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The Impact of 5G Air Interfaces on Converged Fronthaul/Backhaul

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IEEE [WG Project 1914.1]
[Next Generation Fronthaul Interface]
[WG Chair: Jinri Huang]

The Impact of 5G Air Interfaces on Converged Fronthaul/Backhaul
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5G-XHaul Overview

5G-XHaul
www.5g-xhaul-project.eu

European Commission | Horizon 2020
European Union funding
for Research & Innovation

5G-XHaul partners:

ihp, i2cat, Telefónica Investigación y Desarrollo, TES Electronic Solutions, COSMOTE our world is you, University of BRISTOL, University of Thessaly, HUAWEI, ADVA Optical Networking, AIRRAYS, BLUWIRELESS TECHNOLOGY, TECHNISCHE UNIVERSITÄT DRESDEN

Disclaimer:
The presented work is research-in-progress.
The results and conclusions presented do not necessarily represent the view of all project partners.

Outline - The Impact of 5G Air Interfaces on Converged Fronthaul/Backhaul

Agenda:

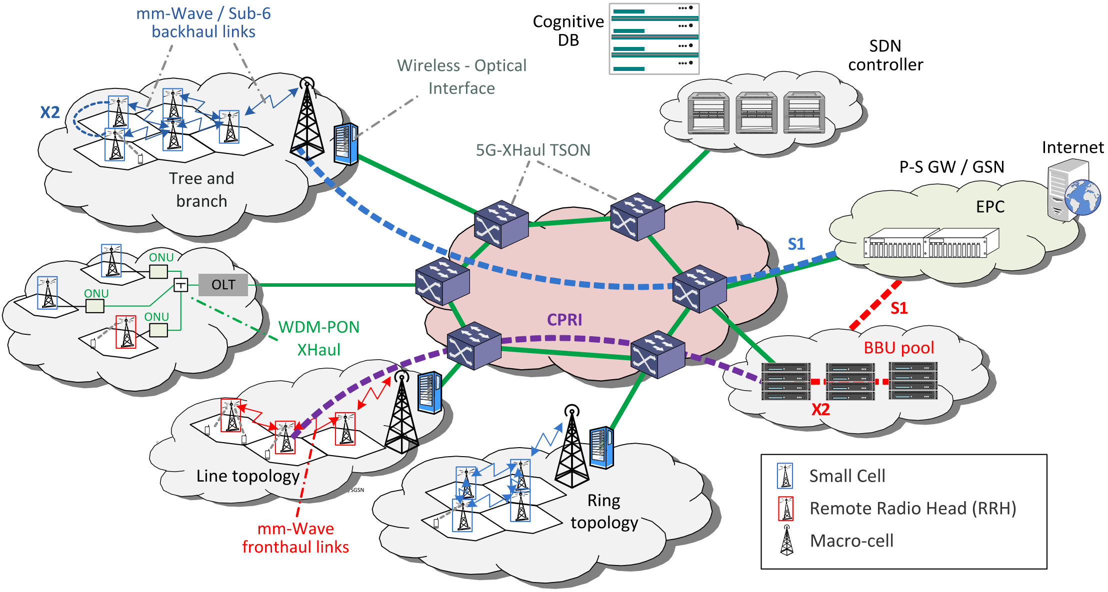
- **Converged transport network for 5G**
- **Assumptions for 5G air interfaces, functional splits**
- **Statistical multiplexing gains in packet-based transport**
- **Resulting requirements for the transport network (data rate, delay, delay accuracy)**
- **Transport classes for converged fronthaul/backhaul**

5G-XHaul in a Nutshell

Focus on transport network

Challenges:

- Heterogeneous RAN technologies: D-RAN vs. C-RAN, sub-6 vs. mmWave, small cells vs. macro
- New RAN requirements: higher data rates, low latency, resilience, MTC



5G-XHaul Approach:

Convergence

- Wireless – Optical
- Backhaul (BH) – Fronthaul (FH)

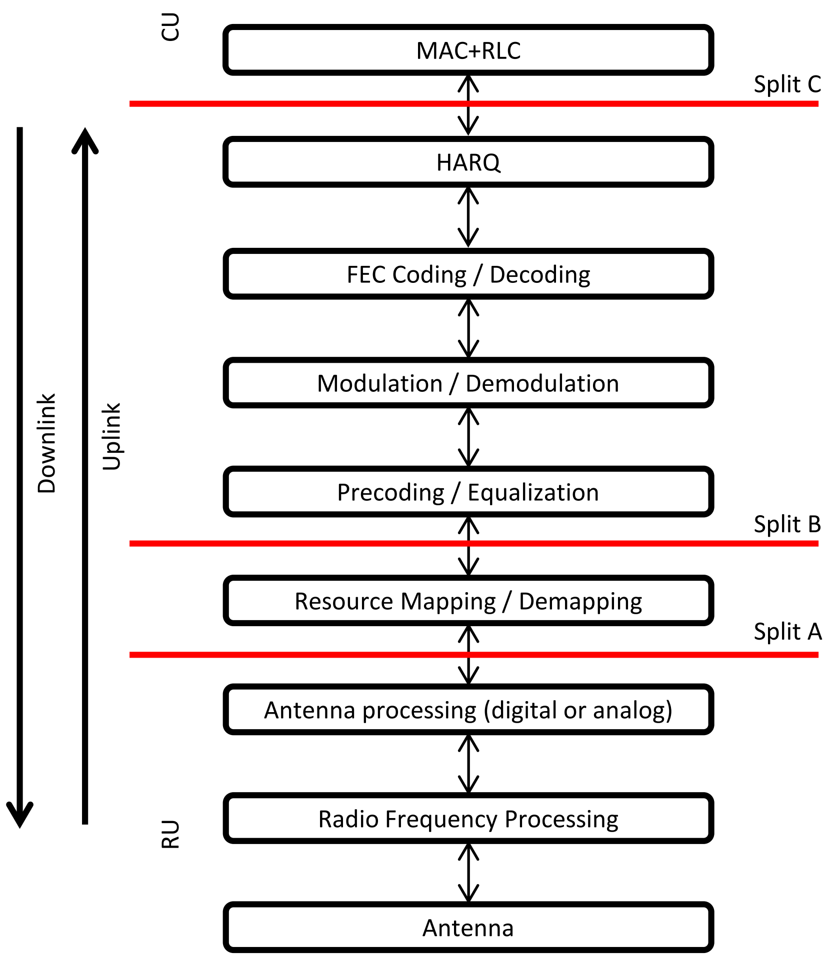
Data Plane

- Wireless
  - P2MP mmWave (60 GHz)
  - Sub-6
- Optical
  - TSON
  - WDM-PON

SDN Control plane

- Unified for wireless & optical
- Aware of spatio-temporal demand variations (in the RAN)
- Interfaces for joint RAN – transport design

Functional Splits Considered

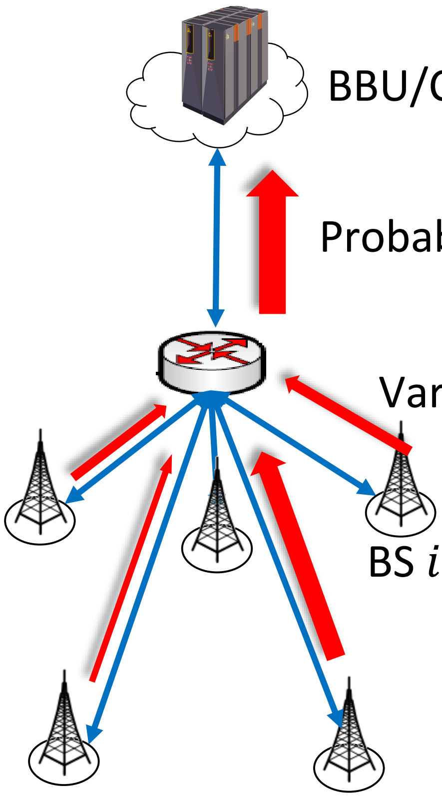


No.	Advantages/Disadvantages
C	• "Centralized MAC" • Data rate depends on actual user data rate • No HARQ delay requirement • Potentially no hardware accelerators at CU • Requirements similar to classical backhaul • No centralized CoMP, MU-MIMO
B	• "Frequency domain FH" • Only utilized RB forwarded (enables stat. mux.) • No guard carriers, cyclic prefix forwarded • Frequency domain (lower A/D res.) • Additional hardware at RU required (FFT)
A	• "Reasonable CPRI" – additional antenna processing at RU for beamforming • No limitation in centralized processing • Very little digital hardware at RU • Very high, static data rate • Low latency required

5G Air Interface Assumptions (based on [4])

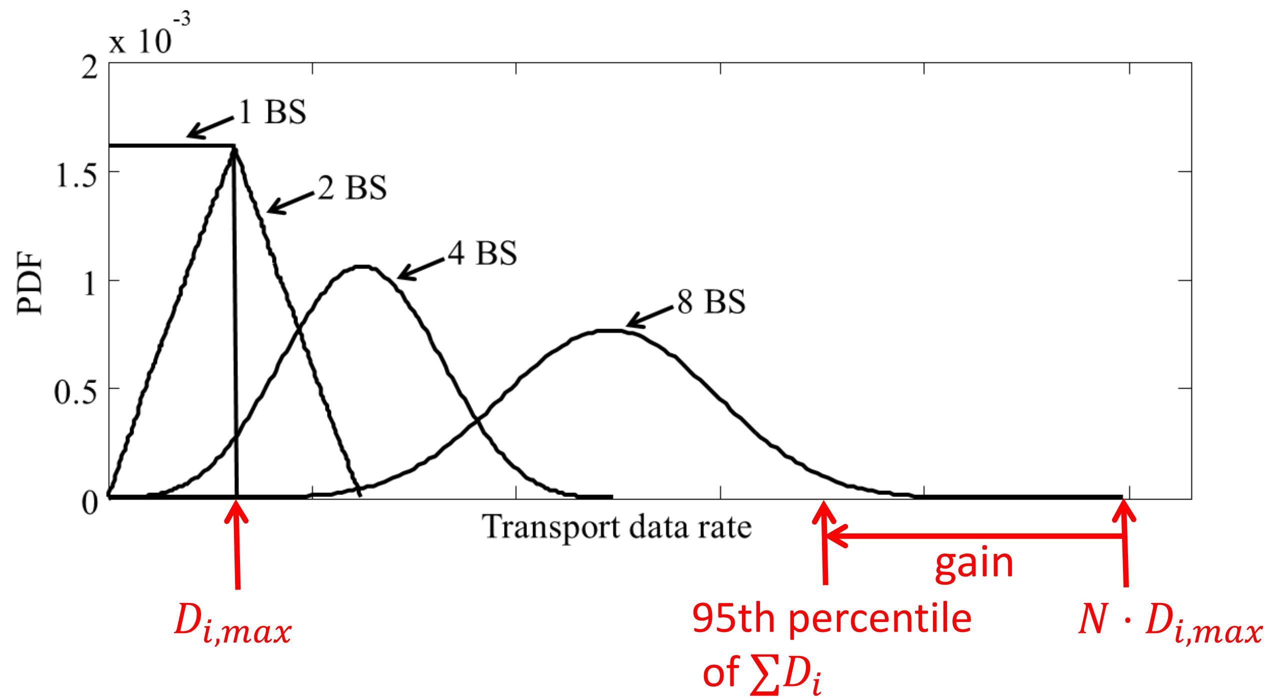
Parameter	Symbol	LTE	Sub-6	Low mmWave	High mmWave
Carrier Frequency [GHz]	f_C	**2**	**2**	**30**	**70**
Channel Size [MHz]	BW	**20**	**100**	**250**	**500**
Sampling Rate [MHz]	f_S	30.72	150	375	750
# Antennas	N_A	**4**	**96**	**128**	**256**
# ADC/DAC chains	N_P	4	16	12	10
# Layers	N_L	**4**	**16**	**12**	**10**
Overhead	γ	1.33	1.33	1.33	1.33
Quantizer resolution time domain	$N_{Q,T}$	15	15	12	10
Quantizer resolution frequency domain	$N_{Q,F}$	9	9	8	7
Modulation order	M	**64**	**1024**	**256**	**64**
Max. code rate	R_C	0.85	0.85	0.85	0.85
Frame duration [ms]	T_F	1	1	1	1
FFT size	N_{FFT}	2048	2048	2048	2048
# Active subcarriers	$N_{SC,act}$	**1200**	**1300**	**1300**	**1300**
# Data symbols per frame	N_{Sy}	14	70	150	300
Peak utilization	μ	1	1	1	1
Formula data rate split A	$D_A = 2 \cdot N_P \cdot f_S \cdot N_{Q,T} \cdot \gamma$				
Formula data rate split B	$D_B = 2 \cdot N_P \cdot N_{SC,act} \cdot N_{Sy} \cdot N_{Q,F} \cdot T_F^{-1} \cdot \mu \cdot \gamma$				
Formula data rate split C	$D_C = N_L \cdot N_{SC,act} \cdot N_{Sy} \cdot R_c \cdot \log_2 M \cdot T_F^{-1} \cdot \mu \cdot \gamma$				
Peak data rate split A [Gbps]	D_A	**4.9**	**95.8**	**143.6**	**199.5**
Peak data rate split B [Gbps]	D_B	**1.6**	**34.9**	**49.8**	**72.6**
Peak data rate split C [Gbps]	D_C	**0.46**	**16.5**	**21.2**	**26.5**

Statistical Multiplexing

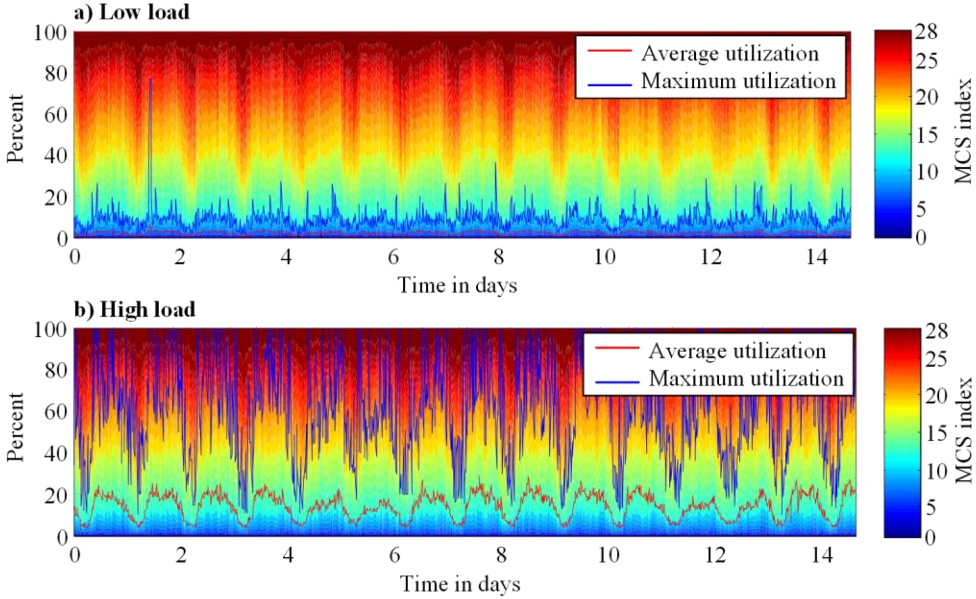


Probability of having to transport $N \cdot D_{i,max}$ is very low

Variable traffic D_i with peak $D_{i,max}$



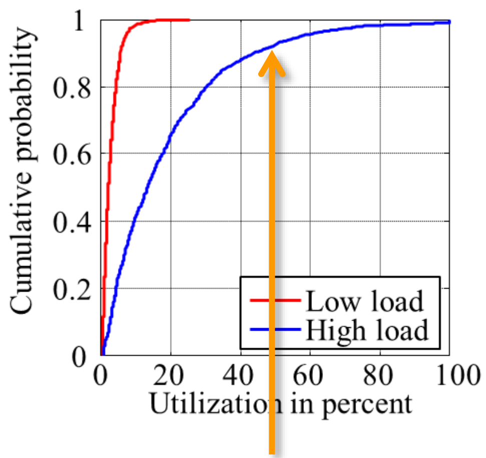
Data Rate Requirements – Measurements

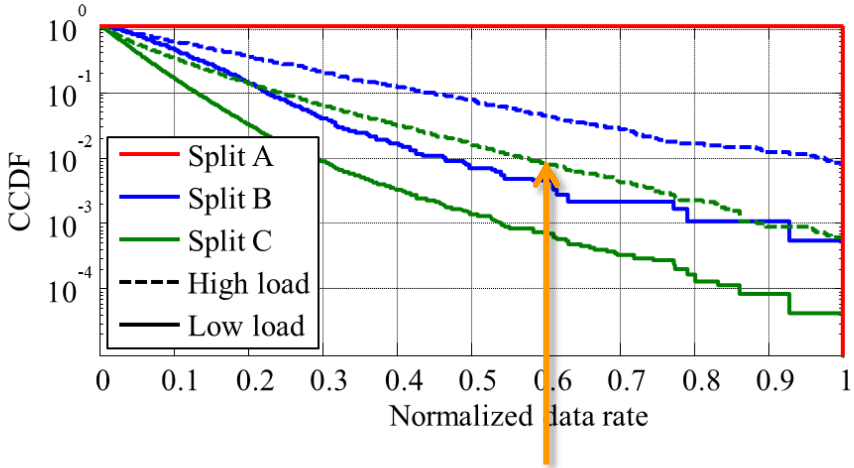


Measure traffic from 33 LTE cells

Scaled to reflect higher utilization

CPRI traffic is static but FH traffic should follow traffic variation to enable statistical multiplexing →splits B, C

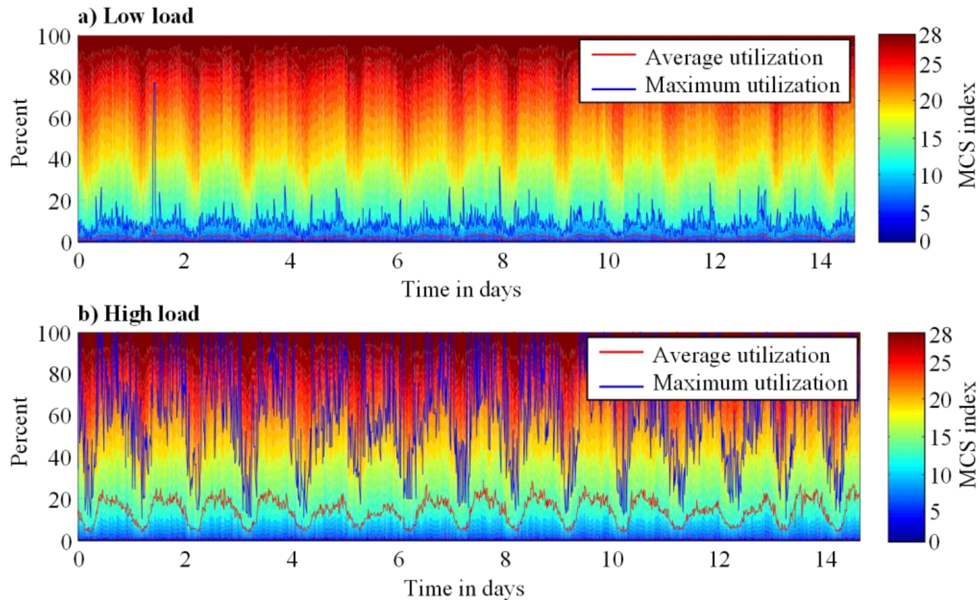




e.g., utilization below 50 % in 90 % of cases

e.g., traffic below 60 % in 99 % of cases

Data Rate Requirements – 4G vs 5G



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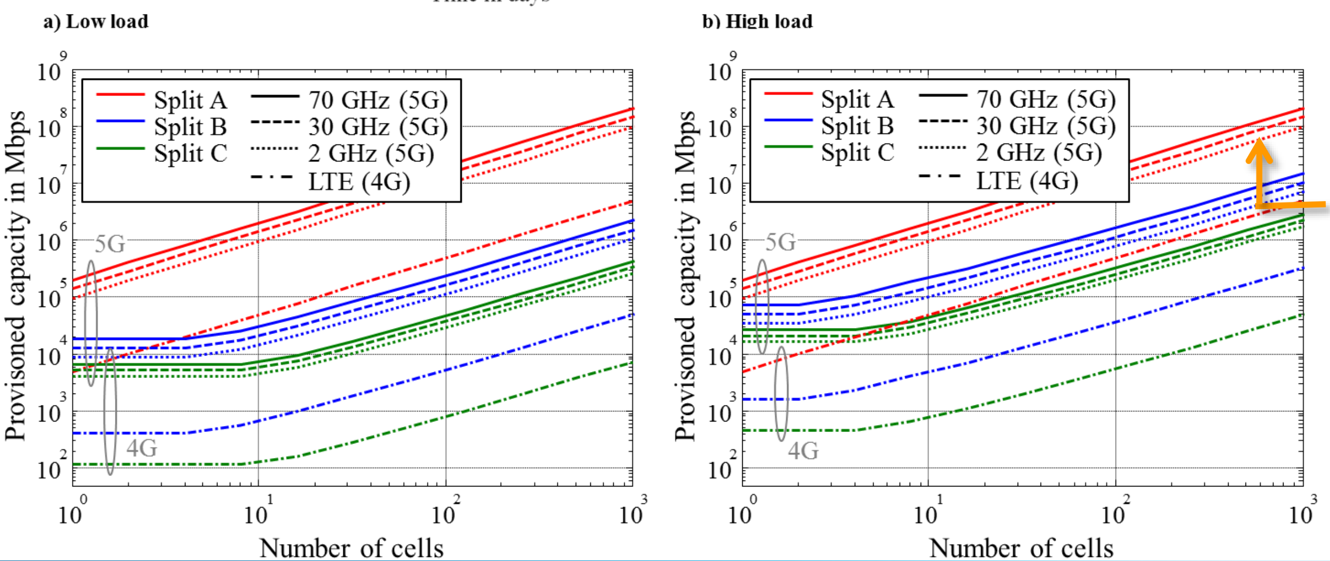
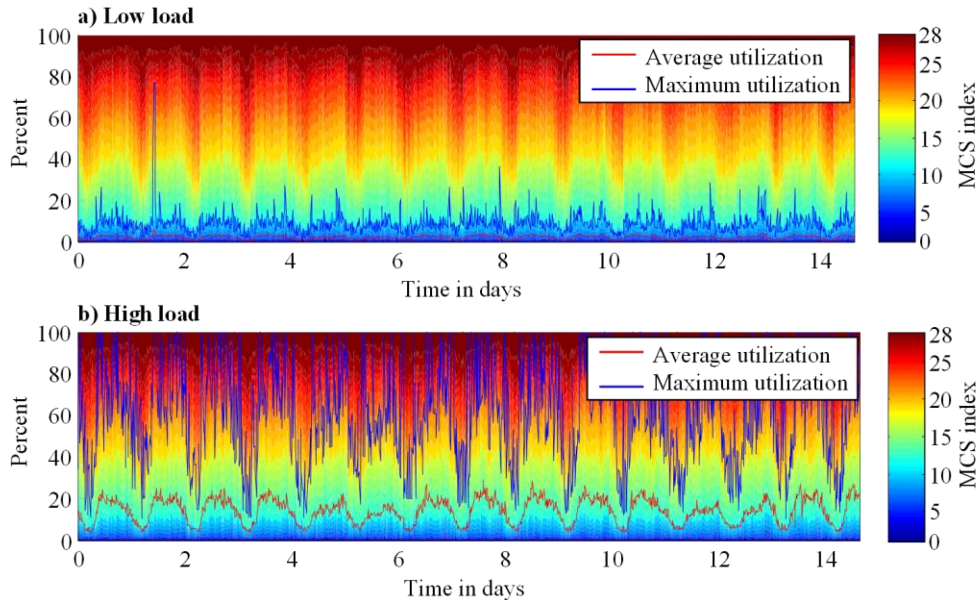


→**increase from 4G to 5G**

Data Rate Requirements – Statistical Multiplexing



Measure traffic from 33 LTE cells

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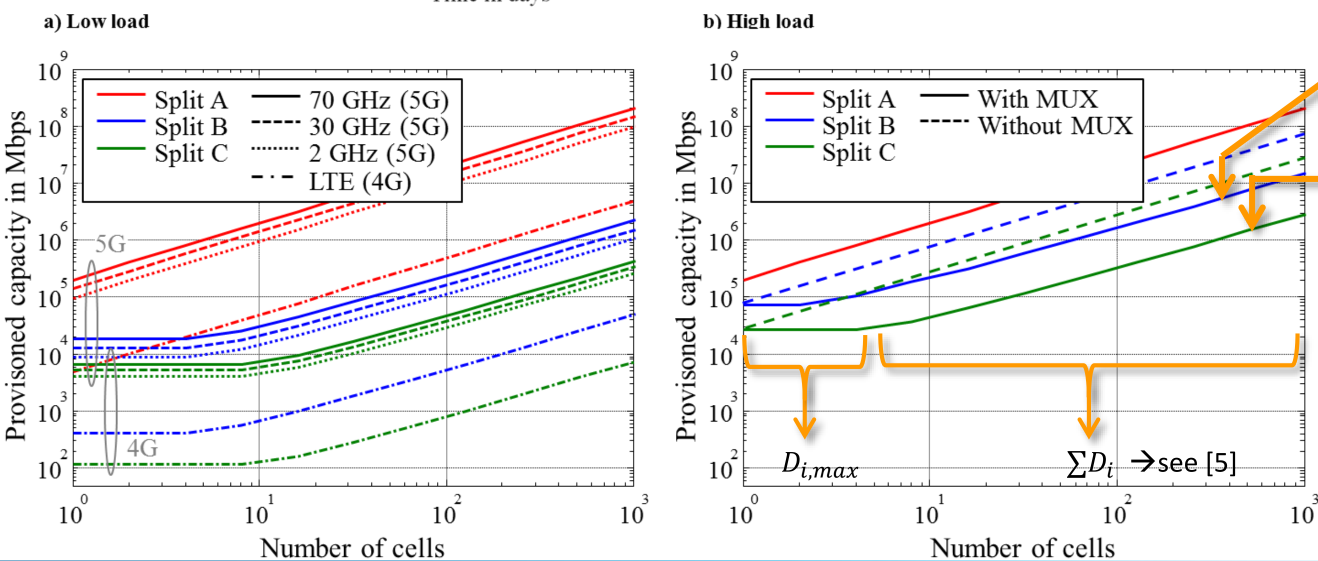
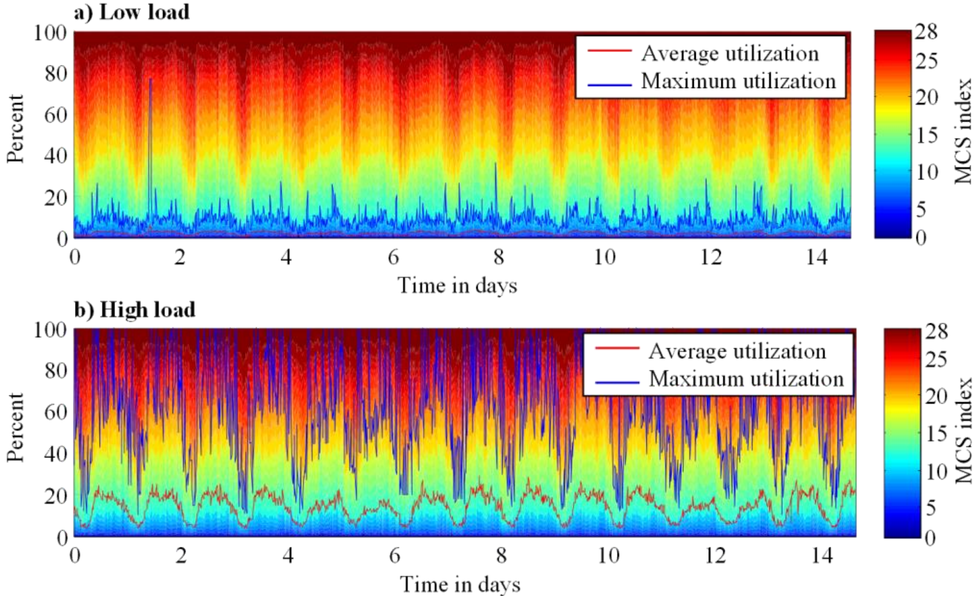


Mux gain ~4.9x
→due to variable utilization

Mux gain ca. ~9.4x
→due to variable utilization and variable MCS (channel quality)
→the more variation, the higher the gain

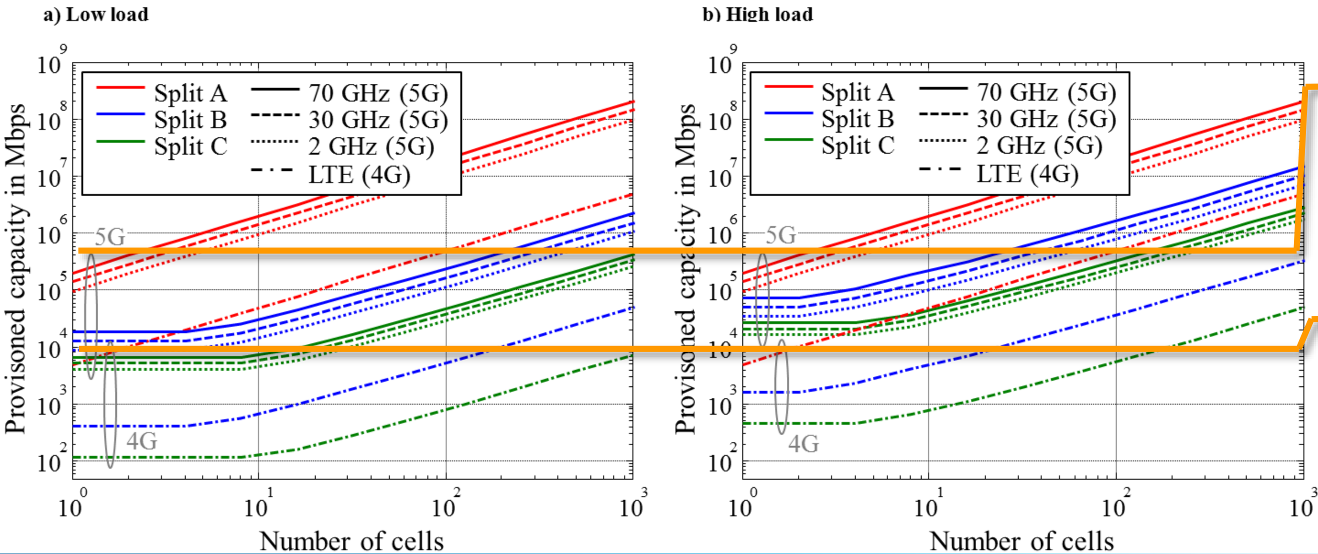
Data Rate Requirements – Ethernet Technologies



Measure traffic from 33 LTE cells

Scaled to reflect higher utilization

CPRI traffic is static but FH traffic should follow traffic variation to enable statistical multiplexing →splits B, C



400G Ethernet (IEEE P802.3bs)
→supports all splits/RATs
→for 5G split A/full centralization only a few cells can be aggregated in one link

10G Ethernet, ~CPRI rate 8
→can support only 4G, low load/split C, no support of 5G split A/full centralization

→more details in [1]

Delay and Delay Accuracy Requirements

- **Delay requirement** of CPRI (~200 µs) induced by **HARQ and BB processing time**
  →depends on **MAC standardization**, **not** necessarily on **physical constraints**
  →**higher margin** could already be **considered in RAN design** if required for transport
- **Maximum delay** based on **channel coherence time** (for centralized precoding, adaptive MCS, needs to also include BB processing time):
  →more relaxed for low speeds, low bands; even stricter for high speeds, high bands

Parameter	Symbol	LTE	Sub-6	Low mmWave	High mmWave
Carrier Frequency [GHz]	f_C	2	2	30	70
Formula for channel coherence time	$T_C = \sqrt{\frac{9}{16\,\pi}} \frac{c}{v \cdot f_C}$				
Channel coherence time at 3 km/h [ms]	$T_{C,3}$	**76.14**	**76.14**	**5.08**	**2.18**
Channel coherence time at 250 km/h [ms]	$T_{C,250}$	**0.91**	**0.91**	**0.06**	**0.03**

- **Delay accuracy** of CPRI (~16 ns) is equivalent to ½ **sample duration**, precise reason unclear (CP should be able to compensate offset between antennas)
- Already very **challenging for Ethernet**, even more challenging for 5G:
  →[2] claims to achieve sub-ns precision via Ethernet

Parameter	Symbol	LTE	Sub-6	Low mmWave	High mmWave
Carrier Frequency [GHz]	f_C	2	2	30	70
Channel Size [MHz]	BW	20	100	250	500
Sampling Rate [MHz]	f_S	30.72	150	375	750
Timing accuracy (1/2 sample duration) [ns]	T_j	**16.3**	**3.33**	**1.33**	**0.67**

Transport Classes

- **Requirements** for transport may not only come **from RAN**, but also **from new applications**:
  - Tactile Internet requiring low round-trip latency (1 ms - 10 ms)
    →low latency required also for transport, even with no centralization (traditional backhaul)
  - V2X requires high reliability
    →highly reliable transport required
- Converged transport network should support **traffic with different requirements**, differentiation into data, control, sync packets might not be sufficient
- **Packets** need to be **prioritized** at SDN-routers but quickly addressable TCAM memory limited [3]
  →proposal of **"Transport Classes"** (TCs)which **consolidate several requirements**
  →initial proposal (will most likely be extended, e.g. adding broadcast):

	Use case	Transport latency (round trip)	Synchronization	Typical data rate per access point
TC 0	• Synchronization	Very low variance	Enabler	10 Mbps
TC 1	• Split A traffic • Split B traffic without relaxed HARQ • Tactile user traffic • Failover signaling • SDN in-band control signaling	**≤ 200 µs**	Synchronous, time aligned	200 Gbps
TC 2	• Split B traffic with relaxed HARQ • Split C traffic with coordinated beamforming • Relaxed tactile user traffic	**≤ 2 ms**	Synchronous, time aligned	80 Gbps
TC 3	• Split C traffic without coordinated beamforming • Conventional BH/ fixed access traffic • Control signaling	**≤ 20 ms**	Asynchronous, not time aligned	25 Gbps

Suggestions to 1914

- NGFI has the potential for **unified transport network**, **converging fronthaul and backhaul**
- Transport network should be **packet-based** (potentially Ethernet), **SDN-enabled**
- **5G** air interface **will increase requirements** for transport, should ideally be **considered from the start**
- Transport network should **support different functional splits/interfaces** over the same infrastructure, i.e. legacy FH, legacy BH, intermediate splits
- Intermediate splits + packet-based enable **statistical multiplexing** which **decreases requirements**
- **Requirements** can not only come **from RAN** but also **from new applications** (low latency, high reliability)
- Different **transport classes** could be introduced to **differentiate packets by requirements** and process appropriately

References

[1] 5G-XHaul Deliverable D2.1, available: http://www.5g-xhaul-project.eu/download/5G-XHaul_D_21.pdf

[2] The White Rabbit Project, http://www.ohwr.org/projects/white-rabbit

[3] see e.g., M. Dong, H. Li, K. Ota and J. Xiao, "Rule caching in SDN-enabled mobile access networks," IEEE Network, vol. 29, no. 4, pp. 40-45, July-Aug. 2015.

[4] 3GPP TR 38.913: Study on Scenarios and Requirements for Next Generation Access Technologies, v0.30, March 2016.

[5] NGMN Alliance, “Guidelines for LTE Backhaul Traffic Estimation,” White paper, July 2011. [Online]. Available: http://www.ngmn.de/uploads/media/NGMN_Whitepaper_Guideline_for_LTE_Backhaul_Traffic_Estimation.pdf. Accessed Jan. 20, 2016.

Thanks for your attention!

Questions?