5G: implementation challenges and solutions

University of Bristol / Cambridge Wireless

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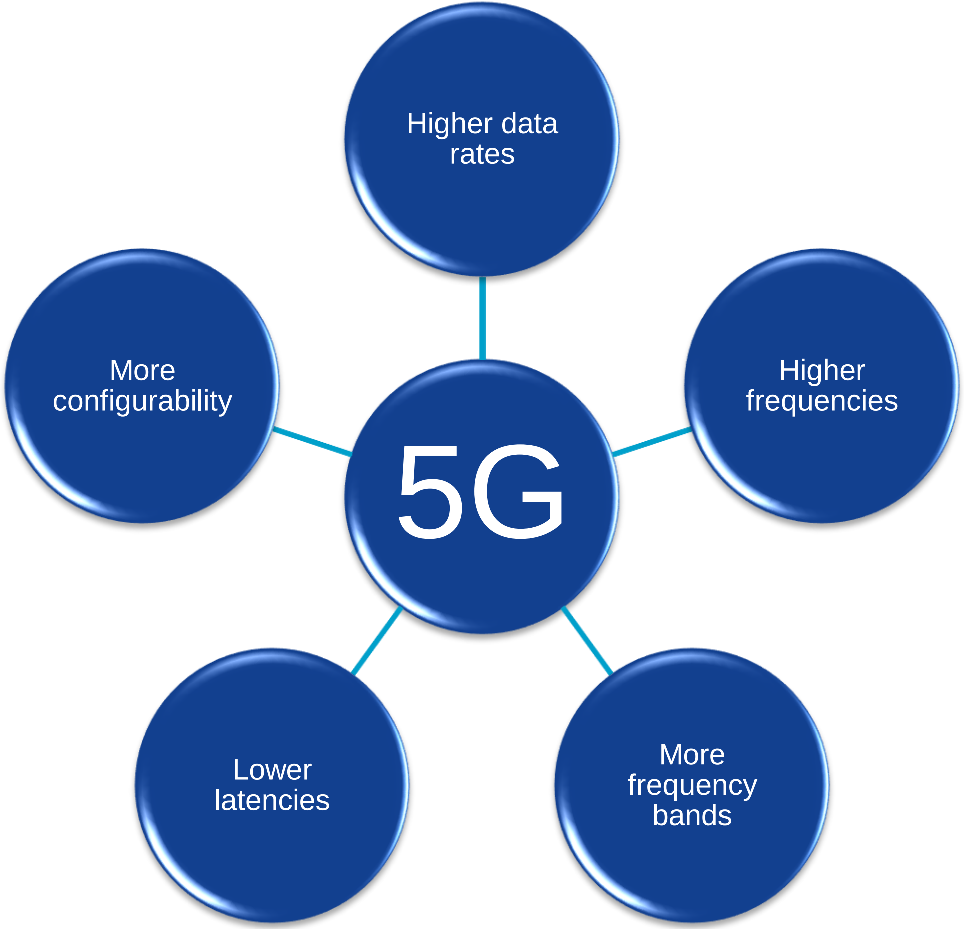
Higher data rates
More configurability
5G
Higher frequencies
Lower latencies
More frequency bands

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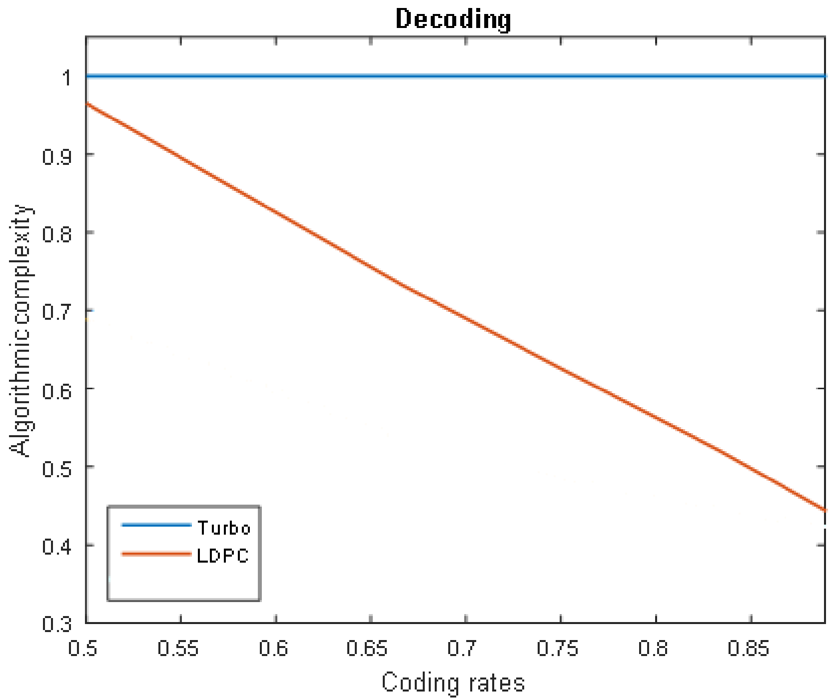
New Channel Coding for New Radio

Low Density Parity Check (LDPC) codes for the data channels enable high data rates with low complexity

Key benefits of LDPC:

- High throughput with manageable complexity (parallel decoding in hardware)
- Good performance
- Adaptable to a wide range of code rates and block sizes
- Well suited to IR-HARQ



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10 – 20 x Capacity with 5G @ sub 6 GHz

5x More Spectrum with 2 – 4x More Efficiency

LTE-AWS
2x2 MIMO

AWS	3.5 GHz
20 MHz	100 MHz
2 bps / Hz	4-8 bps / Hz
40 Mbps cell throughput	400-800 Mbps cell throughput

10-20 x

5G 3500 with
massive MIMO
beamforming

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Massive MIMO at Higher Carrier Frequencies (>>6 GHz)

Poor path-loss conditions	Cost & power consumption	Antenna array implementation	Beam based air interface
Large number of antennas needed to overcome poor path-loss Obtaining channel knowledge per element is difficult	Full digital solutions require transceiver units behind all elements Wide bandwidths: A/D and D/A converters are very power hungry	Smaller form factors Distributed PA solutions → Hybrid arrays Beamforming at RF with baseband digital Precoding	Single sector-wide beam may not provide adequate coverage → Beamform all channels! → Support analogue and hybrid arrays

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Path Loss Difference 3.5 GHz vs 1.9 GHz

Nokia measurements

Outdoor

	LOS				NLOS			
	C_1	n_1	Mean	Std	C_2	n_2	Mean	Std
1.9 GHz	39.06	2	-0.48	3.57	27.69	4	0.03	3.81
3.5 GHz	42.93		-0.65	3.59	33.50		-0.13	3.89
ΔPL	3.87				5.81			

Indoor penetration loss

	Modern building	Old building	Shops
1.9 GHz	17.54 dB	7.16 dB	10.00±2.66 dB
3.5 GHz	22.54 dB	11.45 dB	12.97±2.73 dB
ΔL_P	5 dB	4.29 dB	2.97 dB

Outdoor path loss difference 5.8 dB
Additional indoor loss difference 3 – 5 dB

Massive MIMO at 3.5 GHz Gives 6-9 dB Higher Antenna Gain

More Gain at Higher Frequency with Similar Size Antenna

<1 GHz	2 GHz		3.5 GHz
1.5m	1.3m	**6-9 dB gain** →	0.9m
38 cm	32 cm		48 cm
15 dBi 0.57 m2	18 dBi 0.42 m2		24 dBi 0.43 m2

Passive 4-port antenna

Massive MIMO antenna

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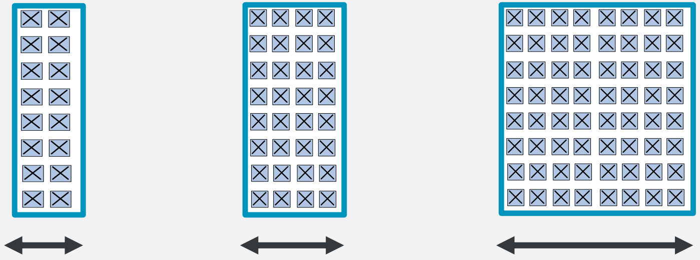
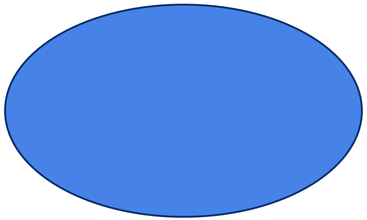
Massive MIMO Configurations

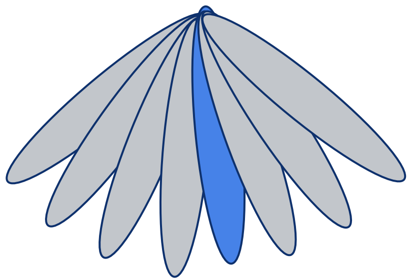
2 columns	4 columns	8 columns



13 cm	21 cm	38 cm

Non-beamforming	8 horizontal beams





- 8 columns is feasible at 3.5 GHz
- 8 columns enables 8 beams

- Coverage gains +6 dB
- Capacity gains +200%

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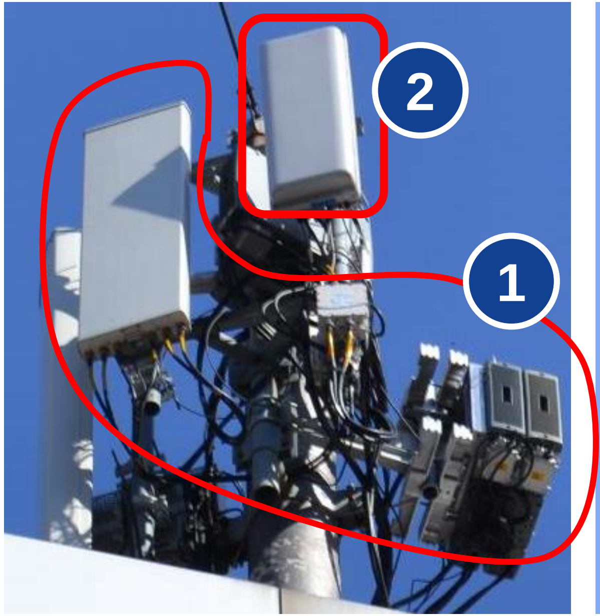
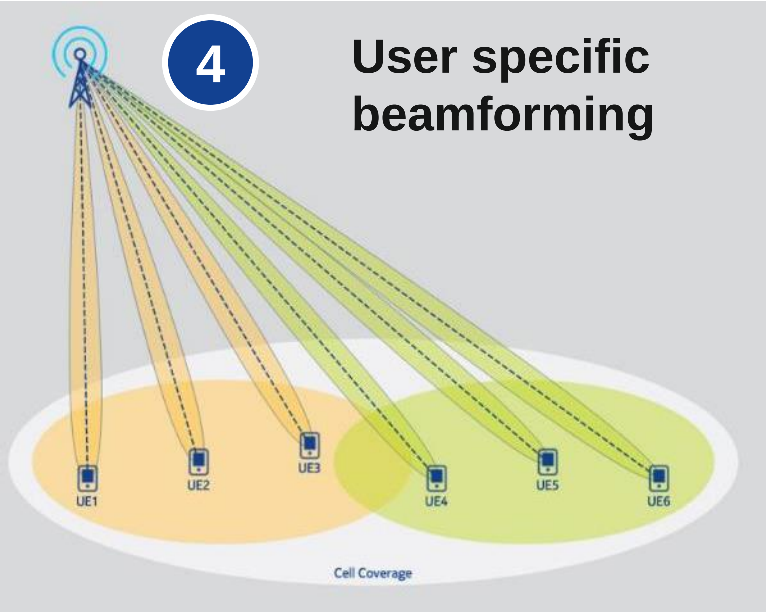
Innovations at Base Station Site with New Antennas and RF

1. Separate RF and antenna	2. Active antenna = RF + antenna	3. Multi-band RF for high integration	4. Massive MIMO with many RF



3 bands in 20 litre volume



Less site space, lower power consumption, better radio performance

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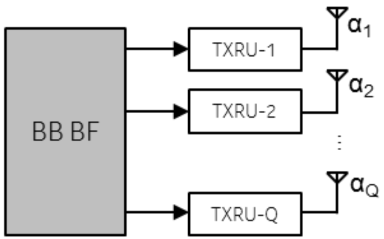
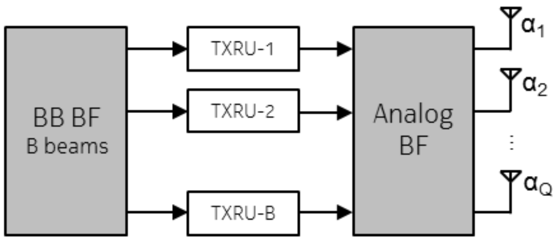
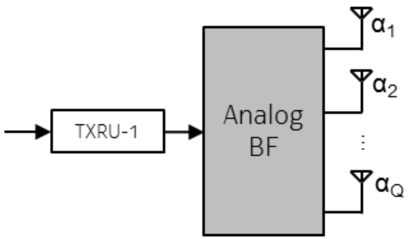
Antenna Array Architectures for scalable flexible MIMO

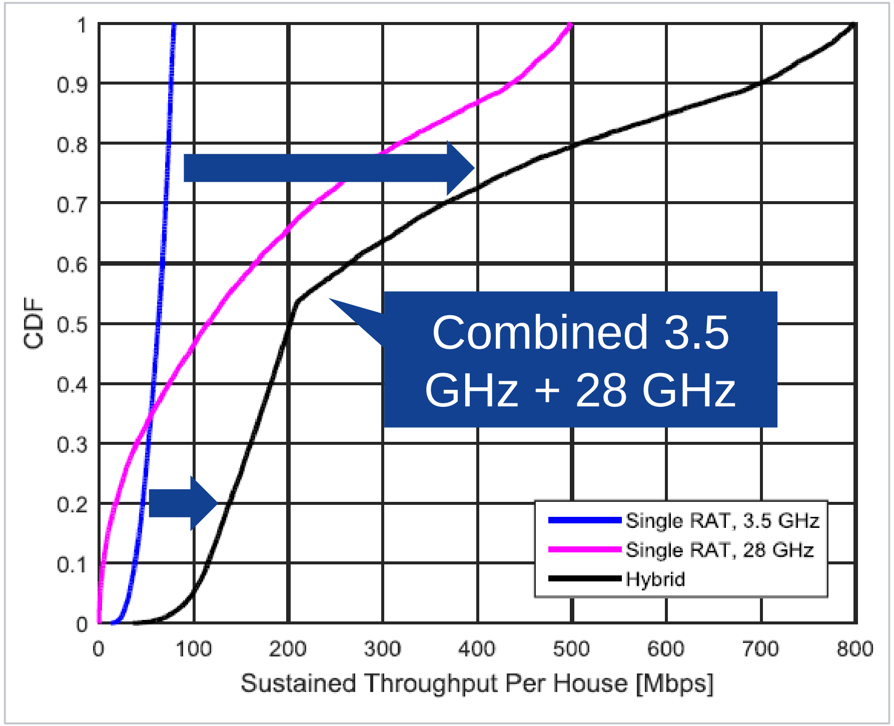




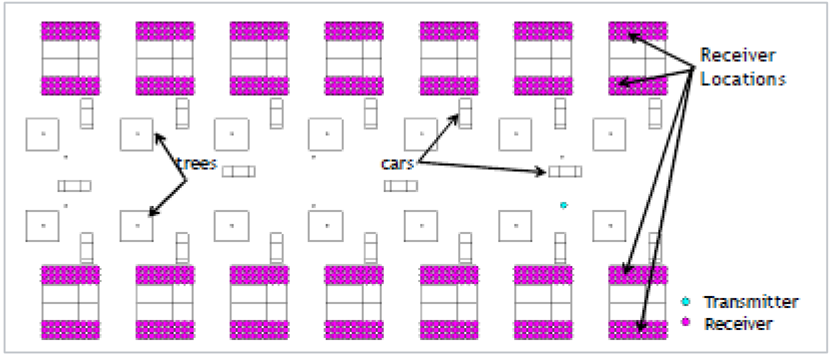


Digital (Baseband) beamforming	Hybrid beamforming	Analog beamforming
Adaptive TX/RX weights at Baseband	Adaptive TX/RX weights at both Analog and Baseband domains	Adaptive TX/RX weights at RF to form a beam
Each antenna element or antenna port has a transceiver unit High number (8->) of transceiver units	Each RF beam has a transceiver unit; Moderate number of transceiver units for capacity (e.g. up to 8)	One transceiver unit and one RF beam with high antenna gain (coverage)
“Frequency-Selective” beamforming	Combination of Analog and Baseband beamforming	“Frequency-Flat” beamforming
Best for capacity and flexibility (subject to high power consumption & cost characteristics when bandwidth increases)	Optimization between both coverage and capacity	Best for coverage (low power consumption & cost characteristics)

28 GHz Band also works for Mobile Use Cases



- 95% of indoor users get >100 Mbps
- 2/3 of users get 28 GHz and 1/3 get 3.5 GHz
- 3-5x higher data rate than 3.5 GHz alone
- Inter-site distance 230 m in suburban area
- 3.5 GHz: 40 MHz bandwidth, 19 dBi
- 28 GHz: 250 MHz bandwidth, 25 dBi



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Multiple bands: Potential 5G Bands in (early) 5G Deployments

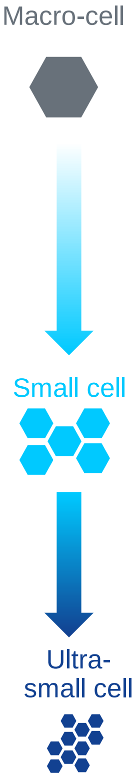
600 MHz	LTE/5G	North America
700 MHz	LTE/5G	APAC, EMEA, LatAm
3.3-3.4	LTE/5G	APAC, Africa, LatAm
3.4-3.6	LTE/5G	Global
3.55-4.2	LTE/5G	US
3.6-3.8	5G	Europe
4.5	5G	Japan China
28	5G	US, Korea Japan
39	5G	US
24.25-27.5	5G	WRC-19 band
31.8-33.4	5G	WRC-19 band (Fra, UK)
~40,~50,~70	5G	WRC-19 bands

Full coverage at <1 GHz

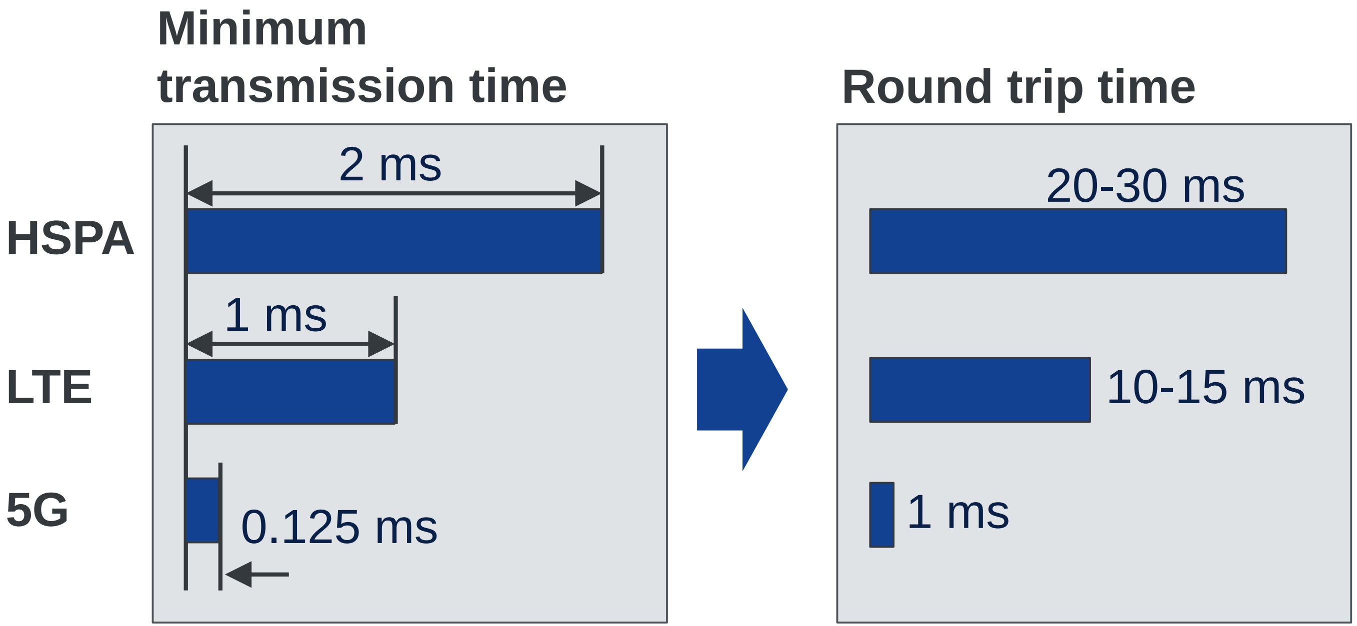
Dense urban high data rates at 3.5 – 4.5 GHz

Hot-spot high data rates at 28 – 39 GHz

Future mmWave options



Lower Latency Radio Transmissions



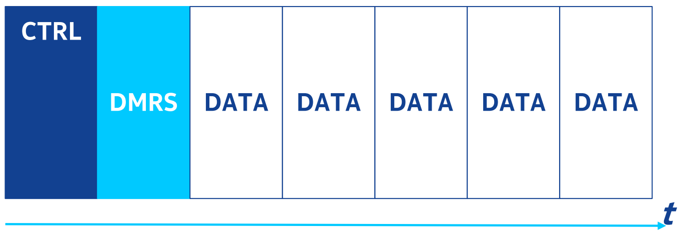
5G physical layer design optimized for low latency

Frame structure

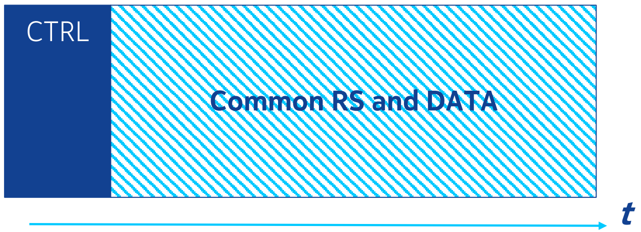
- NR frame structure defined for pipeline processing implementation
  - Channel estimate available early in the slot
  - Decoding each OFDM symbol individually

  ➔ Decoding can start immediately after receiving the first data symbol
- NR uses LDPC channel codec for fast processing; LTE Turbo computationally much more complex (higher latency)
- NR supports short (down to 2 symbol) allocations minimizing queuing and transmission latency for ultra-low latency delivery

5G pipelining



LTE reference



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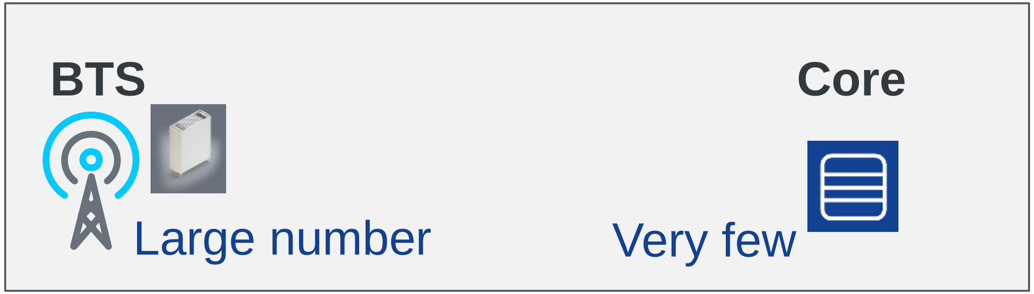
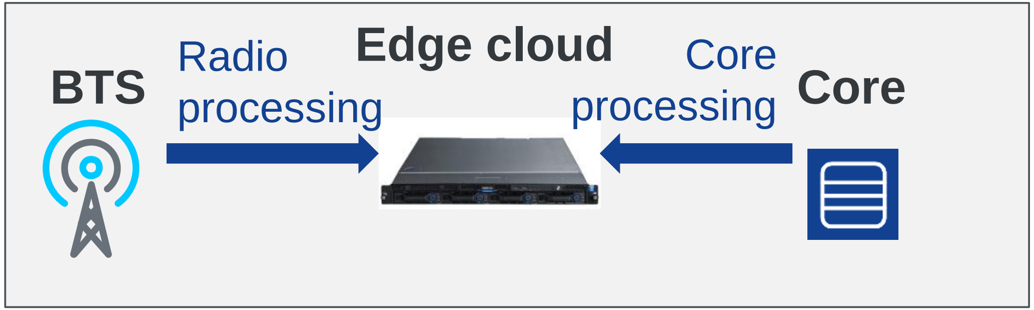
Network Architecture Evolution Towards 5G

Today



- 4G radio is distributed
- 4G core is centralized

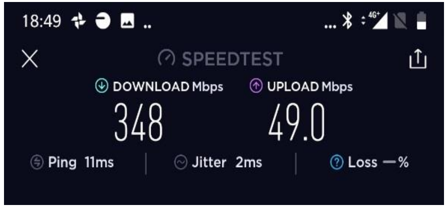
Target



- 5G radio more centralized for faster scalability
- Core more distributed for low latency

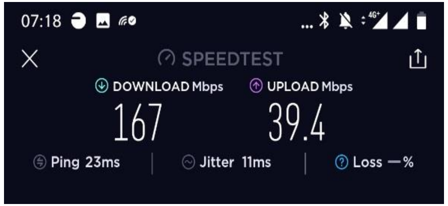
Innovations in Networks Architecture – Local Content for Low Latency

Measured in Helsinki
Server in Helsinki



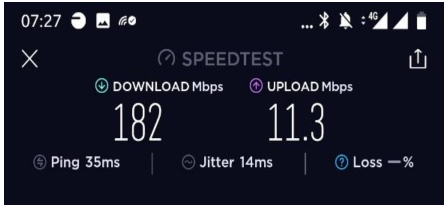
Latency 11 ms

Measured in Oulu
Server in Helsinki



Latency 23 ms

Measured in Oulu
Server in Oulu



Latency 35 ms

- Local content and local networks needed for low latency
- Latency increases by 12 ms with round trip from Oulu to Helsinki

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New opportunities: Industry 4.0 in Nokia Factory Oulu

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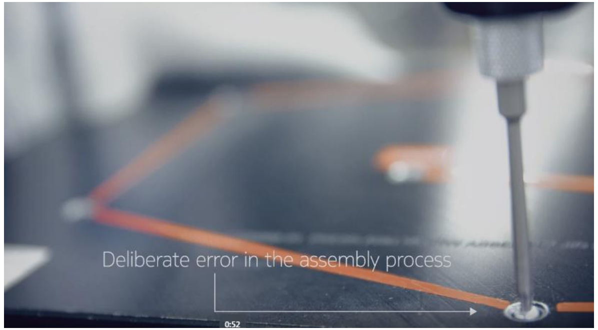
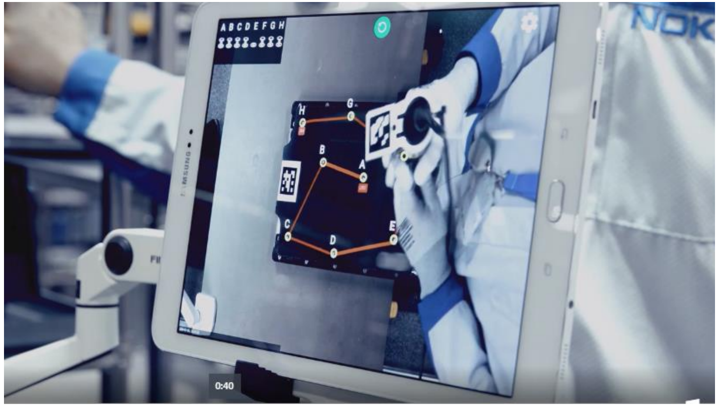
Nokia and Telia conduct Industry 4.0 trial in Finland leveraging low-latency and high-bandwidth of 5G technology



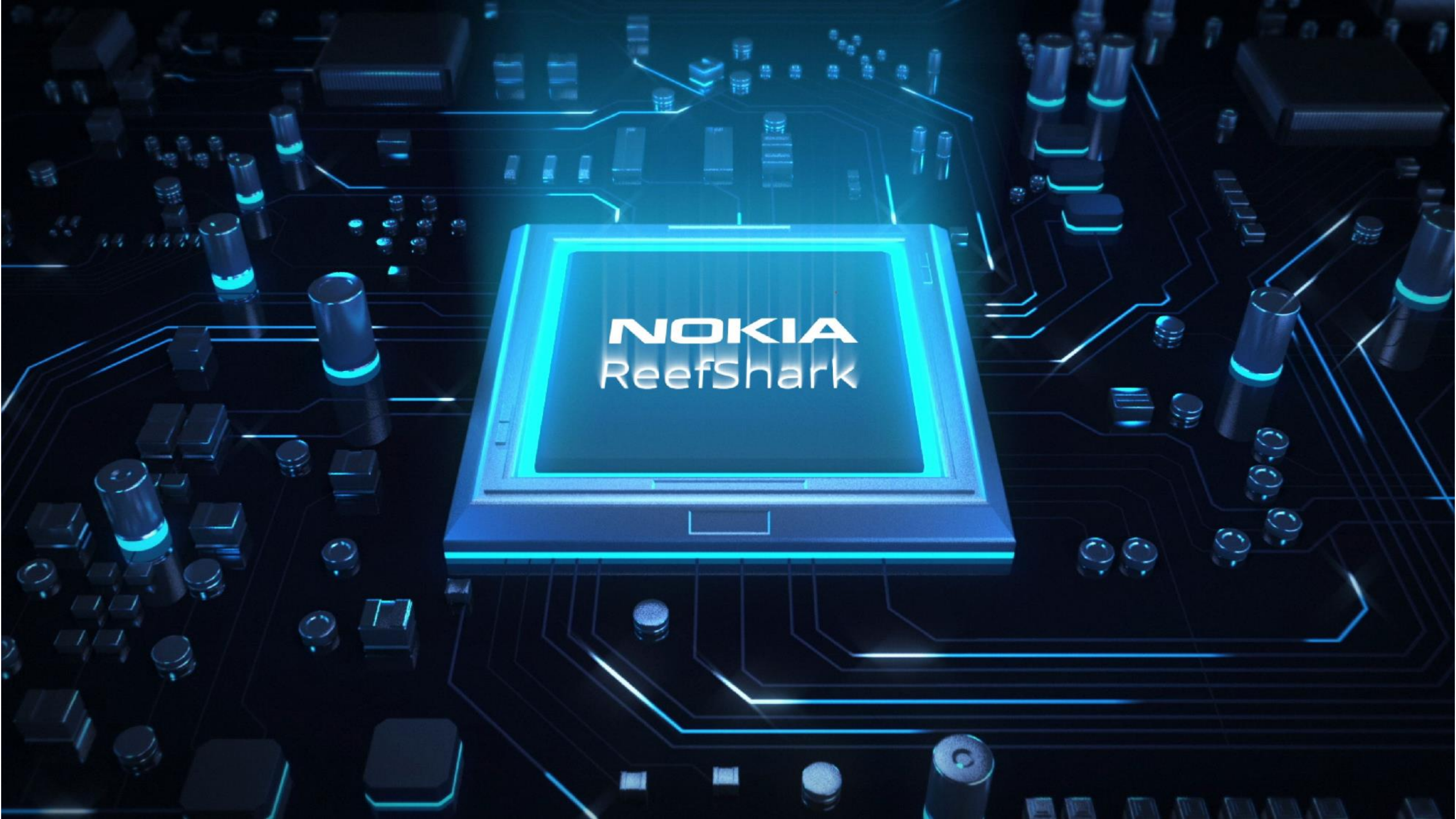


Video! https://www.youtube.com/watch?v=E02Bqblce7E&

Increasing network configurability

- Increased number of Radio Resource Control (RRC) parameters to configure:
  - 60 in first version of LTE -> 600 in first version of 5G NR

- Optimisation of the radio network becomes a super-human challenge!
  - Self-optimising networks (SON) are critical for network operation
  - New artificial intelligence / neural network based techniques needed to manage the network configuration.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