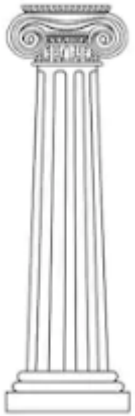
5G Use Cases

Reminder - verticals

Preliminary 5G work defined several vertical markets of interest

- general Internet (broadband)
- AR/VR
- first responders
- smart city
- automotive (V2X)
- e-health
- manufacturing (incl. industrial robots)
- entertainment and gaming
- wearables
- critical infrastructure
- smart utilities
- mass transit
- e-government
- agriculture

and collected specific requirements for each

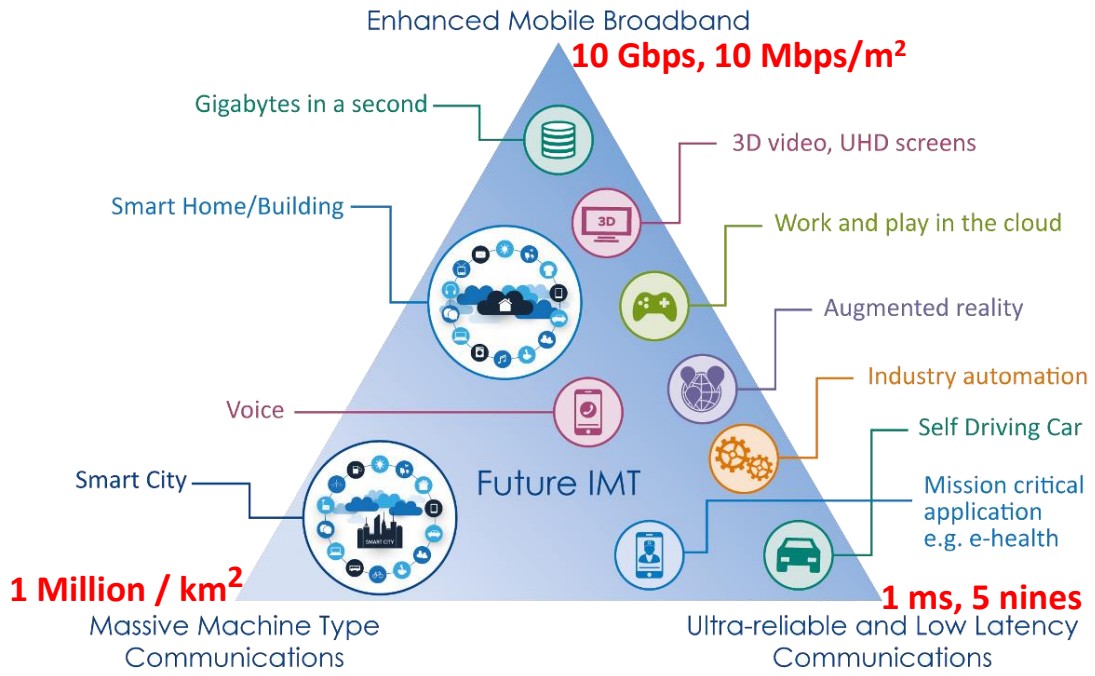


Requirements naturally fell into 3 main categories

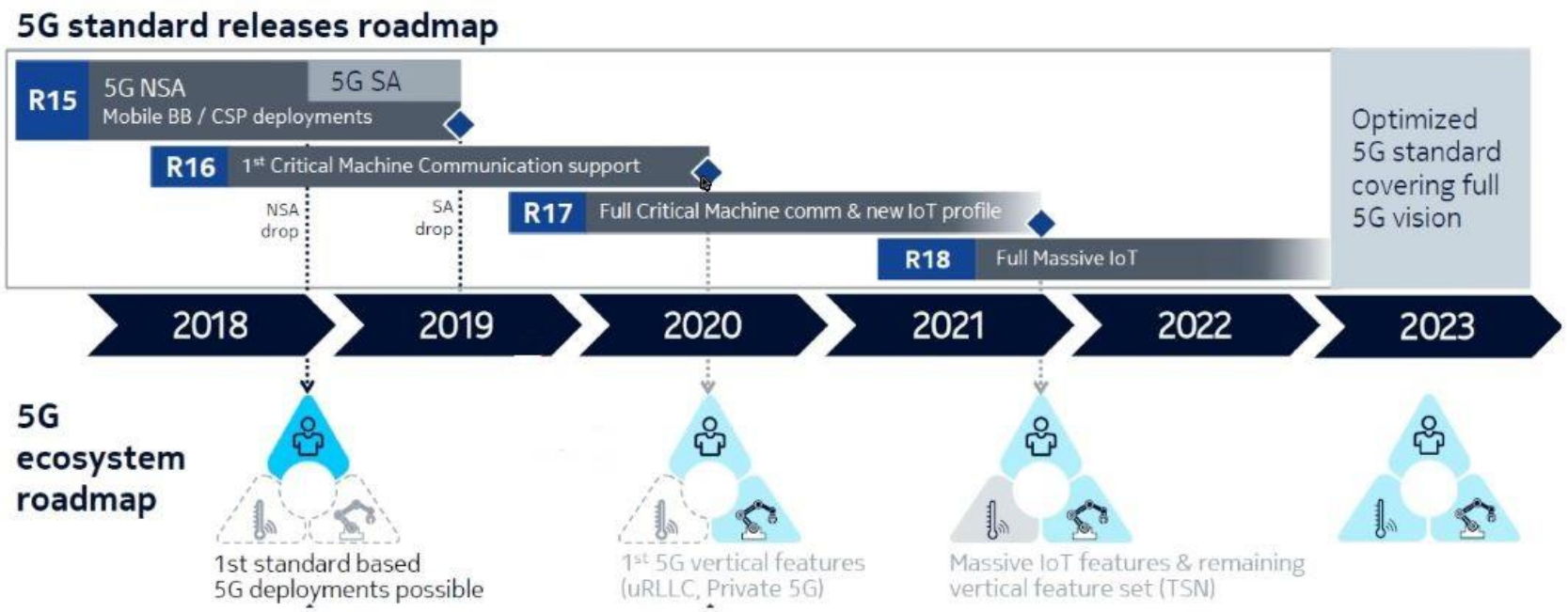
- eMBB enhanced mobile broadband
- URLLC ultra-reliable and low latency communications
- mMTC (AKA mIoT) massive machine type communications

These categories were the basis of ITU-R's framework

3 Categories



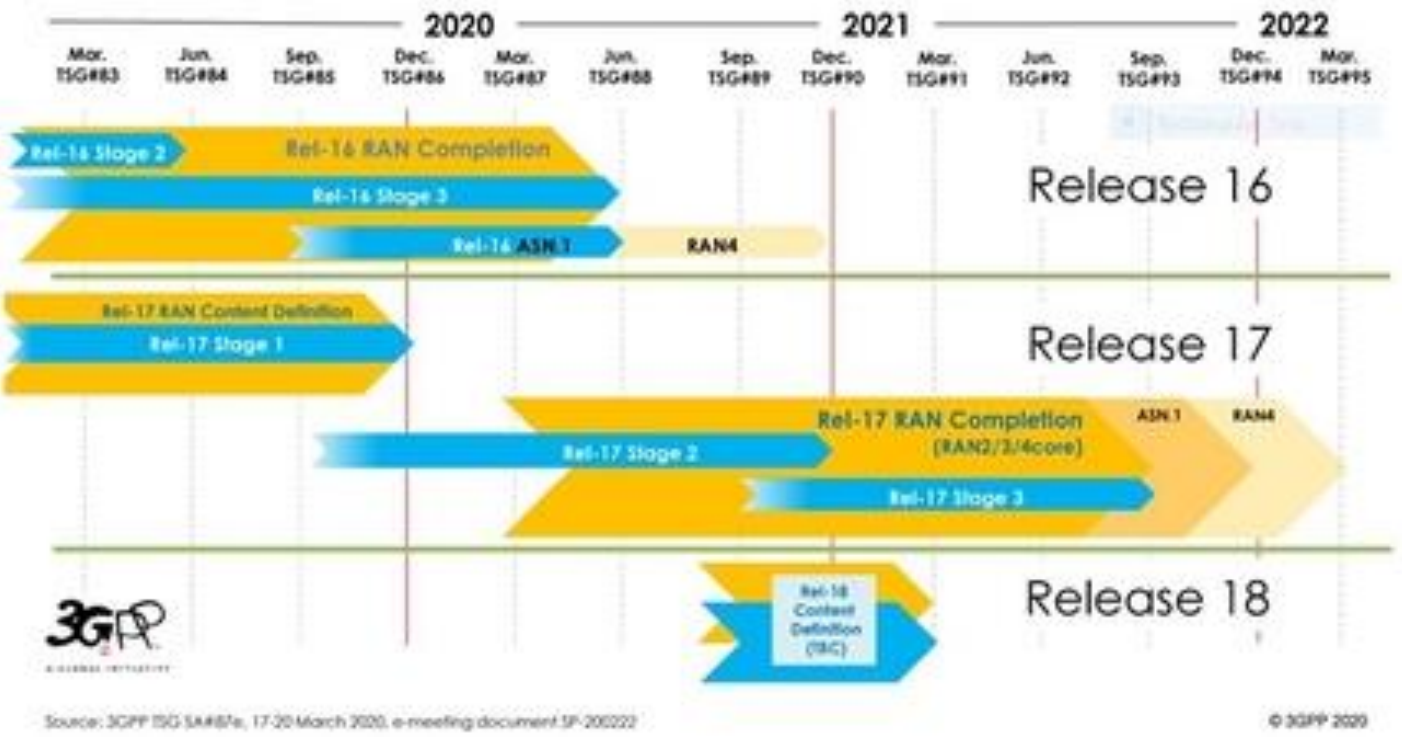
5G standardization according to application



Quick update

Due to the COVID19 situation, 3GPP has delayed some plans by 3 months

- R16 stage 3 freeze has been moved forward to June 2020
- R17 freeze was moved to December 2021



eMBB

The first use case is **e**nhanced (**M**obile) **B**road**B**and

eMBB traffic is an enhanced version of 4G broadband service
with 10 times higher data rates

eMBB is statistically characterized by

- Internet-like packet and session statistics
  - medium to large packet sizes
  - typical session 7 packets, but most bandwidth in very long session
- tolerance to packet loss ratio (0.1% acceptable, 1% unacceptable)
- tolerance to latency (delays of 100 ms acceptable)

eMBB can be subdivided into numerous sub-use-cases, for example

- **F**ixed **W**ireless **A**ccess
- hotspot backhauling
- video downstream / video upstream
- self-backhauling

eMBB will be the focus of the first 5G deployments

Mobile broadband

The most obvious use case is mobile broadband
i.e., faster browsing on your smartphone

This is the use case being addressed by most current deployments

It is not clear that 4G is really lacking here !

One argument often quoted goes something like this:

- downloading a full-length movie using 4G takes about 15 minutes
- with 5G will take only a five seconds

Such arguments are relatively unconvincing

- how much more would a subscriber you pay for this?
- is there any reason to download instead of streaming?

Mobile broadband requirements:

- high bandwidth
- may require high velocity (when in moving car or train)
- 4G packet loss ratio and latency are acceptable

Residential broadband

Cellular broadband access to homes or offices

is often called **F**ixed **W**ireless **A**ccess

Cellular Internet access to homes
can potentially replace existing HFC/DOCSIS, ADSL/VDSL, PON technologies

FWA is potentially must faster and cheaper to set up (studies cite 40% improvement)
(end-user installation will involve mounting an antenna on a roof or window)
but with 4G do not provide sufficiently high data-rates or reliability
(need 500 Mbps as compared to 4G FWA's average 50 Mbps)

Use of mmWave and beam-forming are an attractive FWA option
especially where right-of-way for cable/fiber installation is restricted

However, coverage will be limited to 1 km from a gNB site
and the very high rates to within 150 meters

This will initially limit penetration to

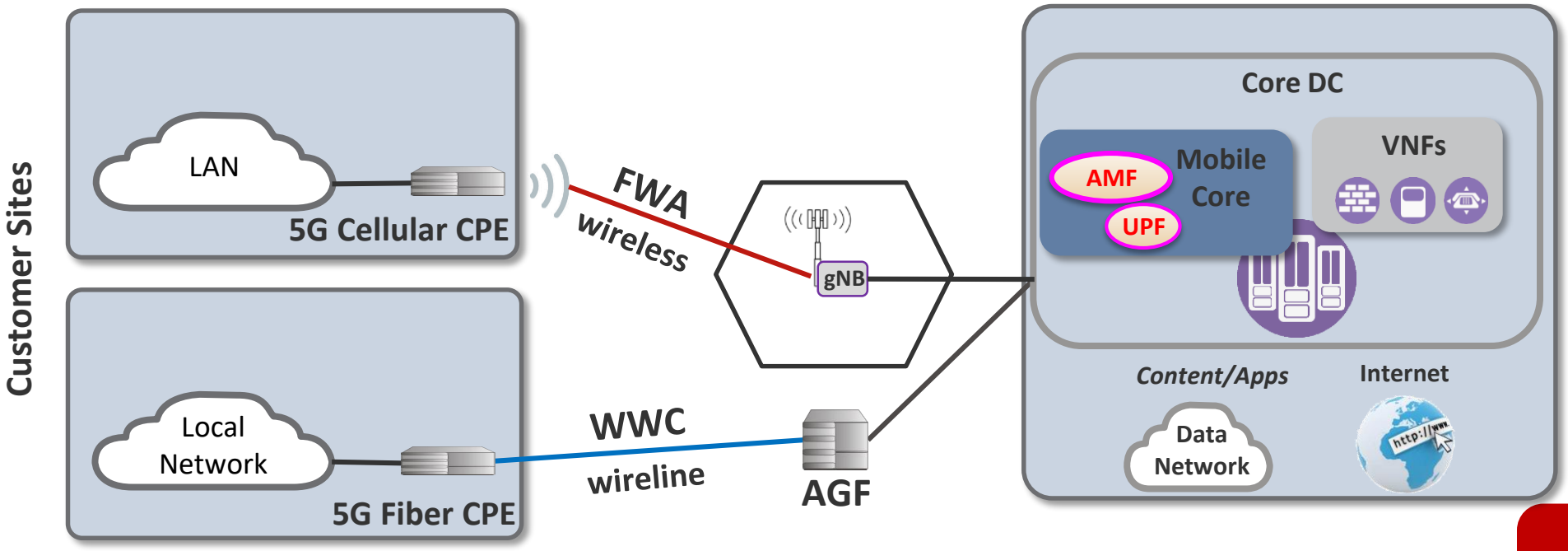
- dense urban environments
- to a small percentage of potential customers in such environments

Business services

Due to LTE's limited data-rates and availability
mobile operators could never provide profitable business services
which typically require fiber or symmetric DSL

With 5G, business sites can be connected to the feature-rich 5G core using

- 5G NR - **F**ixed **W**ireless **A**ccess (*fixed*, since CPE isn't mobile!)
- **W**ireline **W**ireless **C**onvergence (using the **A**ccess **G**ateway **F**unction



5G Home, 5G Office (Verizon)

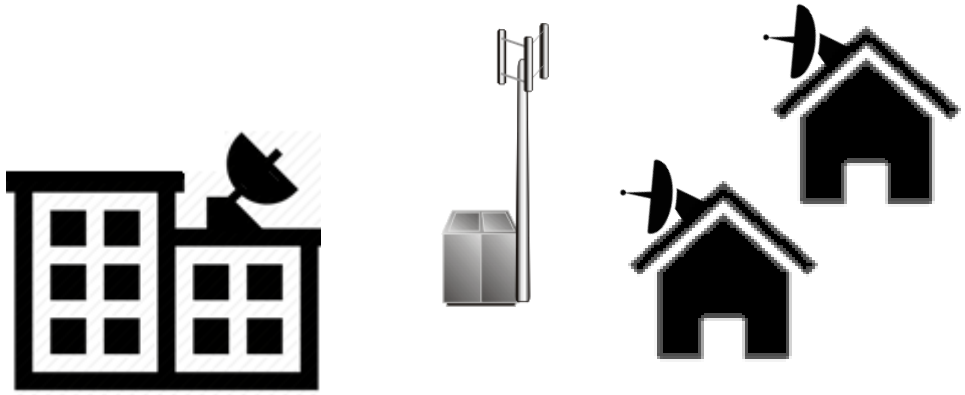
Verizon has only a small share of the US residential Internet access market
and views 5G as a method to catch up

Verizon was a very early adopter of 5G NR
and started deploying pre-standard (5GTF) before R15

Verizon has launched *5G Home* FWA in 4 cities
and stated that it intends to reach 30M households (25% of US market)

5G Home is based on 28GHz spectrum and proprietary 5GTF standards
and will cost $50-$70 per month for > 300 Mbit/s

Verizon has launched a similar service for small offices called *5G Office*



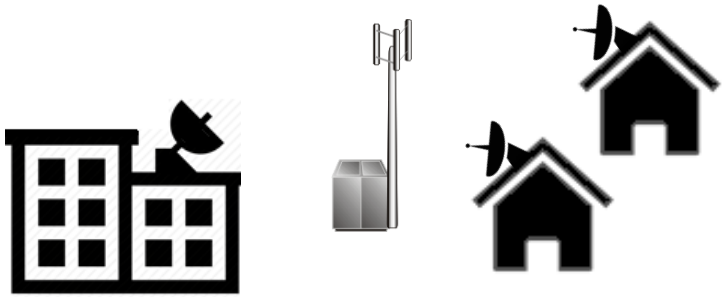
Telecommuting

As a result of the current health situation
there has been an uptick in working from home

Mobile operators are scrambling to increase services

T-Mobile and Verizon have received FCC approval
to borrow spectrum in the 600 MHz band tied to Dish network

Analysts believe that the trend will continue
as reticent corporations realize the benefits in lower expenses



FWA requirements

- Rates comparable with high-rate alternatives
  - VDSL2 – up to 200 Mbps
  - PON : XG-PON – up to 10 Gbps (DS), NG-PON2 up to 40 Gbps
- Reasonable latency (no more than 4G)
- Coverage
  - urban areas – full speed
  - other areas – at least similar to 4G

Full speed FWA necessitates wider system bandwidths
that are to be found in mmWaves which dictate small cells

Non-urban coverage requires finding new spectrum in the sub-6 GHz spectrum, e.g.,

- low frequencies, e.g., 600 MHz (US), 700 MHz (Europe)
- unlicensed shared spectrum, e.g.,
  - **C**itizens **B**roadband **R**adio **S**ervice (in US) at 3.5 GHz
    - may be used as long as do not interfere with incumbent government services
    - may be used as private wireless network as long as do not interfere to the above

AirGig (AT&T)

AT&T developed a novel backhaul physical layer technology
based on waveguiding data transmissions with power lines
and distributing to homes (and to mobile users) using 5G NR

AirGig is protected by an extensive patent portfolio

AirGig, announced in 2016 and to be launched 2021
can introduce broadband to rural areas
where it isn't economical to install conventional cabling

Facebook initiatives

Facebook has been involved in at least 3 projects (not necessarily 5G) to bring Internet access to new coverage areas

- Terragraph (60 GHz, multi-node for dense urban areas)
- ARIES (96 antenna high energy/spectral efficiency)
- Aquila

Aquila is a solar-powered pilotless airplane that acts as a data repeater which first flew in June 2016

Development ceased 2 years later, in June 2018

Its goal was to cover 66% of Earth's surface with no/poor Internet coverage

The Aquila drone

- weighs 400 kg
- has a wingspan about the same as a 737
- flies at altitude of 27 km during the day / 18 km at night
- endurance of up to 3 months
- provides Internet service to a 80 km radius area

OneWeb

OneWeb (ex WorldVu ex Google) is a collection of low altitude small satellites

Current design is for 650 in the constellation, to grow to 1,972

The first 6 satellites were launched in February 2019
and plans call for providing global services starting in 2021

The satellites will fly in circular 1,200 km orbits
and operate in 12-18 GHz spectrum

OneWeb is not alone in this idea of LEO satellites!

- Samsung proposed a 4600-satellite constellation in 2015 proposal
  to provide 200 gigabytes per month to everyone on earth
- Amazon's announced in April 2019 Project Kuiper
  in which it plans to launch 3,236 satellites in the next decade
- SpaceX has proposed a 12,000-satellite *Starlink* constellation
- Both Sierra Nevada and Surrey Satellite have announced similar plans
- Israel's Genesis Consortium is researching an Israeli version

Loon

Google's spin-off uses high altitude (20 km) balloons as 4G base stations

It was named Project Loon, since even Google thought it *loony*

Development began in 2011, and Loon became a separate company in 2018

The polyethylene balloons are filled with Helium
and measure 15 m across and 12 m tall when fully inflated

Solar panels power during the day and onboard battery used at night

Loon balloons navigate by changing their altitude
based on predictive wind models and autonomous algorithms

Longest duration aloft was 223 days (and circled the earth)

Loon delivered emergency Internet connectivity to Puerto Rico in 2017
and is set to provide commercial service in Kenya and Peru in 2020

A group of Loon balloons may creates a network to cover a defined area

Downstream video (Video on Demand)

Tier 1 mobile operators expect 90% of 5G traffic to be mobile video
based on current growth trends of 50% year-on-year

From 2010-2015 mobile video growth was due to increased watch times
since 2015 mobile video growth is mostly due to migration to HD

Much of this consumer video is from 3rd party sources and encrypted
often transported over QUIC (Google) or 0-RTT (Facebook)

For this traffic the mobile operator is a *dumb-pipe provider*

5G data rates are much higher than needed for HD television RT streaming

- standard MP4 TV requires about 3 Mbps
- 4K resolution requires 25-50 Mbps
- 8K 50-100 Mbps

So, 5G has the potential to replace cable TV and **D**igital **T**errestrial **T**elevision
but present data caps will need to be significantly increased
(25 Mbps is 11.25 GB per hour)

There may also be regulatory issues regarding *free* live TV

Upstream video

4G upstream data rates may be insufficient for **U**ser **G**enerated **C**ontent, e.g.:

- event broadcast
- social streaming
- Youtube upload
- e-learning / remote learning
- VR conference calls
- surveillance backhauling
- drone video
- multi-vantage point video

This may be the main difference between 5G and 4G

Video Requirements

- rates reliably over 50 Mbps
- for streaming - reasonable latency (no more than 4G)
- for real-time interactive (e.g., video conferencing) – low latency (under 20 ms)

Other M&E

Other Media and Entertainment use cases:

- ultra high fidelity media
- on-site live event experience
- user generated content & machine generated content
- immersive and integrated media
- cooperative media production
- gaming (including massive multi-user games)
- tactile Internet (very low latency – 0.5 ms so classified URLLC)
- drone control and video

Broad spectrum of requirements

URLLC and mMTC

In 5G we differentiate between 2 kinds of connected devices:

URLLC where the major issues are:
- very low delay
- very high reliability

mMTC where the major issues are:
- device density
- low power

A new work item for R17 defines a new low-cost variety named NR-Light
which is similar to 4G NB-IoT (we will discuss later)

While R15 has some basic URLLC features
URLLC will be introduced and optimized in R16
and mMTC is mainly being developed for R17

While eMBB deployments started in 2019
commercial URLLC services are not expected before early 2021
and mMTC in late 2021 early 2022

VR/AR/MR

Virtual **R**eality is the ability to be virtually present in a scene

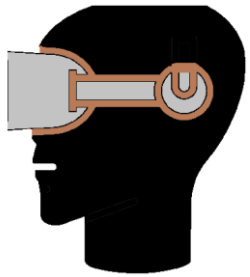
- requires high accuracy rendering of natural/synthetic image and sound
- correlates image and sound to movements of immersed user
- responds to user actions enabling realistic interaction with the scene

Augmented **R**eality is overlaying of information or artificial content
over true real-time environment

Mixed **R**eality is an advanced form of AR
where virtual elements are inserted into the scene
to provide the illusion that these elements are part of the true scene

VR requirements

- data rate of 200 Mbps (much less for AR)
- low latency (under 10 ms)



Smart Home

Analysts predict 25-100 Billion Internet-connected devices by 2020, such as:

- thermostats and temperature control
- home automation (smart lighting, smart temperature control)
- meters (electric, water, gas)
- household appliances (refrigerators, microwaves, water heaters, ...)
- RFID on disposables
- wearable health devices
- household robots

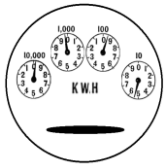
Smart Home requirements

- *large* of devices but each requiring low rates
- low cost per device (perhaps unlicensed spectrum, SIMless)
- edge computation (for privacy and aggregation/blocking)

Smart utilities

Utilities (electric, water, gas) have 3 different types of communications

- **O**perational **T**echnology network (control of critical infrastructures)
- **I**nformation **T**echnology network (as in any corporation)
  note trend of IT/OT convergence
- customer facing network (e.g., automatic meter reading)



The first two are often wired networks
(although some segments may be wireless)
while wireless implementation of metering
may be advantageous due to scale

Smart metering

- *massive* number of endpoints
- infrequent transmission
- low cost per endpoint
- no latency requirements
- some privacy requirements

High voltage distribution

- 5 ms 6 nines 200 km 100Gbps/km^2

Medium voltage distribution

- 25 ms 3 nines 100 km 10Gbps/km^2

Smart City

Smart City refers to the use of large numbers of connected sensors
to collect and forward (big) data
for (ML/AI) analysis
in order to efficiently manage a city's assets, resources and services, e.g.:

- traffic and transportation systems
- electric distribution
- water supply networks
- waste management
- surveillance and law enforcement
- hospitals

Examples of cities with *some* measure of smartness:
Amsterdam, Barcelona, Copenhagen,
Dubai, Madrid, Stockholm, Singapore,
...

Smart City Requirements

- *massive* number of endpoints
- infrequent transmission to or from each endpoint
- low cost per endpoint
- strict security requirements

Digression: What is Industry 4.0?

Factories have undergone generations – just like mobile communications!

- 1st industrial revolution – mechanization
  - use machines instead of manual/animal labor
  - coal, iron, railroads, textiles
  - 1765 Watt invents steam engine
  - 1780s in UK – mechanized factories and agriculture
  - 1878 internal combustion engine, leading to ...
- 2nd industrial revolution – electricity
  - petroleum/gas, steel
  - coal, iron, railroads, textiles
  - 1879 Swan invents light bulb (later perfected by Edison)
  - 1913 first assembly line (Ford)
  - 1930 Tesla's motor
- 3rd generation – computers
  - electronics
  - digital instead of analog
  - 1960 **P**rogrammable **L**ogic **C**ontroller
  - 1980s personal computers
- 4th generation – networked cyber-physical devices

Industrial IoT

Industrial **I**nternet **o**f **T**hings refers to
various sensors/measurement devices/relays/actuators/regulators
and supervisory controllers (microcomputers/servers)
networked together for industrial applications, such as:

- manufacturing
- quality control
- material processing
- energy management

SCADA = Supervisory Control And Data Acquisition

Example applications:

- smart factories (Industry 4.0)
- construction
- **C**yber-**P**hysical **S**ystems
- industrial robots
- smart dust

IIoT requirements

- high availability (typically 5 nines or higher!)
- large numbers of devices
- tight timing constraints (as low as 1 µs)
- accurate timestamping
- strong security if over public networks

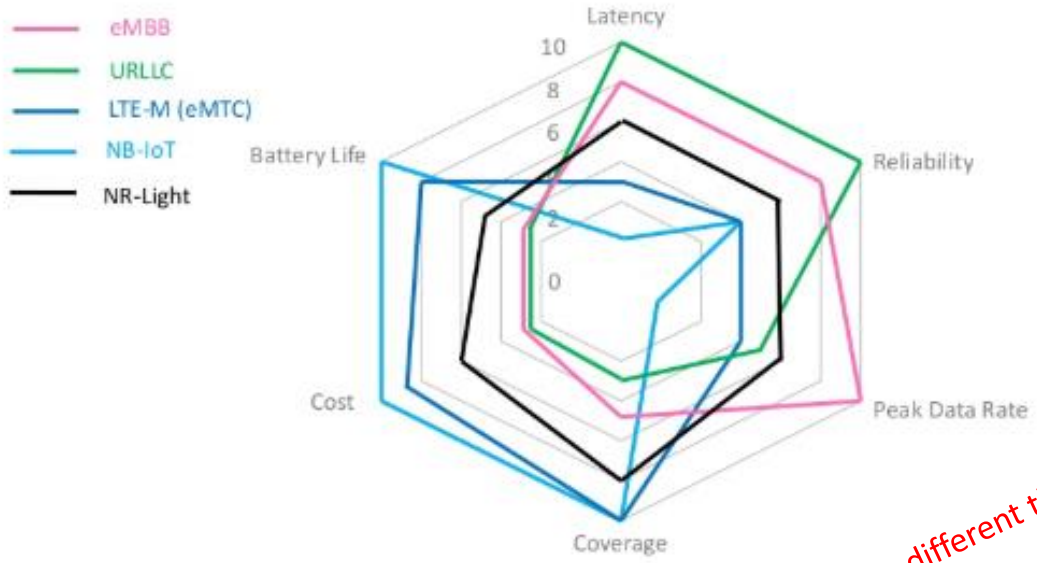
NR-Light

In Dec. 2019 3GPP RAN TSG opened a new work item for R17
concerning low-cost/low-power/long-battery-life IoT devices
which don't fit into the existing eMBB/URLLC/mMTC classes

The positioning of NR-Light (originally called NR-Lite) IoT is as follows:

	eMBB	**URLLC**	**mMTC**	**NR-Light**
Latency	medium	very low	low	high
Reliability	medium	very high	medium	low
Battery life	medium	medium	long	very long
Data rate	high	low	medium	low
Density	medium	low	very high	very high
Device cost	high	high	low	very low
Mobility	very mobile	very mobile	mobile	nomadic

NR-Light spider diagram



Warning – the axes here are different than the usual spider diagram !

Connected vehicles

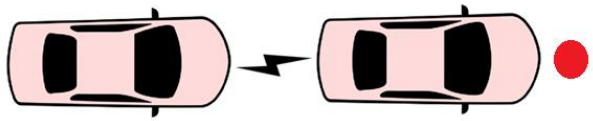
Vehicle-to-everything (V2X) means communications between a vehicle and other vehicles or anything that may affect the vehicle, including

- V2V (vehicle-to-vehicle)
- V2I (vehicle-to-infrastructure)
- V2N (vehicle-to-network – includes broadcasts and Application Servers)
- V2P (vehicle-to-pedestrian)
- V2D (vehicle-to-device, for keyless vehicles, car sharing, etc.)
- V2G (vehicle-to-grid for plug-in electric vehicles)

V2X can be useful for are road safety, traffic efficiency, and energy savings

Specific applications of V2X include

- forward collision warning
- lane change warning
- blind spot warning
- emergency brake warning
- emergency vehicle approaching
- roadworks warning
- platooning (flocking)



5G-V2X

Current V2X communication technologies are based on

- WiFi (802.11p **W**ireless **A**ccess in **V**ehicular **E**nvironments)
  based on **D**edicated **S**hort **R**ange **C**ommunication
  supports V2V and V2I
    Toyota introduced DSRC in Japan in 2016
      and GM/Cadillac introduced DSRC in the US in 2017
- cellular (C-V2X) as defined in R14 (LTE-V2X) and R15/R16 (5G-V2X)
  supports V2V, V2I, and V2N
  V2V exploits PC5 UE-UE interface (instead of Uu)
    LTE-V2X chipsets available, intersection right-of-way PoC in 2018
    Ford announced that all their new US cars will have C-V2X in 2022

One comparative study shows that C-V2X transmission

- have better range enabling earlier receipt of messages
- have better performance at low SNR
- is more likely to successfully deliver urgent messages
- will eventually become available on standard smartphones for V2P

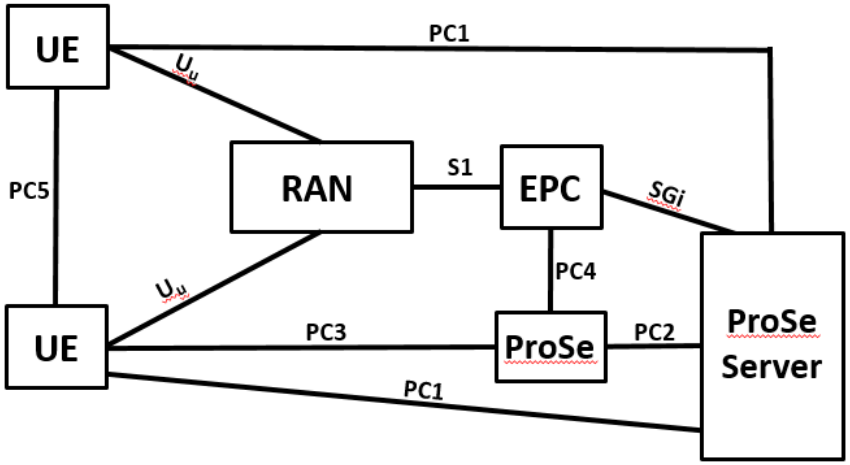
resulting in higher level of accident avoidance and reduction in injury

PC5 interface

4G R12 introduced a device-to-device (D2D) air interface
called PC5, *sidelink,* **Pro**ximity **Se**rvices (ProSe)
with which one UE can communicate directly with a second UE
without going through a base-station

PC5 was introduced in LTE for cases such as
first responders and **P**ush-**T**o-**T**alk (walky-talky)

The R12 architecture allows direct and EPC-aided discovery



5G will extend the PC5 interface for the V2V use case

eHealth / telemedicine

5G will improve/enable new use cases, including

- remote monitoring of health or wellness data
- cloud connected pacemakers
- telepharmacy and smart medication
- micro-hospitals
- hospital asset and intervention management
- remote EKG
- remote surgery (first performed in Sept 2001 – the Lindbergh Operation)
- telenursing and robotics for assisted living
- telerehabilitation (remote audiology, occupational/physical therapy)

Requirements

- very low delay
- ultra high reliability
- strict security requirements