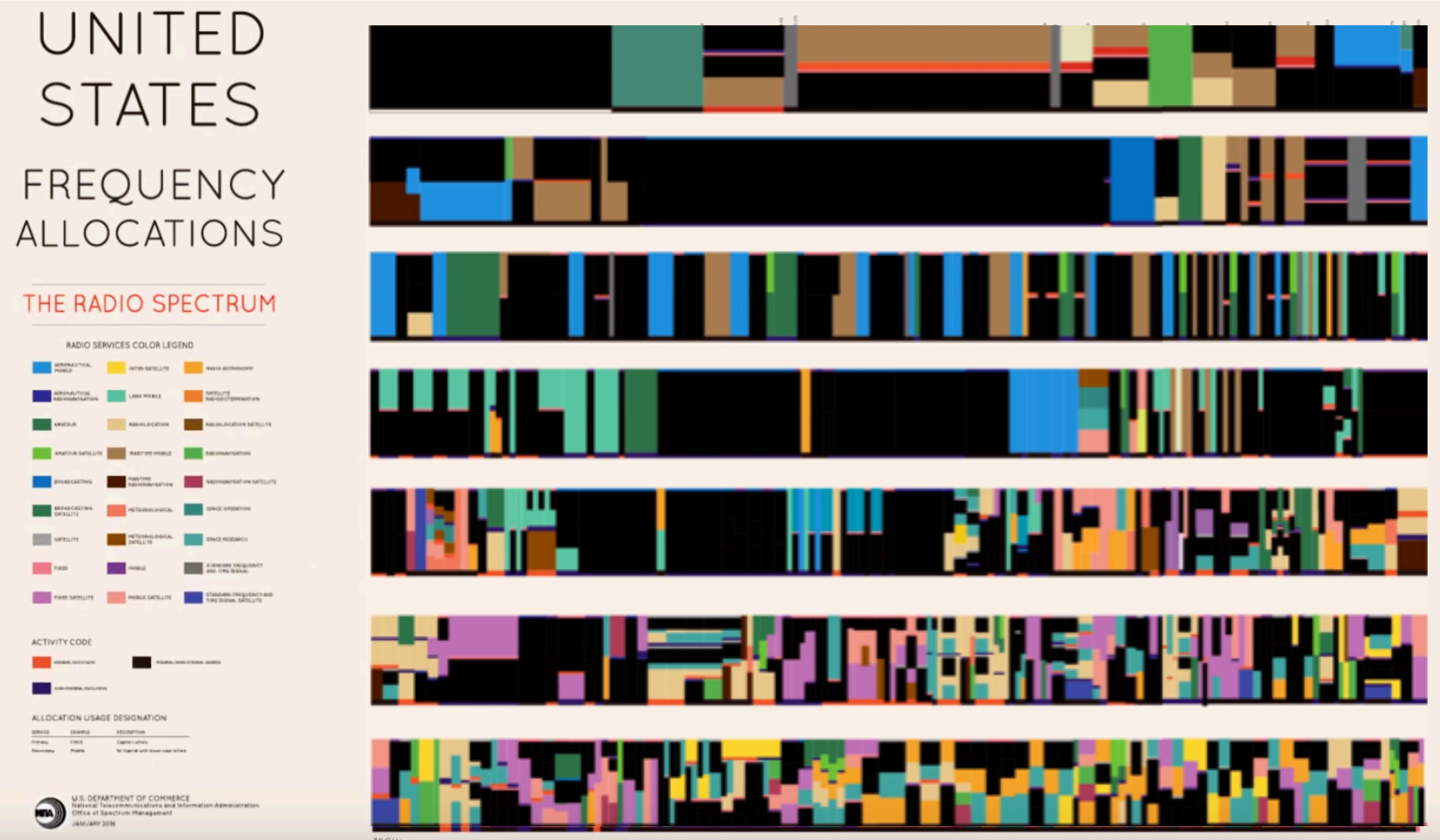
MANY UNUSED SPECTRUM

Source: Darpa SC2, https://youtu.be/cd3kCPvaXOw



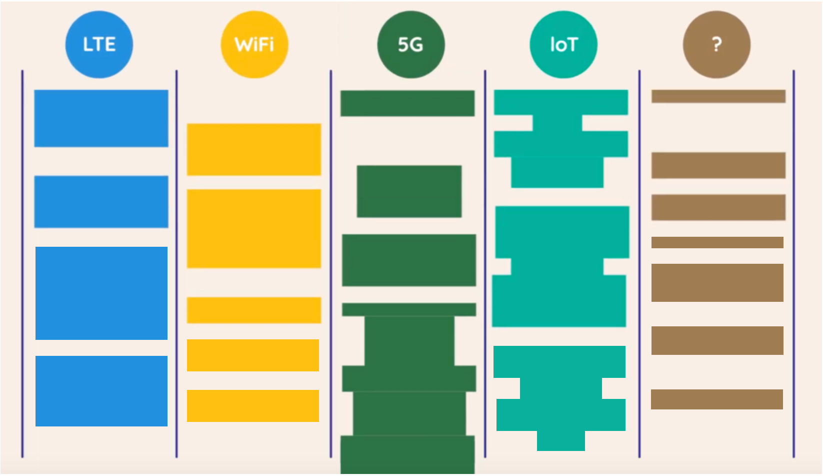
WHY SPECTRUM SHARING?
MANY UNUSED SPECTRUM

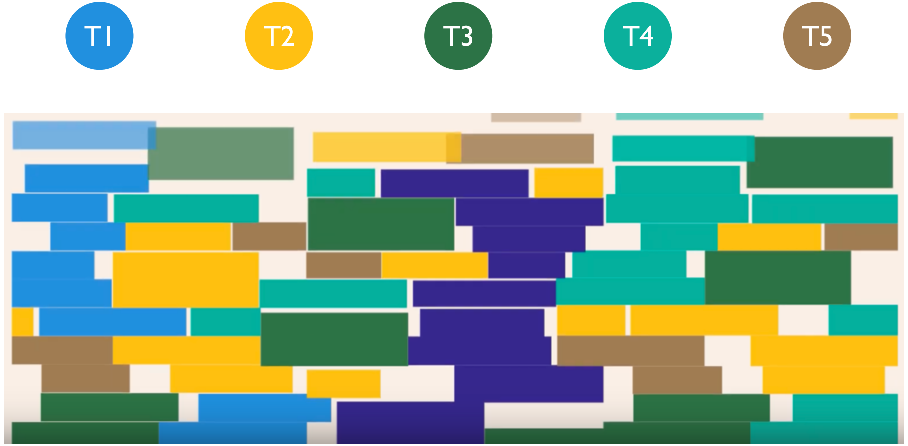
Source: Darpa SC2, https://youtu.be/cd3kCPvaXOw



MOVE AWAY FROM ISOLATION OF SPECTRUM

ISOLATION → AUTONOMY & SPECTRUM COLLABORATION

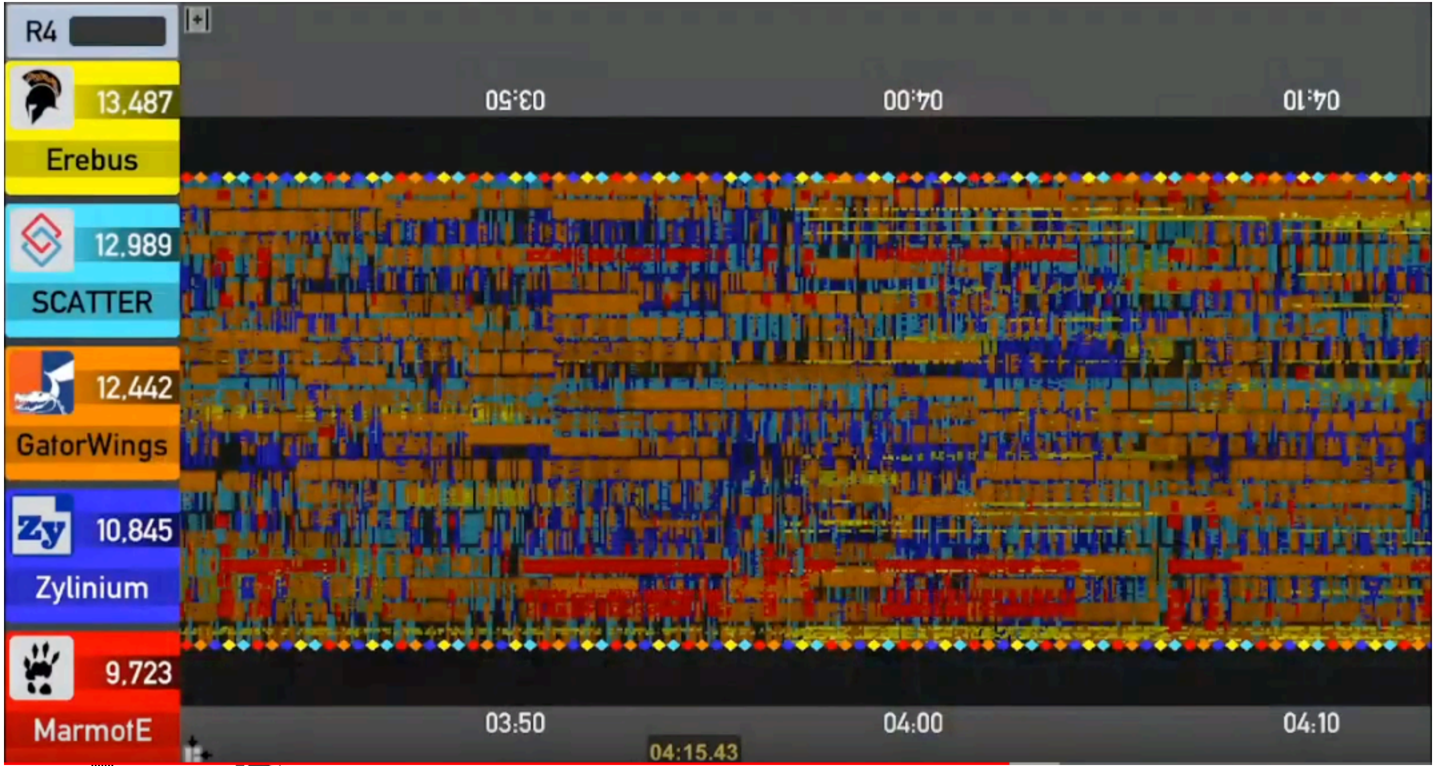


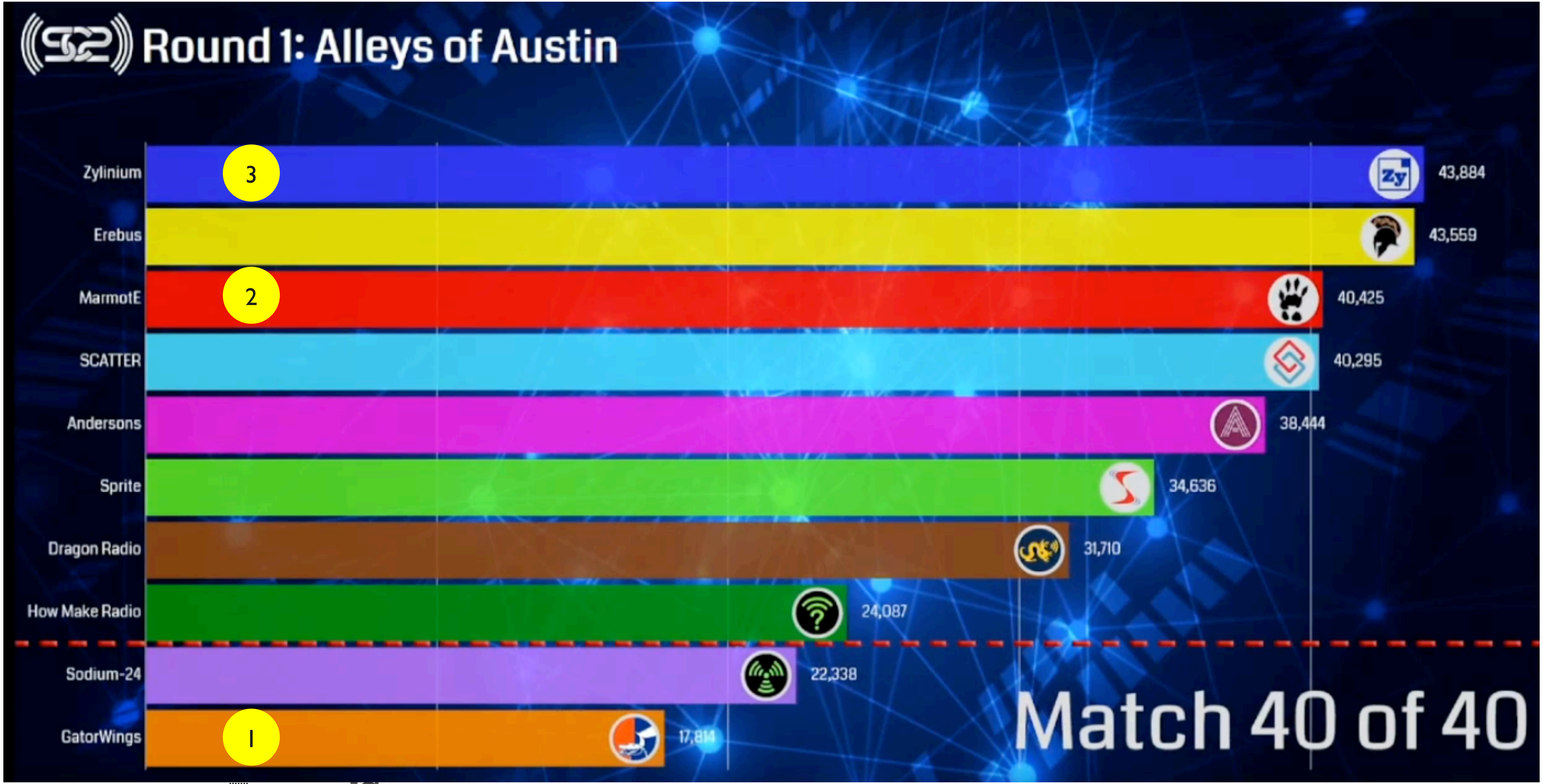


Spectrum silos lead to overdimensioning and waste of spectrum

TEAM SCATTER

EXAMPLE OF SPECTRUM SHARING




Round 1: Alleys of Austin
Zylinium
3
43,884
Erebus
43,559
MarmotE
2
40,425
SCATTER
40,295
Andersons
38,444
Sprite
34,636
Dragon Radio
31,710
How Make Radio
24,087
Sodium-24
22,338
GatorWings
1
17,814
Match 40 of 40

TEAM SCATTER: DOUBLE PRIZE WINNER + FINALIST @ MWC (LA)

Dec 2017: 750 000 USD prize

Dec 2018: 750 000 USD prize

23 Oct. 2019: finalist, 6^{th} position (out of 10)

Belgische onderzoekers halen zesde plaats in internationale wedstrijd rond draadloze communicatie

datanews

Een team van de Vlaamse onderzoeksinstelling Imec is op een zucht van de top vijf gestrand in de finale van de *DARPA spectrum collaboration challenge* **in Los Angeles. Daarbij was het de bedoeling om een systeem voor draadloze communicatie te ontwerpen dat betrouwbaar data kan afleveren in chaotische omgevingen met veel dataverkeer.**

Het Imec-team in de finale van de DARPA spectrum collaboration challenge. © Steven Latré

Welk radiosysteem is klaar voor de toekomst?

Een Belgisch team heeft de zesde plaats veroverd op de finale van de *DARPA spectrum collaboration challenge*. Met die wedstrijd wil de onderzoeksafdeling van het Amerikaans leger de ogen openen: we moeten het radiospectrum op een andere manier gaan gebruiken.

Pieter Van Nuffel
Meer artikels van deze auteur

Meer over de volgende onderwerpen:

Technologie

DARPA spectrum collaboration challenge

INSPIRED BY…

Orca

Orchestration and Reconfiguration Control Architecture

HERMES PARTNERSHIP

TEAM SCATTER

imec +
Rutgers University

SPECTRUM COLLABORATION CHALLENGE