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

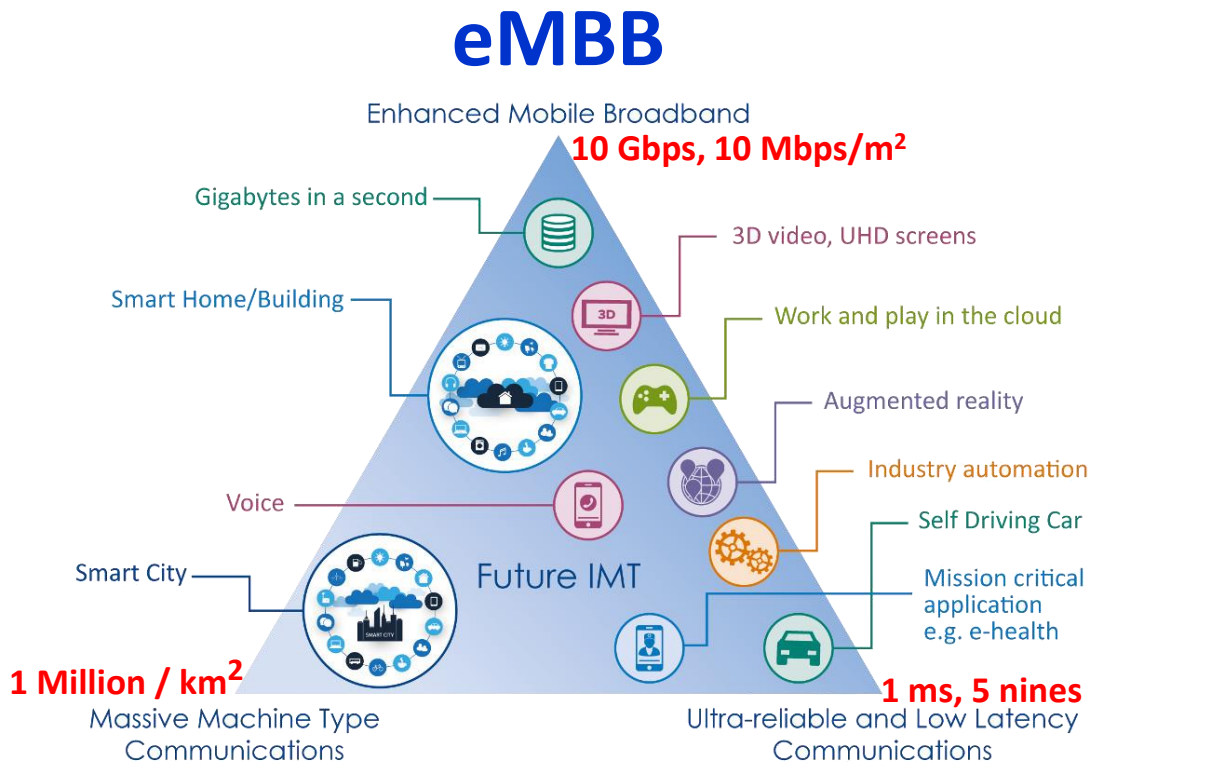
and collected specific requirements for each

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



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

FWA

5G rates open the prospect of cellular Internet access to homes / small offices
thus replacing HFC-DOCSIS/CATV, ADSL/VDSL, PON access technologies

FWA is usually must faster and cheaper to set up (studies predict 40% reduction)
but until 5G did not provide sufficiently high data-rates or reliability

5G mmWave (28 GHz band) and beam-forming are an attractive FWA option
especially where right-of-way for cable/fiber installation is restricted

End-user installation will involve mounting an antenna on a roof or window

5G is expected to deliver much higher data rates than average consumer rates
(500 Mbps as compared to 50 Mbps)

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

5G Home, 5G Office (Verizon)

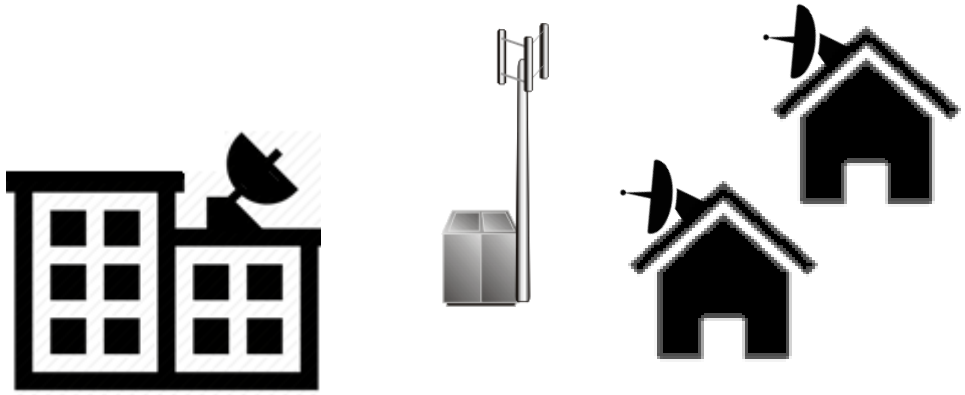
Verizon has only a small share of the US residential Internet access market
and views 5G as a method to catch up

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*



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

Downstream video

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

5G data rates may enable numerous use cases
for **U**ser **G**enerated **C**ontent video, 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

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

Other M&E

Immersive sound is realistic rendering of sound coming from a 360^{o}

3GPP has developed **I**mmersive **V**oice and **A**udio **S**ervices codec
based on **E**nhanced **V**oice **S**ervices codec
which added **F**ull **B**and speech and **S**uper **W**ide**B**and audio

R15 introduced new VR profiles

- 3GPP VR media profile
- VR DASH profile
- VR Scheme

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
- collaborative gaming
- tactile Internet (very low latency – 0.5 ms so classified URLLC)
- drone control and video

IoT

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, ...) see RFC 2324 ☺
- RFID
- wearable health devices
- robots

The Internet of Things will enable such devices to communicate
enabling new applications and increased value to people (non-devices)

IoT devices currently interconnect using (some *short-range* some **L**ow **P**ower **W**ide **A**rea)

- non-cellular protocols transmitting in unlicensed (ISM) bands
  - e.g., ZigBee, SigFox, LoRa, Weightless
- cellular protocols transmitting in licensed bands, notably
  - LTE Cat 1 (R8)
  - LTE-M (R12+) including LTE Cat 0, LTE Cat M1, LTE Cat M2
  - NB-IoT (R13)

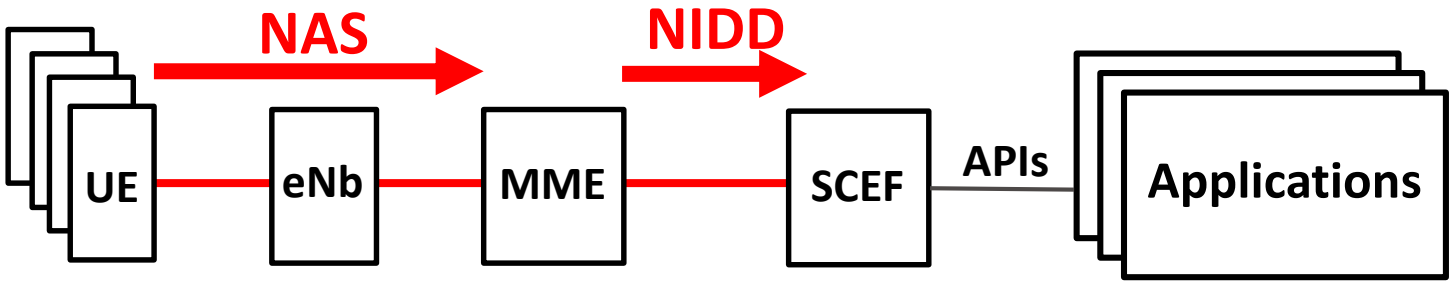
LTE NB-IoT

NB-IoT utilizes an LTE subset optimized for

- low CAPEX cost (much lower complexity than 1.4 MHz LTE modem)
- spectral efficiency (single narrow-band of 200kHz)
- long battery life (minimizes power when transmitting, otherwise sleeps)
- high connection density (up to 50K devices per cell)

NB-IoT data can be transported via the control plane (through MME)

- less power consumption than IP data bearers - **N**on-**I**P **D**ata **D**elivery
- extension of NAS protocol to transfer small amounts of data



5G IoT

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

While R15 has some basic URLLC features
URLLC and mMTC will be introduced and optimized in R16
Requiring work on air interface, N1, N2, N4, NEF, UDM, and AF functions
in order to extend resource reservation, QoS/PCF, and TSN features

eMBB trials are on-going on and NSA deployments are planned for late 2019
Commercial URLLC services are not expected before early 2021
and mMTC in late 2021 early 2022

Industrial IoT

Industrial **I**nternet **o**f **T**hings refers to various

- **P**rogrammable **L**ogic **C**ontrollers
  - sensors / measurement equipment
  - relays/actuators / regulators
- supervisory controllers (microcomputers)

networked together for industrial applications, such as

- manufacturing
- quality control
- material processing
- energy management

The messaging is called **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition

Example applications:

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

IIoT requirements

IIoT requires high availability (typically 5 nines or higher!)

IIoT typically involves huge numbers of devices
although PLCs may be small, dumb, and battery powered

Loss of single packets may be tolerated
but multiple losses may be problematic

SCADA messaging often has tight timing constraints (as low as 1 µs)
for example, in closed-loop automation control
and even when timing is not tight
accurate time synchronization may be needed for timestamping

SCADA messages are typically transmitted periodically (every 10-200 ms)
and often carry short payloads (from a few bytes to 250 bytes)

SCADA messaging over public networks require strong security
SCADA firewalls are often used

Example – electricity distribution control

- high voltage distribution : 5 ms 6 nines 200 km 100Gbps/km^2
- medium voltage distribution : 25 ms 3 nines 100km 10Gbps/km^2

Smart metering

Utilities (electric, water, gas) conventionally read meters manually

There are better ways:

- **A**utomatic **M**eter **R**eading (e.g., hand-held reader)
- Smart meters

Smart meters can record usage frequently (hourly, or at least daily)

Unlike AMR, smart meters usually employ bidirectional communication

Wireless communication options:

- cellular
- Wi-Fi or ZigBee and wired backhaul
- wireless ad hoc, wireless mesh
- LoRa and LoRaWAN **Lo**ng **Ra**nge (spread-spectrum in unlicensed bands)
- Wi-SUN (Smart Utility Networks) **F**ield **A**rea **N**etwork

V2X

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

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)