ODVA INDUSTRY CONFERENCE 20TH ANNUAL MEETING

5G - Not Just for Cell Phones Anymore

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Abstract

5G is an upgrade to the cellular system. It is not the same as prior generations, where the upgrade focused almost exclusively on improved rates for cell phones. Along with improved rate, enhancements include higher device density, lower latency, increased reliability, and a push for private deployment - that all combine to target a wider range of applications. Expected usage includes "Ultra Reliable Low Latency Communication" (URLLC) for real time control, "enhanced Mobile Broadband" (eMBB) for uses including augmented and virtual reality, and "enhanced/massive Machine Type Communications" (eMTC) for wide-area (usually battery powered) wireless. Not only did the cellular industry target industrial automation in their IMT-2020 vision, but there is a coordinated effort called 5G-ACIA to rally industrial automation behind 5G and to influence the 5G standards to meet industrial automation use cases and requirements. The 5G standards from 3GPP are delivered in a series of releases. Earlier releases had already included Ethernet bridging, IP routing, and DSCP-based QoS – valuable features to carry EtherNet/IP traffic. Release 15 is moving into the market, bringing many of the stated enhancements. Release 16 is in development and goes even further with the addition of TSN capability. Various visions include the replacement of wired switches and the enablement of collaborative mobile manufacturing platforms. This paper presents an overview of this topic area.

5G Background

Mobile Phone Generations

1G

1979

Analog Voice

2 kb/s

[1]

2G

1991

Digital Voice
Messaging

64 kb/s

[2]

3G

1998

Early Smartphone
Mobile Web
Email
Camera

144 kb/s - 2 Mb/s

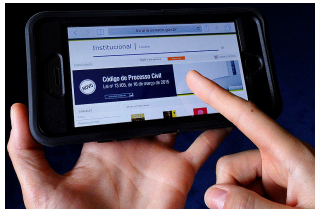
[3]

4G

2008

True Smartphone
True Internet
Apps
Multimedia

100 Mb/s – 1 Gb/s



[4]

5G

2018

AR/VR, 3D
Instant Downloads
Difficult Coverage

1 Gb/s – 10 Gb/s
1 ms latency

[5]

[6]

Other
Pervasive Internet of Things
Realtime Control

How/when did 5G features originate?

- ***ITU*** ***International Telecommunication Union (a part of the United Nations)***
- ***ITU-R*** ***Radiocommunication Sector of ITU***
- ***IMT*** ***International Mobile Telecommunications (ITU-R initiative to create a global standard for a generation of wireless data networks)***
  - IMT-2000, IMT-Advanced, IMT-2020

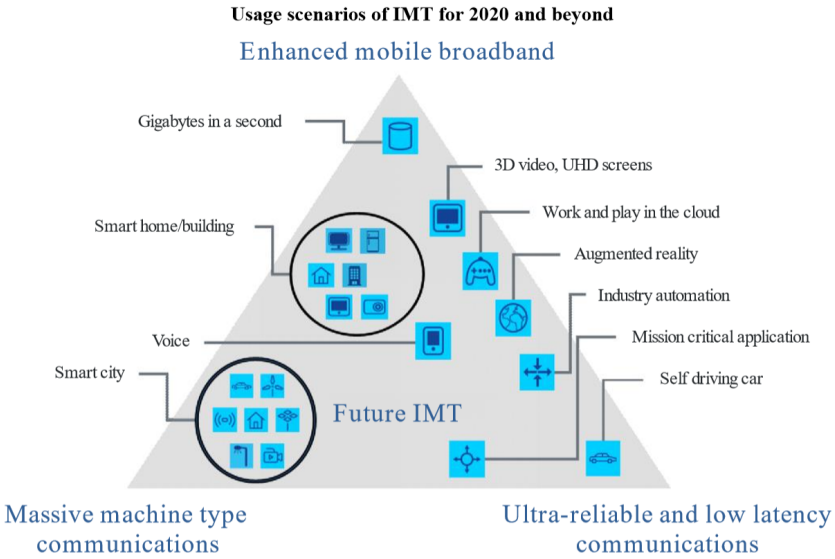
- ***5G (IMT-2020, ca. 2018)***
  - "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond", Recommendation ITU-R M.2083-0, 09/2015 [7]

- ***4G (IMT-Advanced, ca. 2008)***
  - Recommendation ITU-R M.2012 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)
- ***3G (IMT-2000, ca. 1998)***
  - Recommendation M.687 – International Mobile Telecommunications-2000 (IMT-2000)

5G "Triangle" (IMT-2020)

- ***IMT proposed <u>three</u> primary usage scenarios***

- ***Enhanced Mobile Broadband (eMBB)***
  - Augmented and virtual reality
- ***Ultra Reliable Low Latency Communication (URLLC)***
  - Real time control
- ***Enhanced/massive Machine Type Communications (eMTC)***
  - Wide-area
  - Usually battery powered

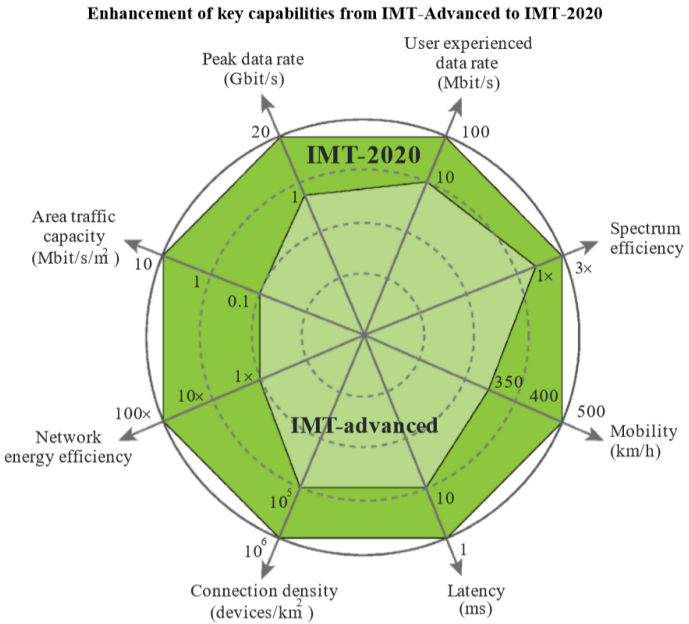


[7]

5G "Spider Diagram" (IMT-2020)

- ***IMT proposed <u>eight</u> metrics for improvement over IMT-Advanced***
- ***The enhancements enable the use cases***
- ***Note a few enhancements:***
  - User experienced data rate = 100 Mb/s
  - Area traffic capacity = 10 Mb/s/m^2
  - Latency = 1 ms

1 ms latency can support motion



[7]

5G Standards Development

- ***The Third Generation Partnership Project***
  - https://www.3gpp.org

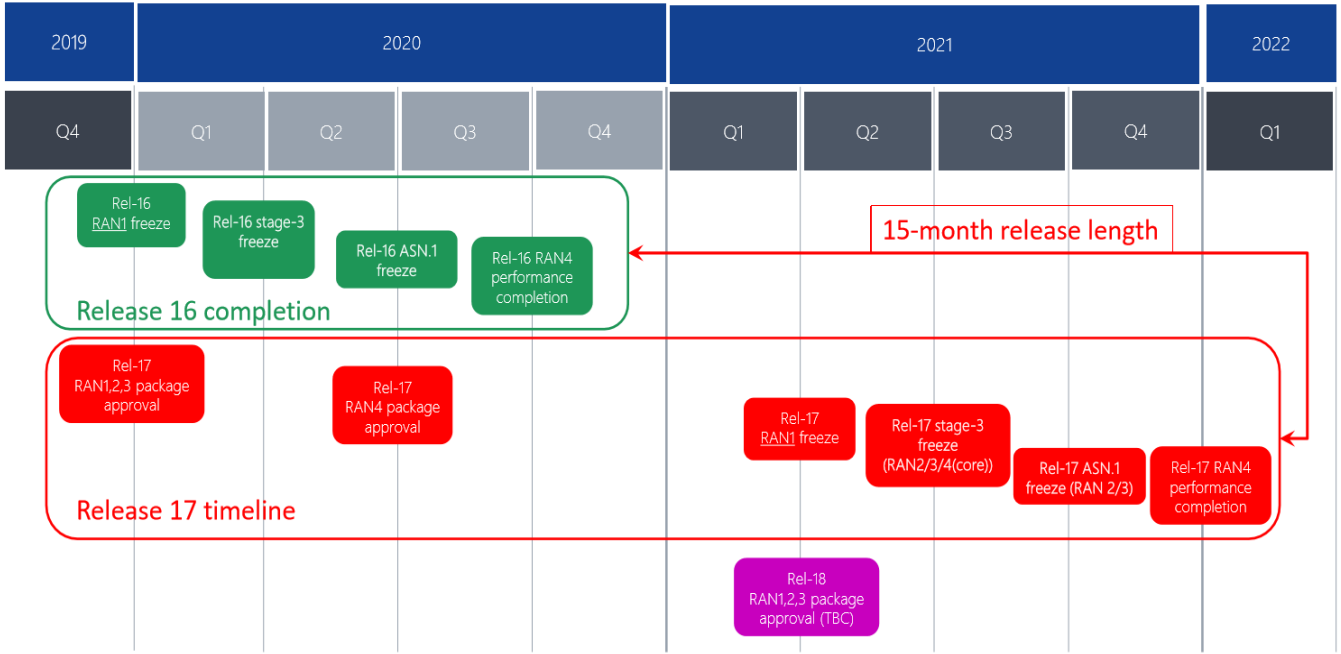
- ***Produce Specifications and Reports for cellular systems***
  - Original scope (1998) was 3G, then 4G, now 5G
  - In 4G/LTE - created “Evolved Packet Core” (EPC)
    - Internet Protocol, packet switching
  - Specifications are available - free of charge [8]

- ***Organization of seven telecommunications standard development organizations***
  - ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC

- ***Technical Specification Groups (TSG)***
  - Radio Access Networks (RAN)
  - Core Network and Terminals (CT)
    - WG3: Interworking with external networks
  - Services & System Aspects (SA)

3GPP Releases

- ***Release 15 (completed) introduced 5G NR (New Radio)***
  - Non-Standalone (NSA) which utilizes the LTE control plane
  - Standalone (SA) which is fully native
- ***Release 16 is adding TSN for Industrial Automation use cases***



[9]

5G-ACIA

- ***5G Alliance for Connected Industries and Automation***
  - Working Party of ZVEI (German Electrical and Electronic Manufacturers' Association)
- ***Industrial + Telecom members***
- ***Industrial use case development***
  - Whitepapers
  - Contributions to influence 3GPP, ETSI, etc.

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 km²
	Video-operated remote control	>99.9999%	10 – 100 ms	15 – 150 kbytes	100	< 1 km²
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 km²	

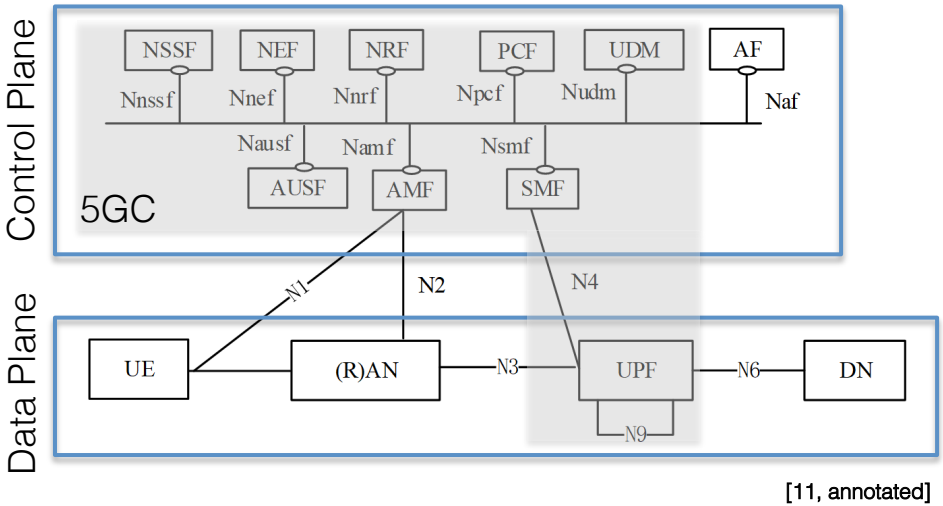
Source: ZVEI

[10]

Six Nines (99.9999%) is wired Ethernet reliability

5G Technology

System Architecture



[11, annotated]

Data Plane

UE	User Equipment (e.g., Phone)
(R)AN	Radio Access Network (i.e., basestation + antennas)
UPF	User Plane Function (e.g., bridge/router)
DN	Data Network

Control Plane

NSSF	Network Slice Selection Function
NEF	Network Exposure Function
NRF	NF Repository Function
PCF	Policy Control Function
UDM	Unified Data Management
AF	Application Function
AUSF	Authentication Server Function
AMF	Access and Mobility Management Function
SMF	Session Management Function

Interworking

5G defines "interworking" between UE and DN [12]

- ***IP routing***
  - Route on IPv4 or IPv6
  - Act as DHCP client/server
  - Link with RADIUS/AAA, etc.

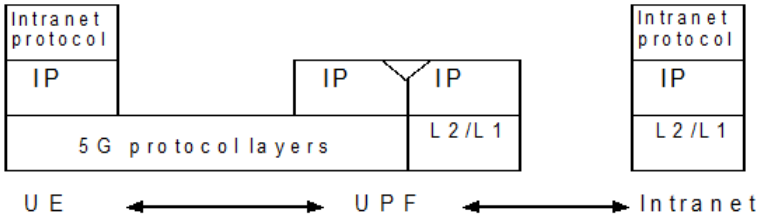


Figure 8.2.2.1-2: Transparent access to an Intranet

[12]

- ***Ethernet bridging***
  - Strips/adds Ethernet headers
  - Bridge on MAC addresses
  - Provide ARP proxy

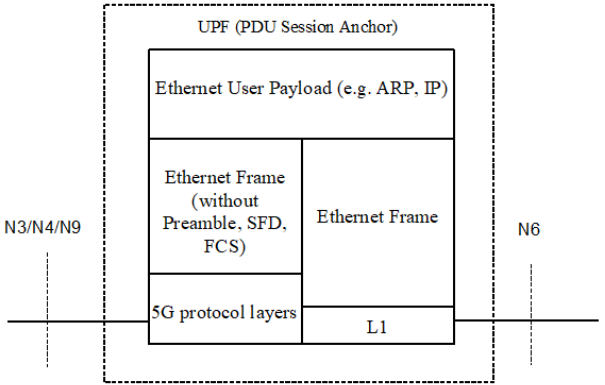
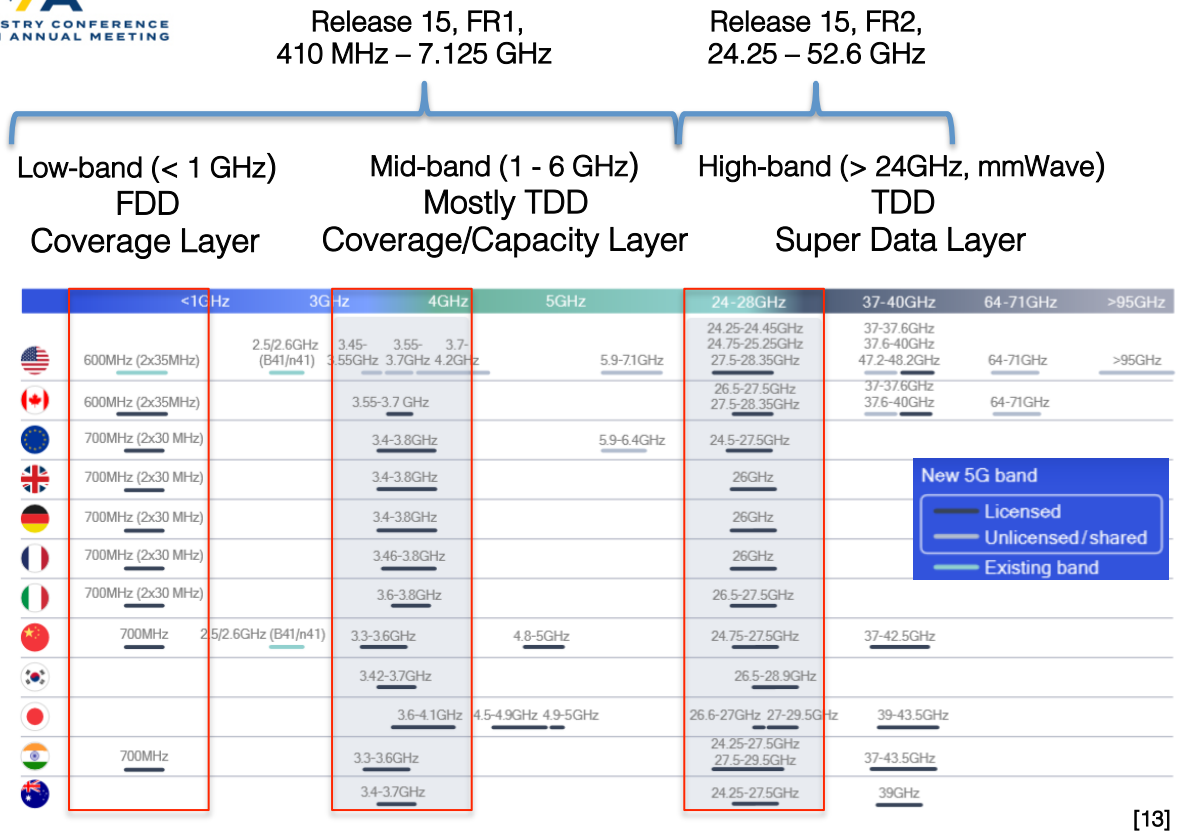


Figure 14-1: Protocol stacks for Ethernet PDU type data (user plane) for N6 reference point

[12]

Early testing indicates unmodified EtherNet/IP protocols can run over 5G

Spectrum

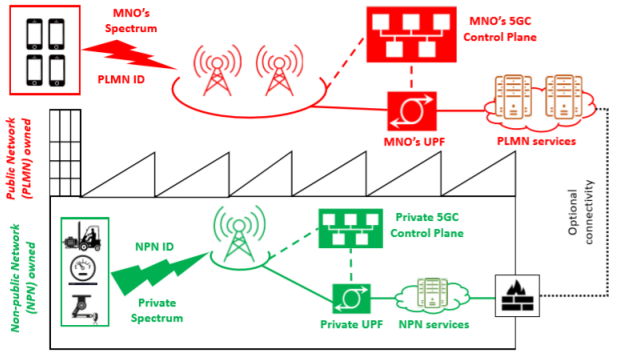


[13]

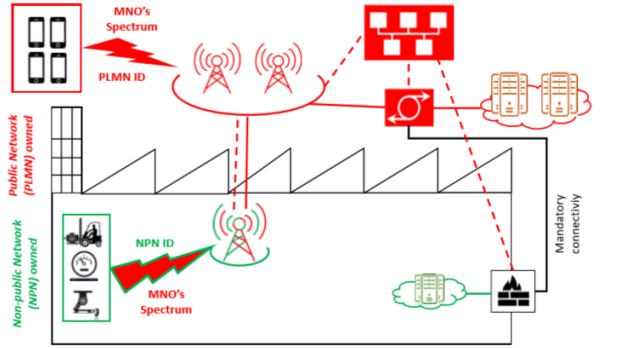
- ***Global coverage is primarily emerging from operator licensed bands***
  - Three optimized layers [42]
- ***Unlicensed and flexibly licensed bands exist in specific geographies***
  - US, 3.5-3.7 GHz (CBRS band), license database
  - Germany, 3.7-3.8 GHz, company licenses

Non-Public Networks (NPN)

- ***Various levels of NPN:***
  - Fully stand-alone
  - All components shared with public network
- ***Market studies indicate 3x basestations by NPN [43], motivating equipment vendors***
  - Complexity needs to shrink, possibly by "small cells" [45]
- ***Private spectrum is available in some geographies***
- ***Operators may be enticed to share their spectrum by new opportunities***
  - Spectrum sub-licensing
  - Equipment and service sales
- ***5G "slicing" technique [44] allows virtual network division (similar to VLANs)***
- ***URLLC performance improves as the loop is closed closer to the equipment***



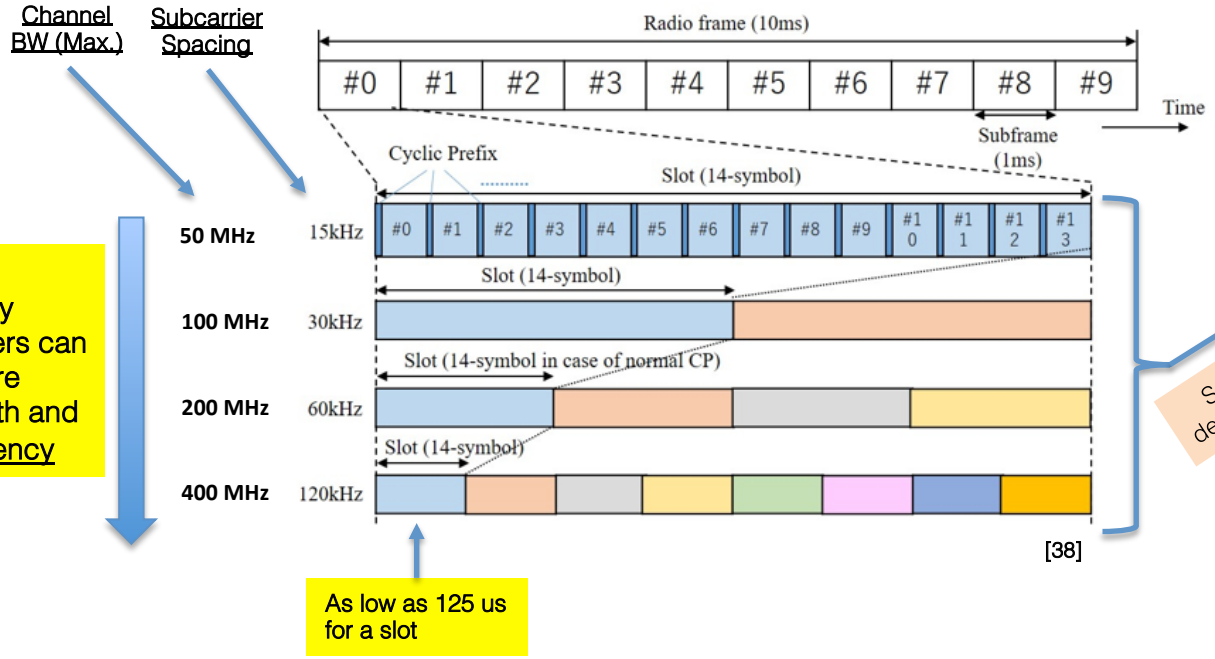
[14]



[14]

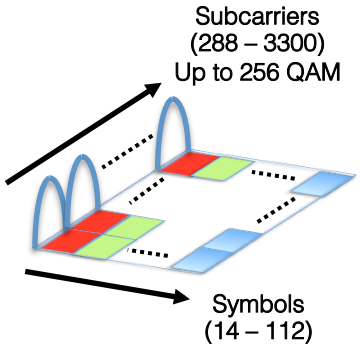
Frame Structure

Backward-compatible frame (10 ms) and subframe (1 ms) provide carrier-agnostic time reference



Higher frequency subcarriers can have more bandwidth and lower latency

One Subframe
- A Resource Grid
- Filled by scheduler
- OFDMA

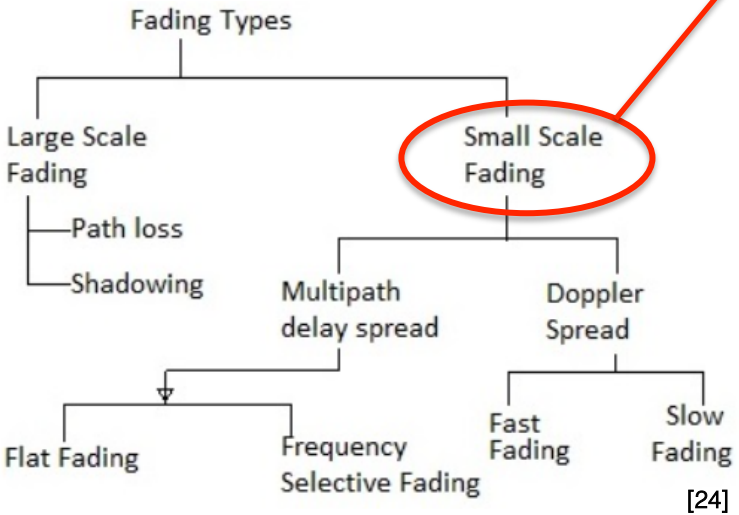


Each symbol can be:
- Uplink
- Downlink
- Flexible

Based on fixed slot formats

Fading

- ***Wireless channels are <u>not constant</u>***
  - *Fading* – Fluctuations in the strength of the signal at the receiver



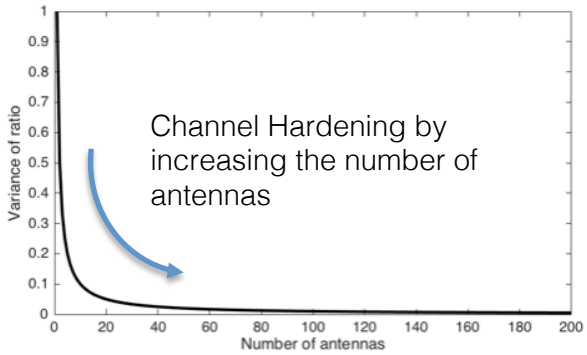
[24]

- ***Small scale fading is concerned with <u>rapid fluctuations of received signal strength</u> over very short distance and short time period***
- ***Channels may be very dynamic. Even if the transmitter and receiver are fixed, the surroundings may vary.***
- ***The actual (not statistical) measurement of a specific channel is only valid for a limited time, then the channel must be re-measured.***
  - *Coherence Time* - Time for which the channel characteristics are constant
- ***Fading can change faster than adaptations are made (the result is unpredictable latency)***

Channel Hardening

- ***"Channel Hardening Makes Fading Channels Behave as <u>Deterministic</u>" [25]***
  - *Channel Hardening* – decreasing the variations of the channel gain in time and frequency
  - An application of *spatial diversity*

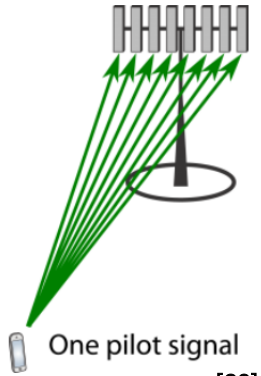
Variance of the ratio of:
Instantaneous Channel Gain
Average Channel Gain



[25]

- ***Practical implications:***
  - Improved reliability leads to <u>lower latency</u>
  - Transmissions are <u>schedulable</u> (frequency diversity is not required)
  - Rapid channel measurement combats fading

- ***Uplink pilot only***
- ***Reciprocity-based channel estimation [26]***
- ***Complex processing (primarily in the basestation) compensates for the channel in both directions [27]***



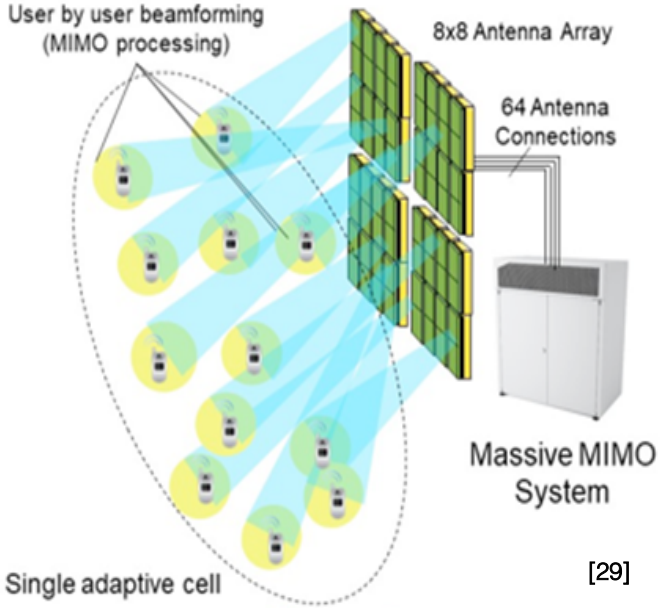
[26]

Massive MIMO

- ***MIMO (Multiple In Multiple Out) simultaneously utilizes multiple transmit and receive antennas in the same channel for a mix of improvements [30]***
  - Beamforming (distance)
  - Space Time Block Coding (reliability)
  - Spatial Multiplexing (rate)

- ***"Massive" MIMO structure***
  - Large number of antennas in the basestation
    - Ideally 100's
  - User equipment benefits without modification

- ***Benefits***
  - Per user beams theoretically offer full cell capacity for each user
  - Channel hardening … rapid channel estimation … high reliability + low latency



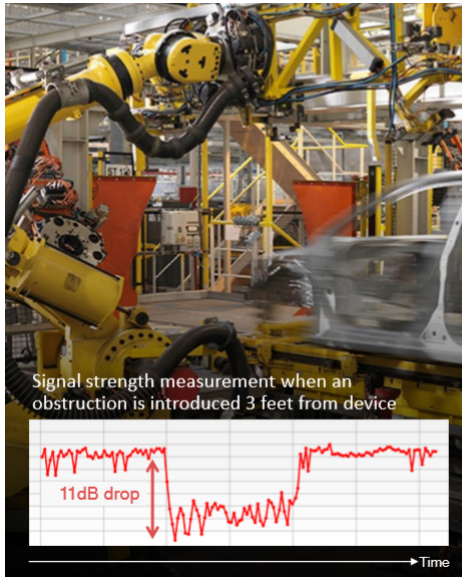
[29]

Homework: "Massive MIMO and Beamforming: The Signal Processing Behind the 5G Buzzwords" [28]

Multiple antenna paths. Upstream pilots. Reciprocity (TDD). Detection and Precode matrices. Constructive upstream and downstream multipath signals. Separate user data streams detection.

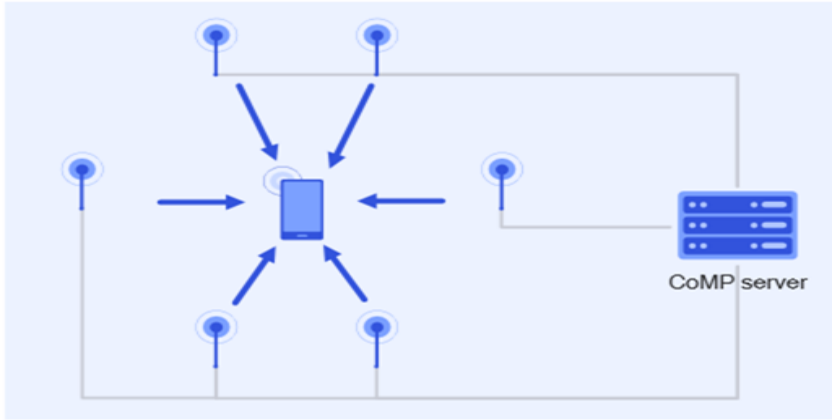
Coordinated Multi-Point

- ***Blockage and reflections from fast moving metal objects can cause sudden drops in signal strength***



[31]

- ***Coordinated Multi-Point (CoMP) builds on massive MIMO by distributing MIMO across multiple basestations***
  - Increase capacity
  - Increase reliability with low latency

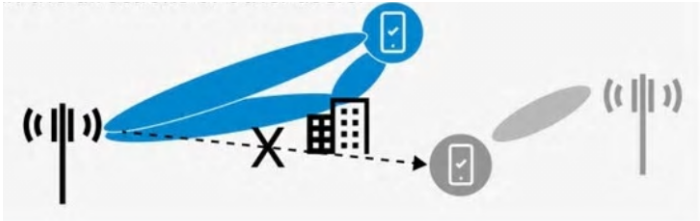


[31]

- ***Not a new idea - tested in Berlin in 2009 for LTE***

Low Power Wireless

- ***5G maintains three IoT radios: LTE-M, NB-IoT, and EC-GSM-IoT***
  - All three can achieve battery life (> 10 years), with two AA batteries totaling 5 Wh, for a daily report of a 200 byte message, at 164 dB MCL, at data rates < 1 kb/s, and latency approaching 10 seconds. [40]
  - In-band deployment (unifying)
- ***Release 15 continues the cumulative improvements [38]***
  - Reduced network participation overhead
  - Small cell support (reduced power levels)
  - Wake up signaling
  - Battery efficient security
- ***Small cells and non-public networks***
  - Free Space Path Loss is reduced 6 dB at half distance
- ***"Generalized" beamforming***
  - Doubling antennas adds 3 dB gain [33]
  - 200 antennas demonstrated 28 dBi [32]
- ***Optimization of chipset solutions***
- ***Mesh***
  - Future enhancement?



[33]

5G IoT radios are under continuous improvement, driven by a huge technical community

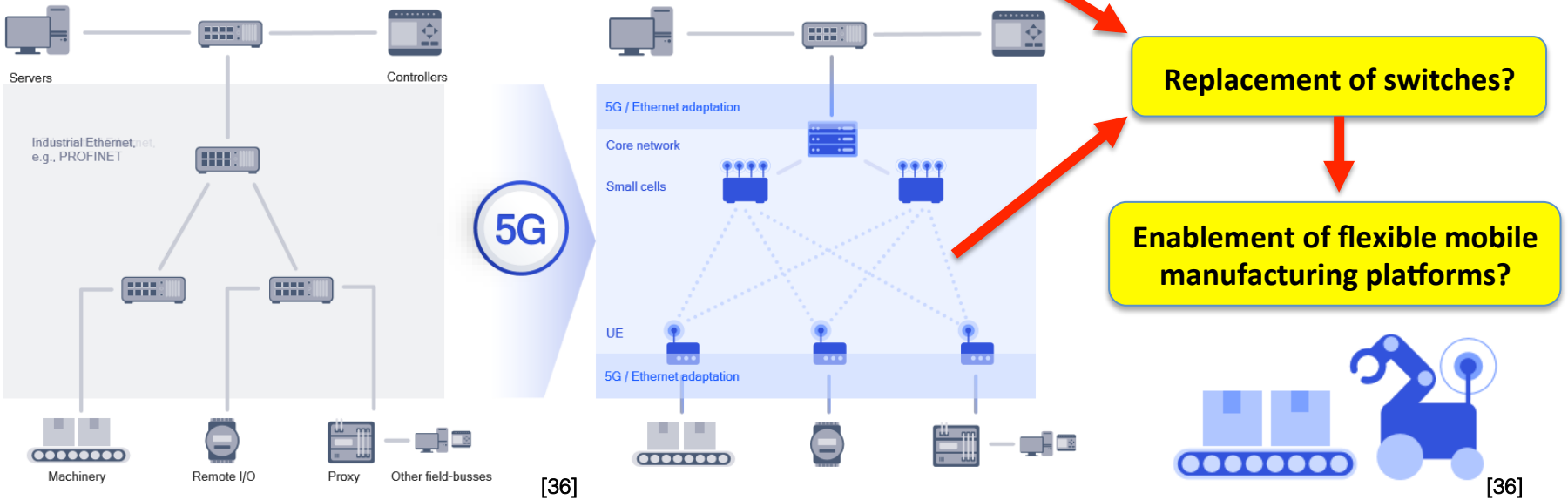
Wrap-up

5G Industry Vision

3GPP Chair: "Release 16 progressing towards

Industrial IoT and URLLC enhancements

- Adding 5G NR capabilities for full wired Ethernet replacement in factories: Time Sensitive networking, etc… with high reliability



[36] [36]

Conclusions

- ***5G will implement a wide range of technical enhancements***
- ***These enhancements improve on prior wireless solutions and may open new market areas – including industrial automation***
- ***5G has already emerged – capabilities are limited, but enhancement will continue***
- ***For the first time, we have a substantial set of industrial automation players pushing for a common wireless standard – 5G***
- ***Since 3G, the 3GPP standards have included: packet switched Internet Protocol, Ethernet connectivity, and quality of service - matching EtherNet/IP needs***
- ***Paradigm shifts may be either an opportunity or a threat***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Backup Material & References

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