5G AND THE EVOLUTION OF THE AUTOMOTIVE SECTOR

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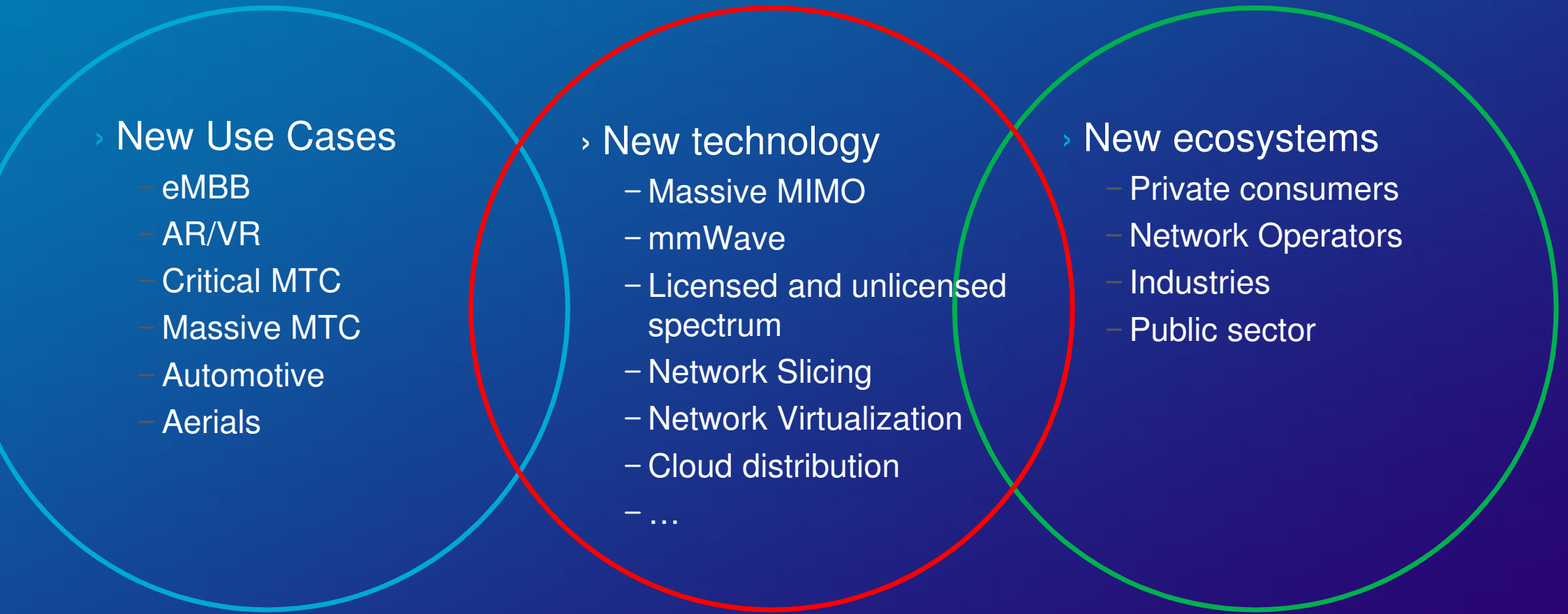
5G: WHAT IS NEW ABOUT IT?

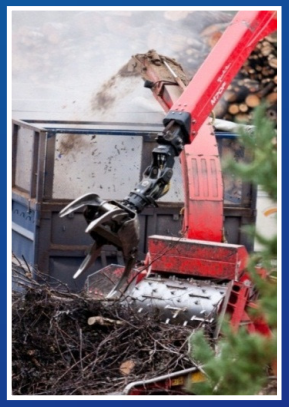


5G – BEYOND MOBILE BROADBAND

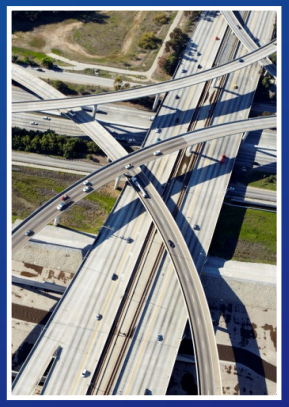
Broadband experience everywhere anytime

Mass market personalized media and gaming

Meters, sensors, “Massive MTC”



Remote controlled machines



Smart Transport Infrastructure and vehicles

Human–machine interaction

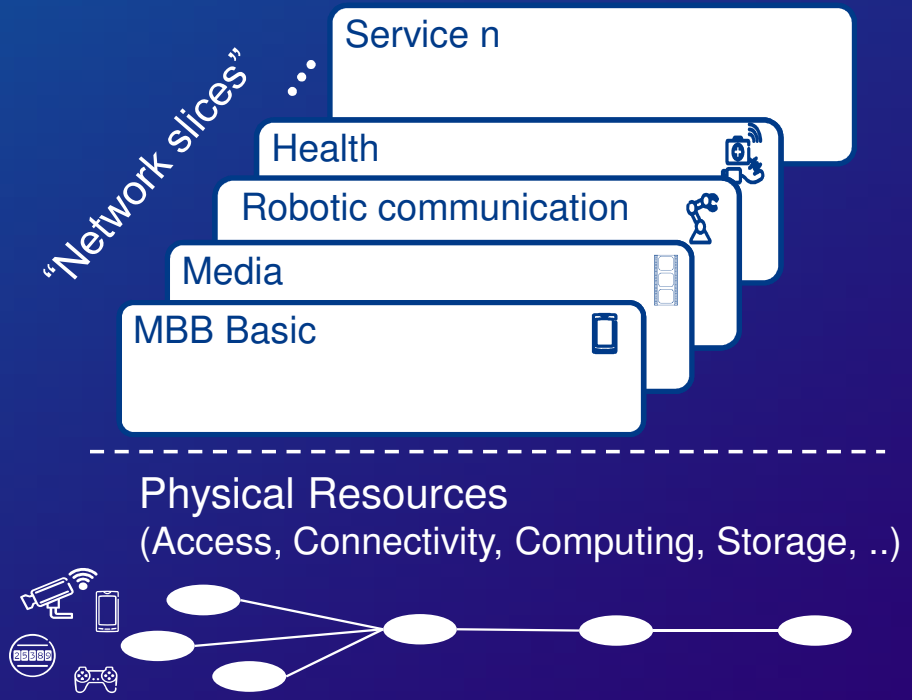
And much more beyond the crystal bowl

Wide range of use cases – wide range of requirements

ONE NETWORK – MULTIPLE INDUSTRIES

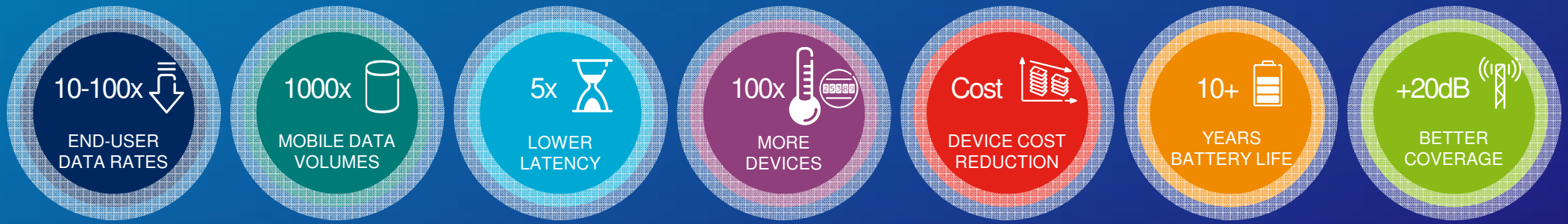
From dedicated physical networks and resources for different applications…

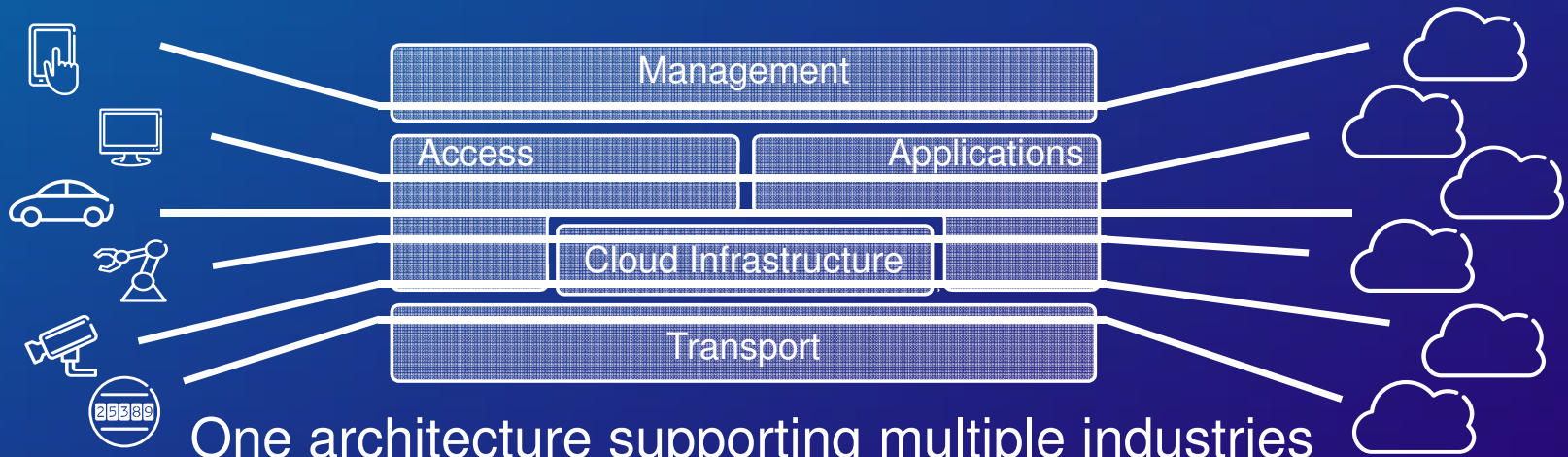
…to a “network factory” where new networks and architectures are “manufactured by SW”



WHAT IS 5G – WHAT WILL IT BRING

A Network for the Networked Society

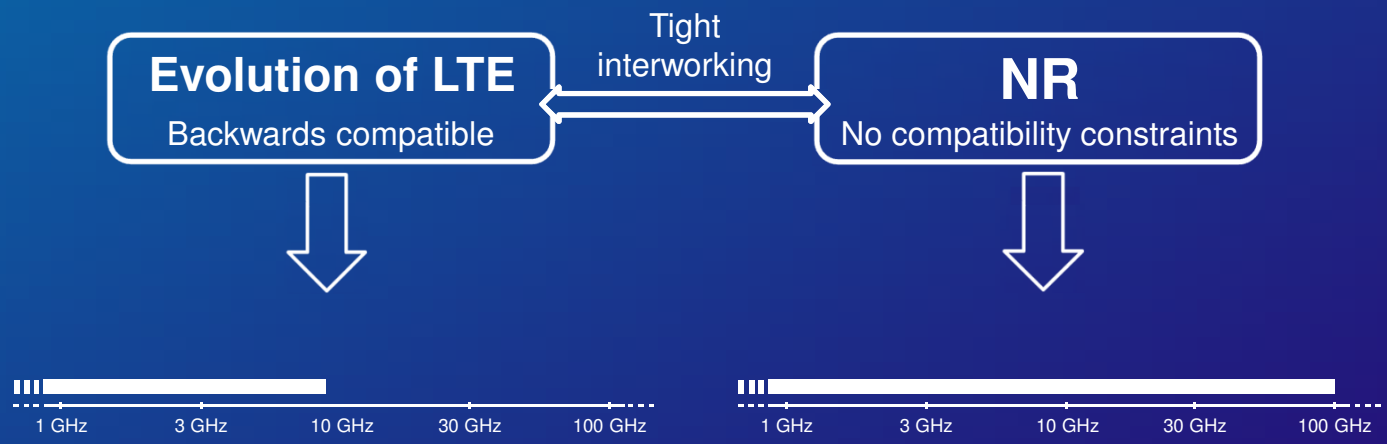




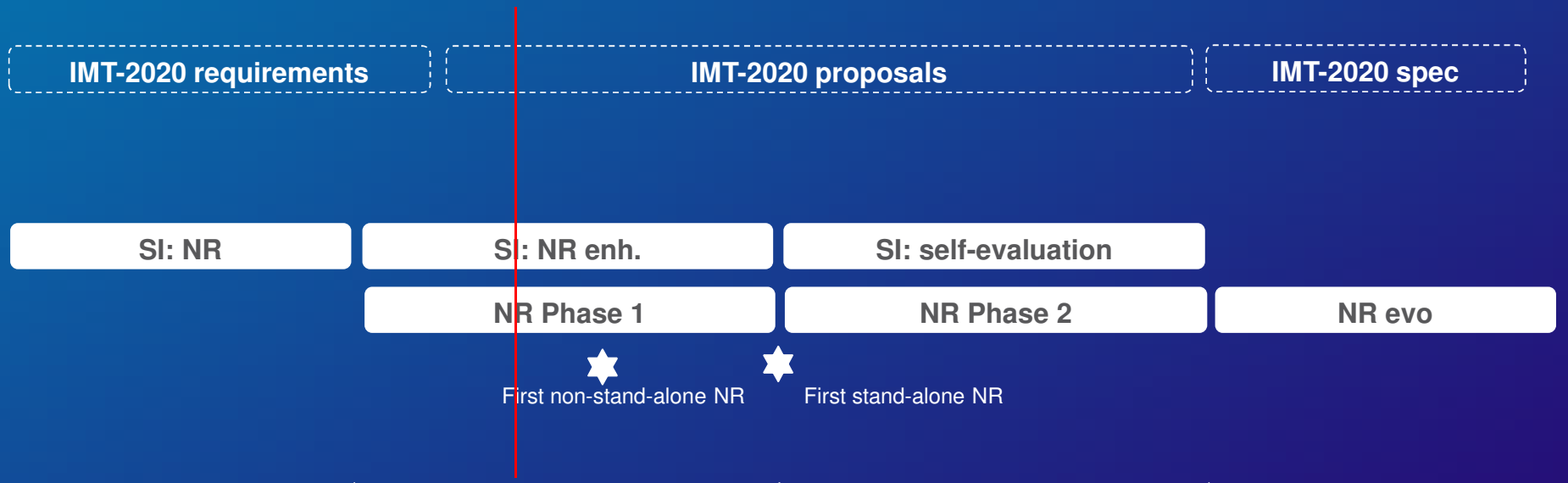
One architecture supporting multiple industries

5G RADIO ACCESS

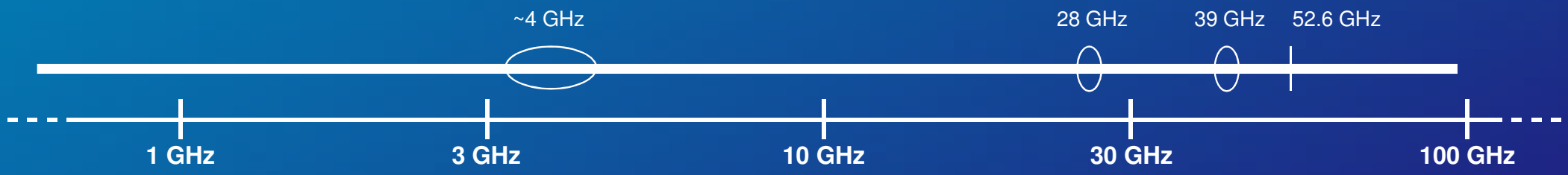
Evolution of existing technology + New radio-access technology



3GPP STANDARDIZATION



NR SPECTRUM RANGE



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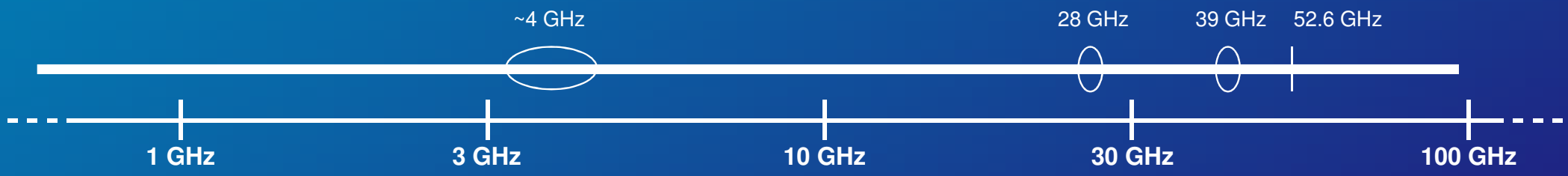


Why “mm-wave”?

- Large amounts of spectrum ➡ high capacity
- Very wide bandwidth per carrier ➡ very high data rates
- Beamforming with large number of antennas possible
  - …and needed due to propagation conditions

MM-WAVE CHALLENGES

Propagation

Diffraction

Outdoor-to-indoor penetration

Rain/atmospheric attenuation

(Less of an issue for small cells)

Body loss

Regulation

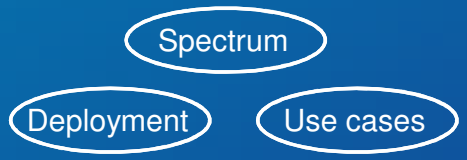
Additional Tx power limitations above 6 GHz

Implementation

Efficiency, dynamic range, output power, …

NR – KEY TECHNOLOGY FEATURES

Flexible and scalable design

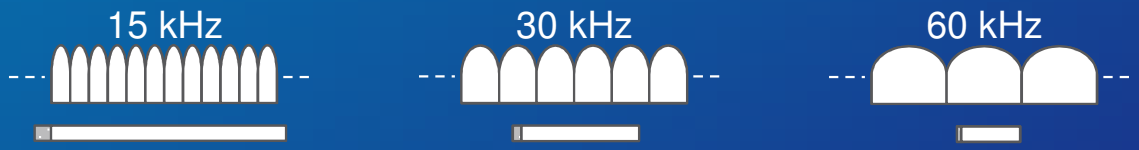


Ultra-lean design

Minimize network transmissions
not directly related to user data delivery

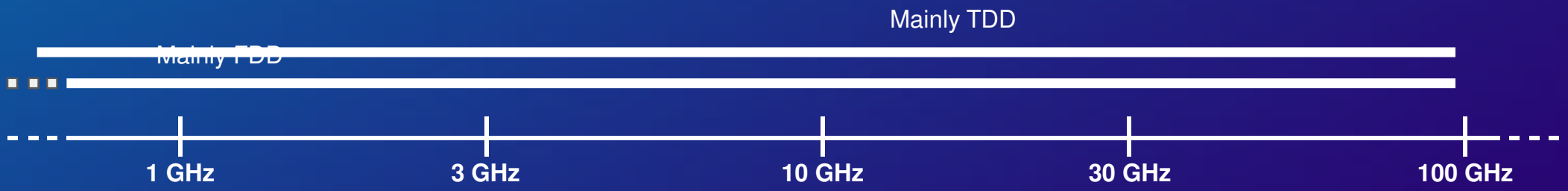
WAVEFORM AND DUPLEX SCHEME

- OFDM with scalable numerology – subcarrier spacing $\Delta f = 2^n \cdot 15$ kHz
  - Coexistence with LTE and NB-IoT



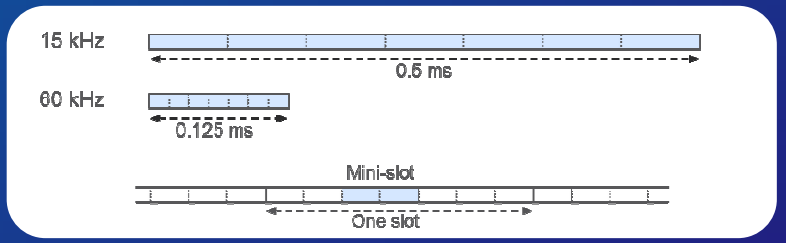
Δf	T_{cp}
15 kHz	4.7 µs
30 kHz	2.3 µs
60 kHz	1.2 µs
120 kHz	0.6 µs
240 kHz	0.3 µs
480 kHz	0.15 µs

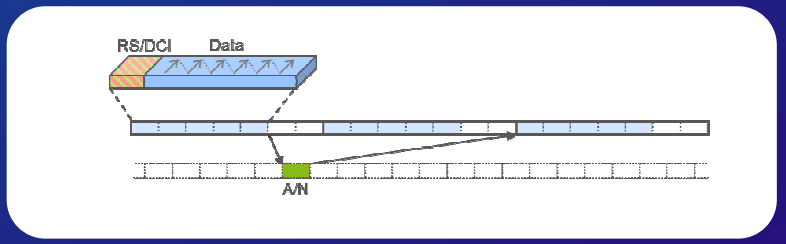
- TDD and FDD
  - Dynamic TDD to exploit traffic variations in small cells

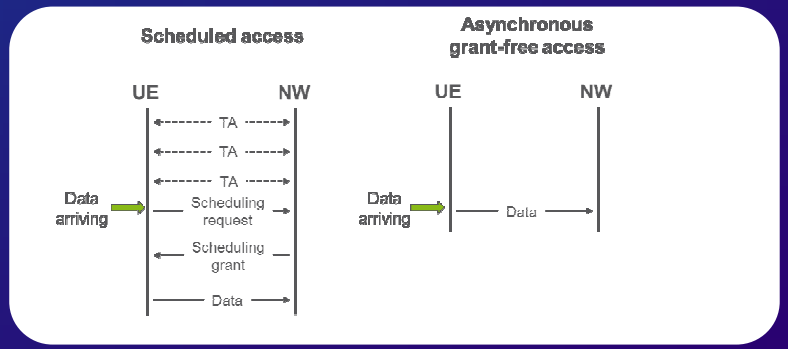


LOW LATENCY

- Short scheduling units
  - Short regular slots – 125 µs at 60 kHz
  - "Mini slots" – Arbitrary starting point and length within a slot
- Fast retransmissions
  - Fast ACK
  - Enabled by front-loaded DMRS/DCI and frequency-first mapping allowing for rapid data demodulation/decoding
- Uplink grant-free transmission
  - Fast access to channel
  - Preferably avoiding explicit time alignment (asynchronous access)







BEAM-FORMED TRANSMISSION

To enable the capacity, data rate, and coverage needed in the 5G era

A unified toolbox for low and high frequencies

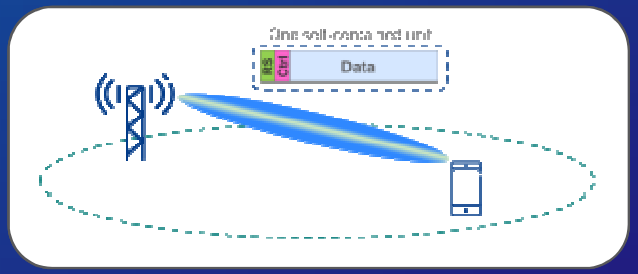
Beam-centric NR design

- Self-contained data transmissions
- “Beam mobility” – Mobility between beams rather than nodes
- Initial access matched to beam-formed user plane

SELF-CONTAINED TRANSMISSIONS

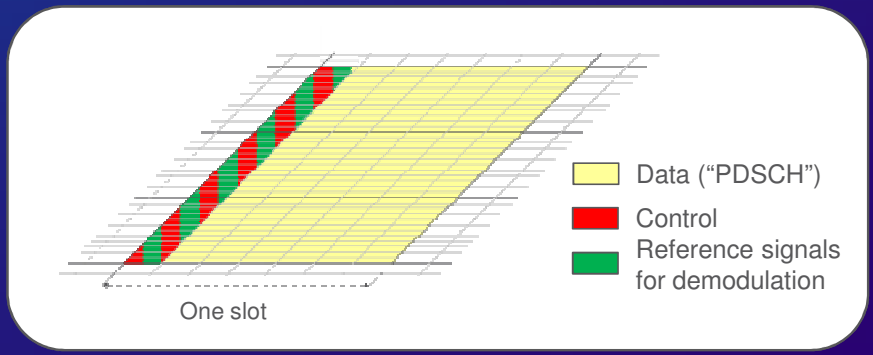
- All information needed to detect and decode a transmission contained within the transmission itself
  - Scheduling assignments
  - Reference signals for demodulation

⇨ Joint beam-forming of data and all associated transmissions



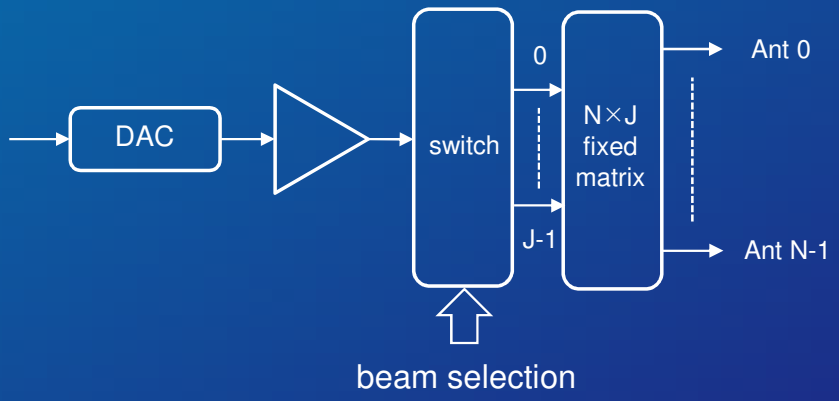
- All information needed to detect and decode a transmission located at the beginning of the slot

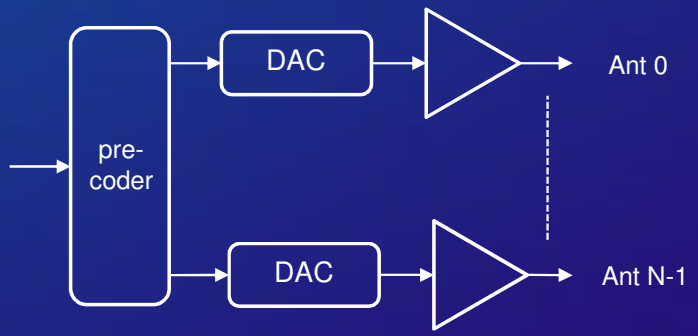
⇨ Enables low-latency detection/decoding



ANALOG VS DIGITAL BEAMFORMING

- Analog beamforming
  - Limited degrees of freedom
  - Entire carrier points in one direction at a time
- Digital beamforming
  - Highest degree of freedom
  - Different signals can be sent in different directions at the same time

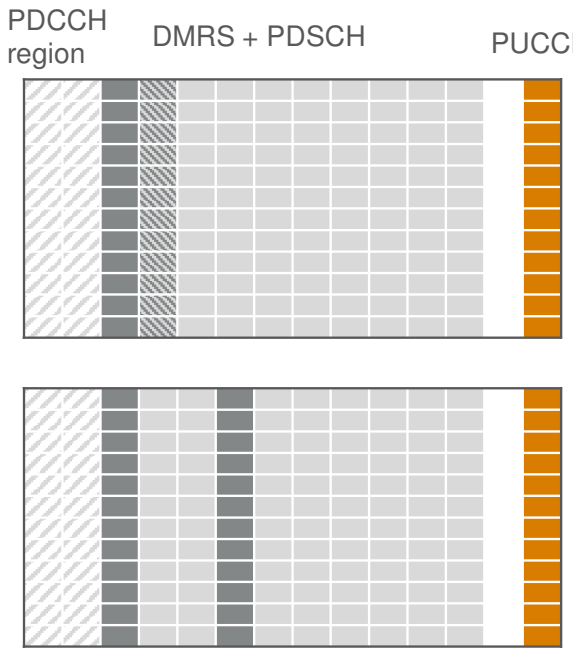




Both schemes (and hybrids) to be supported by the final specifications!

DMRS

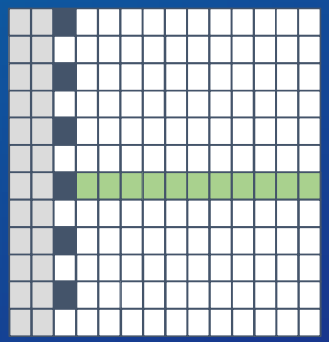
- Demodulation to start before receiving the whole slot
- Front-loaded DMRS in 1 or 2 adjacent OFDM symbols
  - Can only handle low mobility/Doppler
- Distributed DMRS within the slot
  - To handle some mobility/Doppler
  - Possibly some channel interpolation
  - First DMRS aligned with front-loaded
- Up to 12 orthogonal DMRS ports

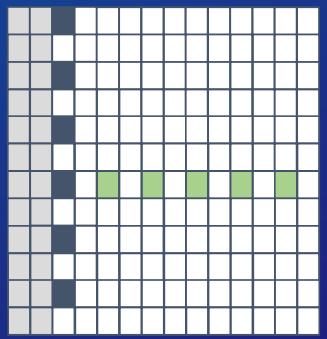


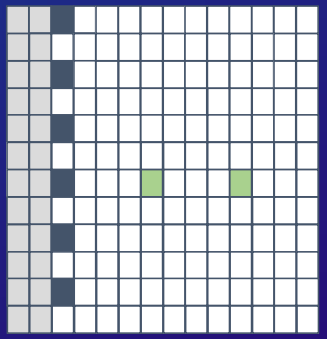
DMRS position indicative

PTRS

- Phase tracking reference signal (PTRS) can be used to compensate for common phase error
  - Can be seen as extension of a DMRS symbol in time domain
- Dynamic PTRS overhead
  - Frequency density = f(data allocation size in frequency domain)
  - Time density = f(modulation and coding scheme, MCS)



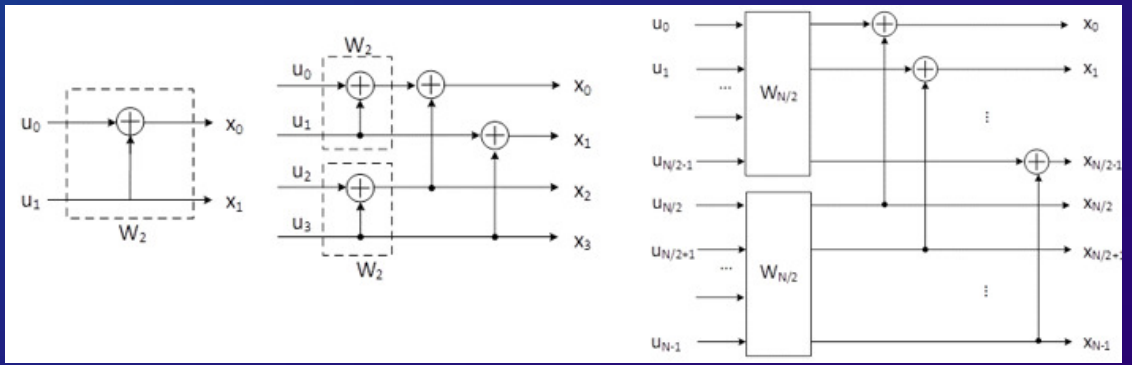




CHANNEL CODING

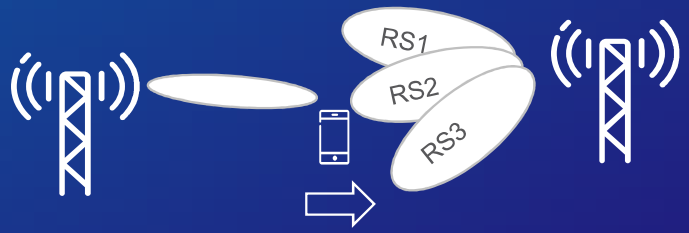
- Turbo, LDPC, and Polar coding investigated in 3GPP
  - No major difference in performance, different views on implementation complexity
- Highly political discussions!
- LDPC for MBB data (PDSCH / PUSCH)
- Polar coding for control signaling UCI/DCI (>11 bits) & PBCH

$$H = \begin{pmatrix} 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{pmatrix}$$

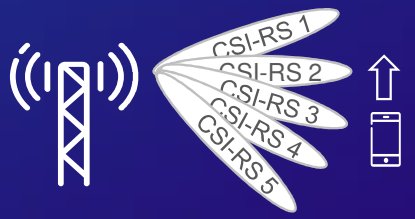


CONNECTED-MODE "MOBILITY"

- (RRC) mobility
  - Typically between (beams of) different transmission points
  - Based on periodic downlink reference signals (CSI-RS, SS)
  - Slower L3 (RRC) reporting

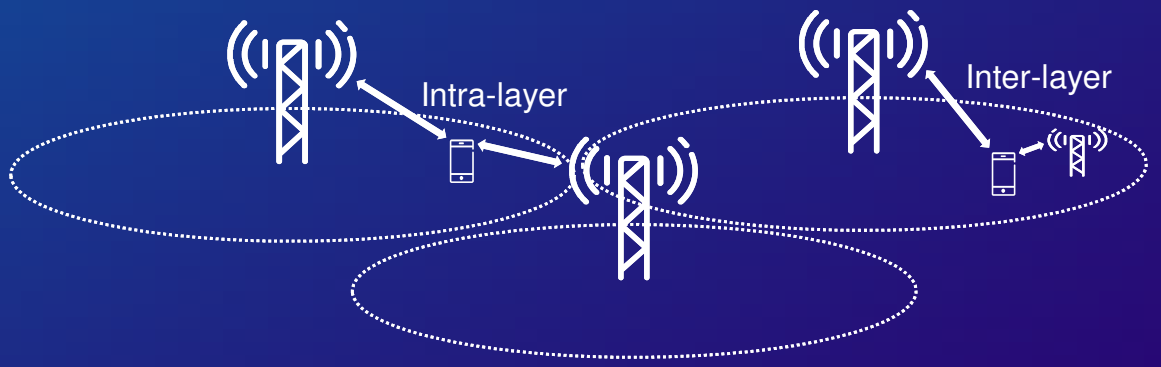


- Beam management
  - Update the beams used for transmission and reception
  - Typically between beams within a transmission point
  - Also including beam-adjustment, beam-refinement, …
  - Based on CSI-RS, uplink measurements, …
  - L1/L2 reporting



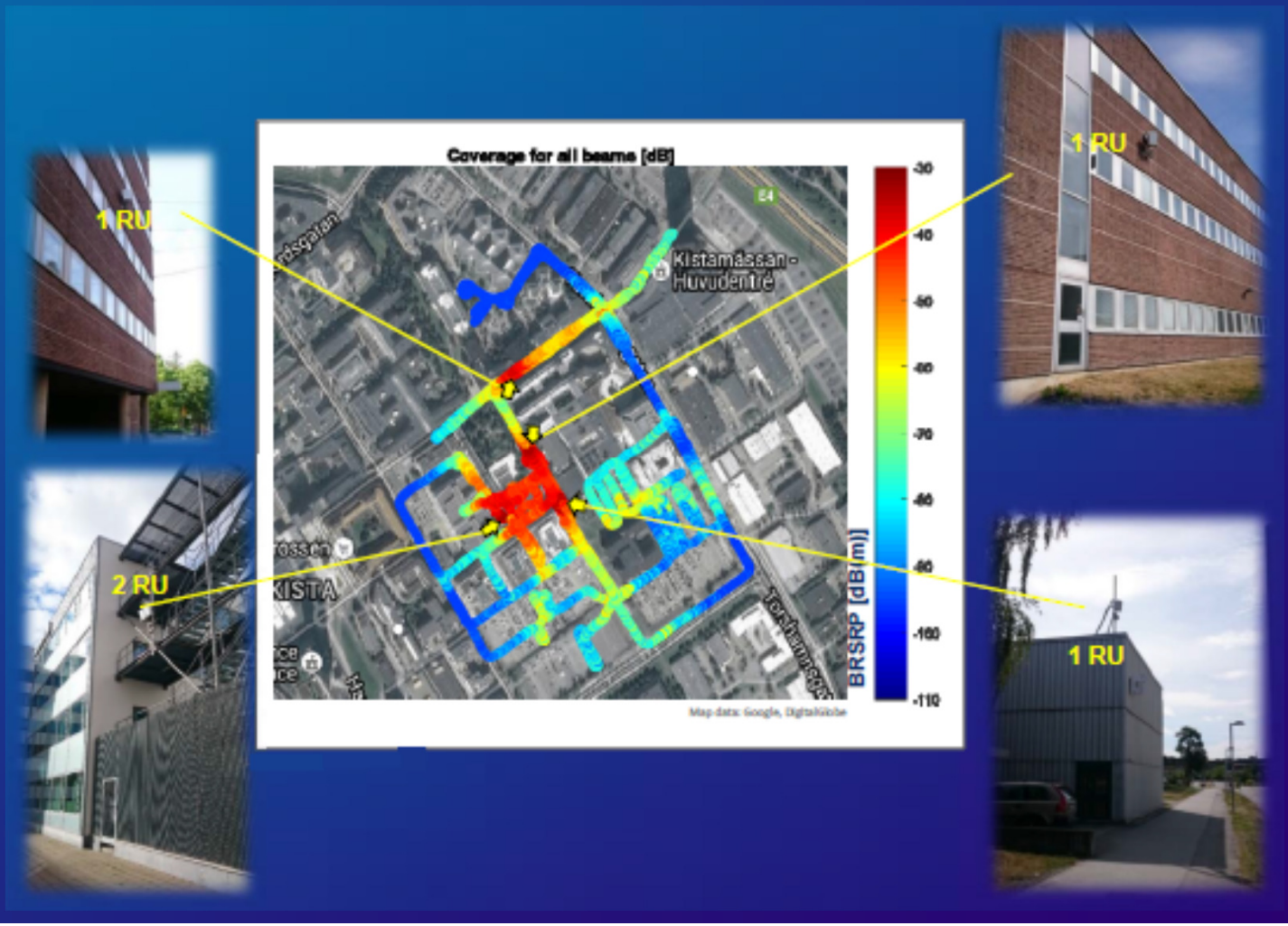
MULTI-SITE CONNECTIVITY

- Joint connectivity to multiple sites
- Intra-layer connectivity
  - Joint transmission/reception: Enhanced coverage
  - Distributed MIMO: Higher peak data rates
- Inter-layer connectivity
  - Enhanced connectivity robustness
  - Intra-RAT or inter-RAT (LTE+NR)



ERICSSON 5G TRIAL SYSTEM

- High-frequency operation
  - 15 GHz / 28 GHz
- Very wide bandwidth
  - 800 MHz
- Massive beam forming
  - 4x128 antennas
- Ultra-lean transmission
- OFDM-based
- Interworking with LTE




THE AUTOMOTIVE CASE

AUTOMOTIVE AND ITS TODAY

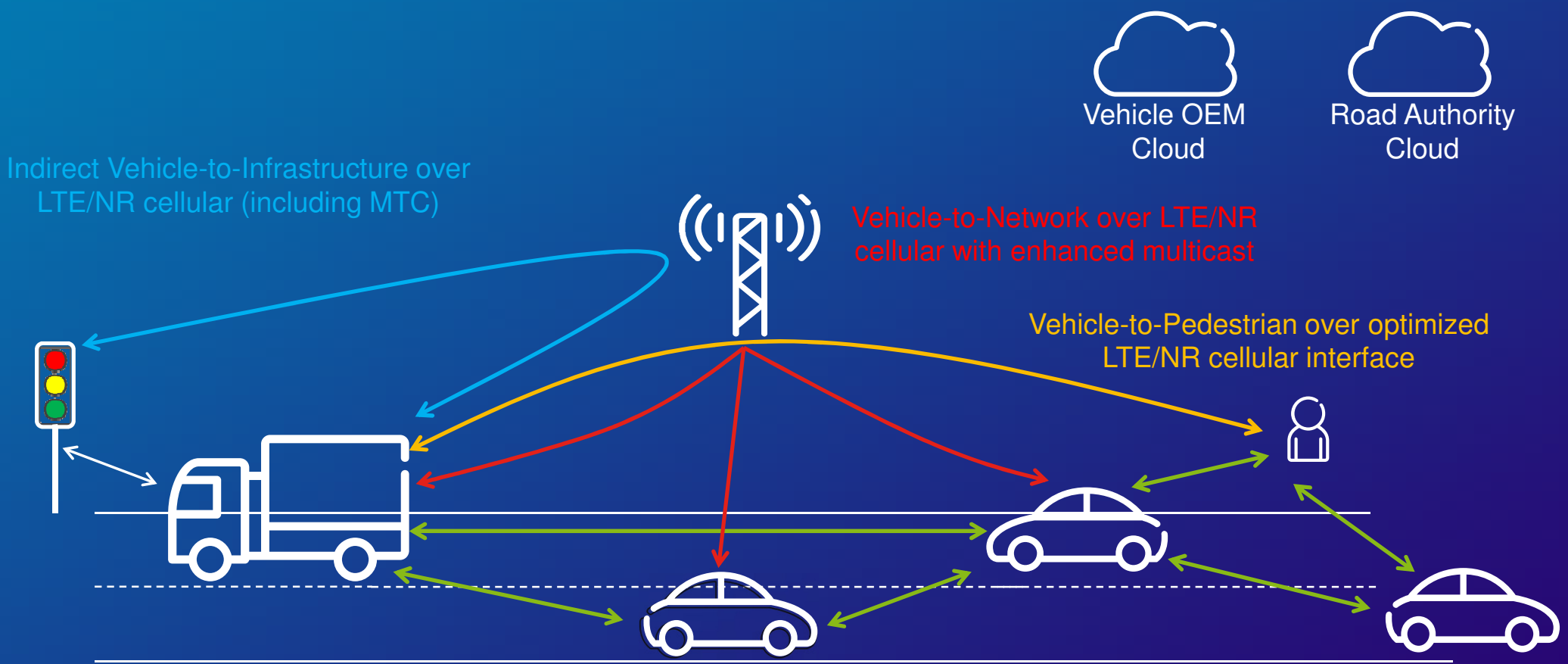
- Automotive services
  - Focus on value add services to owners of connected car, brand loyalty
  - Proprietary solutions (based on industry standards)

LTE MBB evolution

- Intelligent Transportation System (ITS)
  - Focus on traffic light management, road hazard warnings, collision avoidance, etc
  - Standardized solutions

Complementary technology options: DSRC/G5, LTE-V, NR-V

CELLULAR-V2X RADIO FEATURES: LTE-EVO AND NR



FIRST SAFETY USE CASES IN EU (2019)

- Standard messages: CAM and DENM
- Communication types
  - V2V, V2I or V2X (V=vehicle, I=infrastructure, X=anything, e.g. pedestrian)
- Primary purpose of the service
  - Road safety, traffic information, freight services, etc.

#	Day 1 Services		
1	Emergency electronic brake light	V2V	Safety
2	Emergency vehicle approaching	V2V	Safety
3	Slow or stationary vehicle(s)	V2V	Safety
4	Traffic jam ahead warning	V2V	Safety
5	Hazardous location notification	V2I	Motorway
6	Road works warning	V2I	Motorway
7	Weather conditions	V2I	Motorway
8	In-vehicle signage	V2I	Motorway
9	In-vehicle speed limits	V2I	Motorway
10	Probe vehicle data	V2I	Motorway
11	Shockwave damping	V2I	Motorway
12	GLOSA / Time To Green (TTG)	V2I	Urban
13	Signal violation/Intersection safety	V2I	Urban
14	Traffic signal priority request by designated vehicles	V2I	Urban

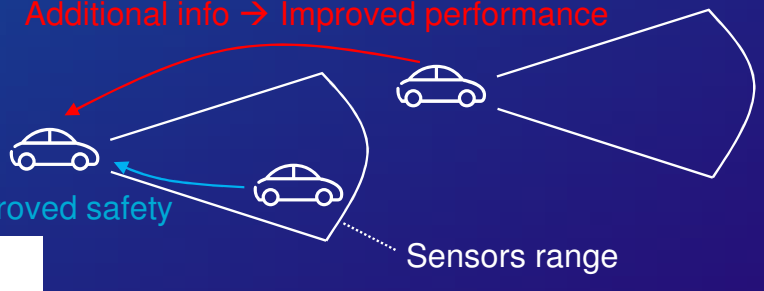
#	Day 1.5 Services		
1	Off street parking information	V2I	Parking
2	On street parking information and management	V2I	Parking
3	Park & Ride information	V2I	Parking
4	Information on AFV fuelling & charging stations	V2I	Smart Routing
5	Traffic information and smart routing	V2I	Smart Routing
6	Zone access control for urban areas	V2I	Smart Routing
7	Loading zone management	V2I	Freight
8	Vulnerable road user protection (pedestrians and cyclists)	V2X	VRU
9	Cooperative collision risk warning	V2V	Collision
10	Motorcycle approaching indication	V2V	Collision
11	Wrong way driving	V2I	Wrong Way

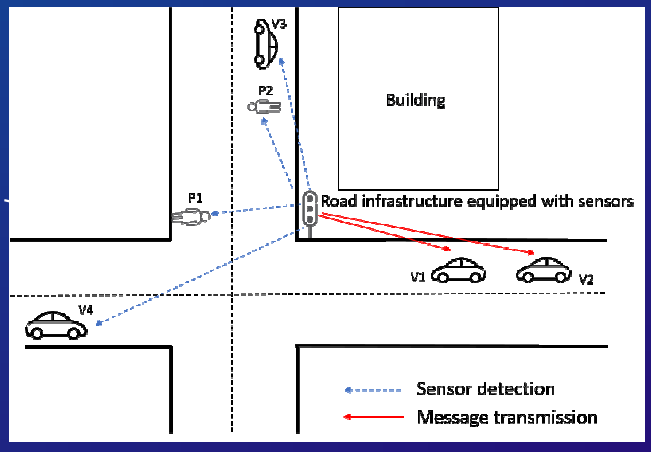
RADIO TECHNOLOGY OVERVIEW

- Up to 70MHz of license-exempt ITS spectrum in the 5.9GHz band:
  - Limited to “short range” communication → typically 100-300m due to emission limitations
  - 802.11p (DSRC, ITS-G5) is likely to be deployed in US and EU, despite being an aged technology
  - LTE-V and NR-V are the choice in China and the likely future at least in EU
  - **Very controversial technology choice at 5.9GHz!**
- Licensed spectrum:
  - Can accommodate both “long range” and “short range” communication
  - Reuse 4G and 5G mobile networks and smartphones base
  - **Best technology but new business models including mobile Operators are needed!**
- New 63-64GHz ITS spectrum in EU
  - A lot of spectrum, interesting for NR-V, but blocking might limit its usability to very short LoS links

5G FOR AUTOMOTIVE

- ITS evolution
- Autonomous driving
- Remote driving
- Platooning
  - See-through
- Advanced driving assistance
  - Collective perception/sensor sharing
  - Cooperative intention sharing
- Traffic safety
  - Vulnerable road user protection
  - Intersection assistance
- Accurate positioning





THE AUTONOMOUS DRIVING EXAMPLE

- Autonomous vehicles drive based on own sensors
  - What is the purpose and value of 5G in autonomous driving?

- Some examples:
  - Communication extends the vehicle sensors beyond their physical limitations
    - E.g., cooperative perception, sensor sharing
  - Communication enables distributed and centralized decision making
    - ML, continuous algorithms updates
    - Improved performance and safety
  - Communication enables virtualization of decisions for improved safety, control and computational offloading in the vehicle
    - E.g., pre-process aggregated data in the (distributed) cloud

TECHNOLOGY EVOLUTION FOR 5G AUTOMOTIVE

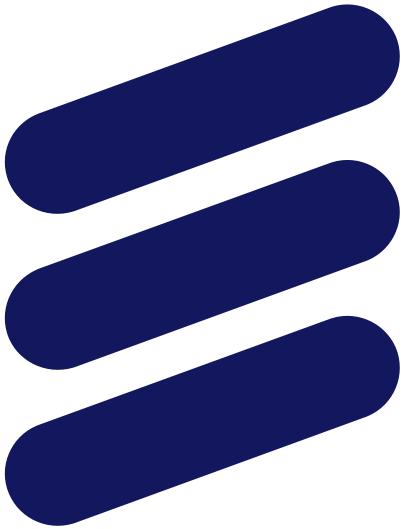
- The first real challenge to 5G automotive is cost-effective network coverage in rural areas:
  - Enhancements to physical channels for improved coverage
  - Combination of multihop and cellular access
  - Deployment and processing optimizations for “highway” deployments
  - Seamless interoperability with LTE
  - “Predictive QoS” to assist applications
- The second challenge is cost of connectivity for enormous amounts of background data
  - Cloud distribution
  - Predictive mobility and optimizations to optimize resource utilization
  - Smart use of licensed and unlicensed spectrum
  - Multicast delivery when applicable
- The third challenge comes from ultra-reliable low-latency connectivity in high mobility

SOME OPEN ISSUES

- Modernization and digitalization of the transport sector implies radical changes also in the regulatory domain
  - Liability
  - Privacy
  - Data ownership
  - …
- For safety ITS, a sustainable business model involving both private and public sector needs to be found
- Market scale is essential, especially for highly customized devices with demanding requirements such as in the automotive world

CONCLUSIONS AND FINAL REMARKS

- In addition to evolved MBB use cases, 5G directly addresses industries and verticals
- A common flexible technology to accommodate very different requirements
- Industries, telecom companies and public research are cooperating to define 5G technology jointly
- The automotive vertical is one of the most promising and at the same time challenging ones for 5G
- 5G will be soon soon reality, from 2018!



ERICSSON