教育部「5G行動寬頻人才培育跨校教學聯盟計畫」
5G行動網路協定與核網技術聯盟中心

行動邊緣計算
可推廣教材模組

單元-03：行動邊緣計算之應用 (Use Cases)

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MEC Use Cases

- Mobile Edge Computing is
  - a key enabler for IoT and mission-critical, vertical solutions
  - one of the key architectural concepts and technologies for 5G
    - helping to satisfy the demanding requirements for the 5G era in terms of expected throughput, latency, scalability and automation.
  - offers additional privacy and security and ensures significant cost savings
- Many of the use cases can be enabled with Mobile Edge Computing prior to 5G.

Preliminary 5G Markets of Interests

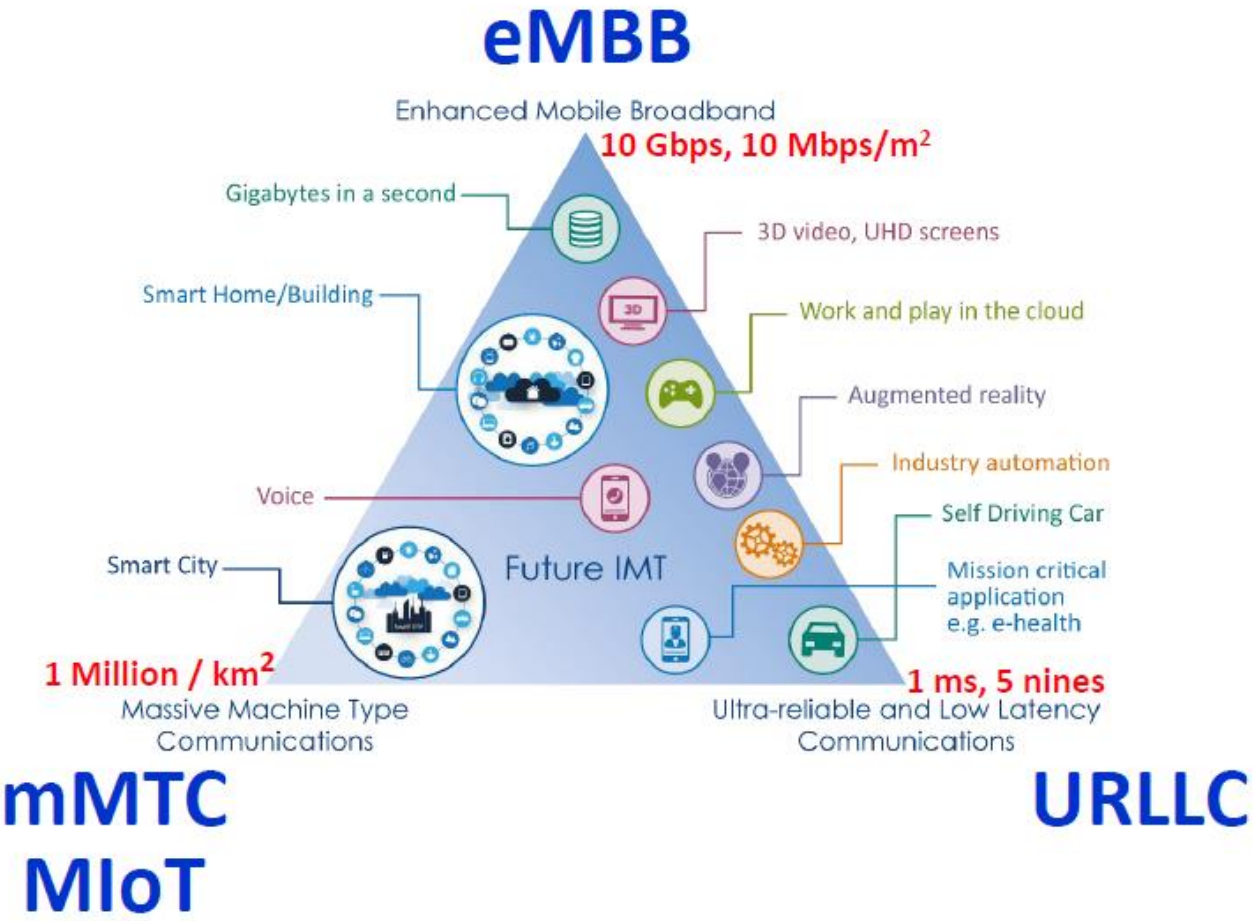
- Preliminary 5G work defined several vertical markets of interest
  - general Internet (broadband)
  - entertainment and gaming
  - AR/VR
  - wearables
  - first responders
  - critical infrastructure
  - smart city
  - smart utilities
  - automotive (V2X)
  - mass transit
  - e-health
  - e-government
  - manufacturing (incl. industrial robots)
  - agriculture

Requirements:
Three Main Categories

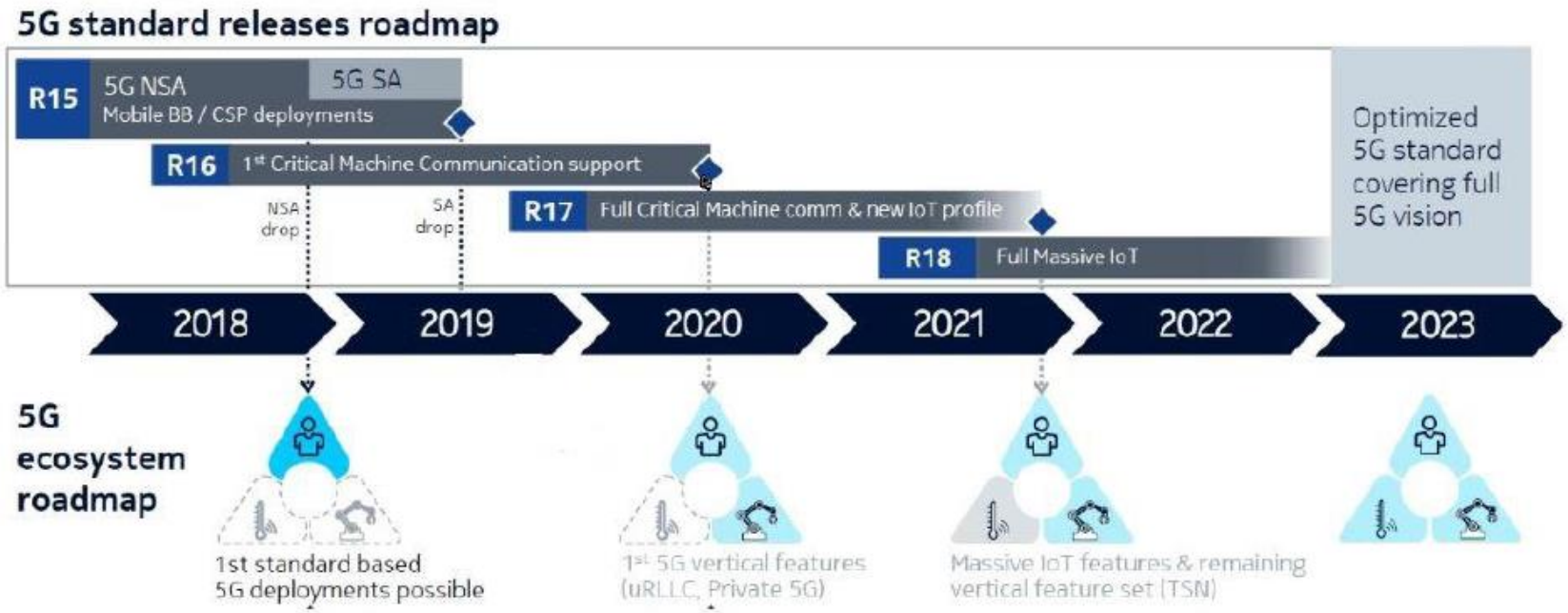
- **eMBB**: enhanced mobile broadband
- **URLLC**: ultra-reliable and low latency communications
- **mMTC**: (aka mIoT) massive machine type communications

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

Three Main Categories



5G Standardization According to Applications



eMBB: enhanced Mobile BroadBand (1/2)

- The first use case is enhanced (Mobile) BroadBand
- eMBB traffic is an enhanced version of 4G broadband service with 10 times higher data rates
- eMBBis 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: enhanced Mobile BroadBand (2/2)

- eMBBcan be subdivided into numerous sub-use-cases, for example
  - Fixed Wireless Access
  - hotspot backhauling
  - video downstream / video upstream
  - self-backhauling
- eMBB will be the focus of the first 5G deployments

Mobile Broadband (1/2)

- 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

Mobile Broadband (2/2)

- 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 (1/2)

- Cellular broadband access to homes or offices is often called Fixed Wireless Access
- Cellular Internet access to homes can potentially replace existing HFC/DOCSIS, ADSL/VDSL, PON technologies
- FWA is potentially faster and cheaper to set up
  - studies cite 40% improvement
  - end-user installation will involve mounting an antenna on a roof or window
  - with 4G, do not provide sufficiently high data-rates or reliability
  - need 500 Mbps as compared to 4G FWA's average 50 Mbps

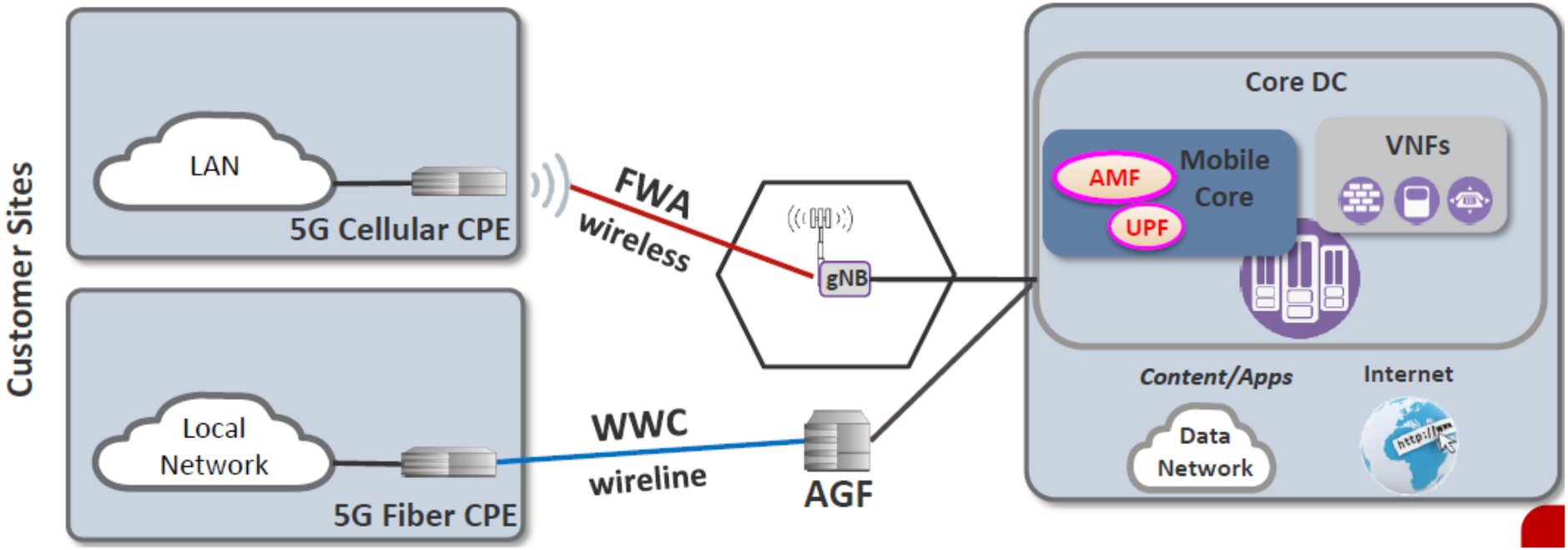
Residential Broadband (2/2)

- 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: Fixed Wireless Access (fixed, since CPE is not mobile)
  - Wireline Wireless Convergence: using the Access Gateway Function

Business Services



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 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 (1/2)

- 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

FWA Requirements (2/2)

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.,
  - Citizens Broadband Radio Service (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
- AirGigis protected by an extensive patent portfolio
- AirGig, announced in 2016 and launched 2021, can introduce broadband to rural areas, where it isn’t economical to install conventional cabling

Facebook Initiatives (1/2)

- 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

Facebook Initiatives (2/2)

- The goal of Aquila 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 80km radius area

OneWeb (1/2)

- OneWeb (ex WorldVuex 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 12-18GHz spectrum

OneWeb (2/2)

- Other ideas 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 (1/2)

- 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 15m across and 12m tall when fully inflated
- Solar panels power during the day and onboard battery used at night

Loon (2/2)

- 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 (1/2)

- 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 3rdparty sources and encrypted often transported over QUIC (Google) or 0-RTT (Facebook)
- For this traffic the mobile operator is a dumb-pipe provider

Downstream Video – Video on Demand (2/2)

- 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
- 5G has the potential to replace cable TV and Digital Terrestrial Television, 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 (1/2)

- 4G upstream data rates may be insufficient for User Generated Content:
  - event broadcast
  - social streaming
  - Youtube upload
  - e-learning / remote learning
  - VR conference calls
  - surveillance backhauling
  - drone video
  - multi-vantage point video

Upstream Video (2/2)

- There 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)

Media and Entertainment Use Cases

- 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 0.5ms so classified URLLC)
  - drone control and video

URLLC and mMTC: Differences

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

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

URLLC and mMTC

- A new work item for R17 defines a new low-cost variety named NR-Light, which is similar to 4G NB-IoT
- R15 has some basic URLLC features
  - URLLC will be introduced and optimized in R16 and mMTC is mainly being developed for R17
- 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 Reality 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 Reality is overlaying of information or artificial content over true real-time environment
- Mixed Reality 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 predicted 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 (1/2)

- Utilities (electric, water, gas) have 3 different types of communications
  - Operational Technology network (control of critical infrastructures)
  - Information Technology network (as in any corporation)
  - 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 Utilities (2/2)

- 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/km2
- Medium voltage distribution
  - 25 ms, 3 nines, 100 km 10Gbps/km2

Smart City

- Smart City refers to the use of large numbers of connected sensors
  - to collect and forward (big) data
  - for (ML/AI) analysis
- To efficiently manage a city's assets, resources and services:
  - traffic and transportation systems
  - electric distribution
  - water supply networks
  - waste management
  - surveillance and law enforcement
  - hospitals

Smart City Requirements

- Massive number of endpoints
- Infrequent transmission to or from each endpoint
- Low cost per endpoint
- Strict security requirements

Industry 4.0 (1/2)

- 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
- 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

Industry 4.0 (2/2)

- 3rd generation –computers
  - electronics
  - digital instead of analog
  - 1960 Programmable Logic Controller
  - 1980s personal computers
- 4th generation –networked cyber-physical devices

Industrial IoT (1/2)

- Industrial Internet of Things (IIoT) 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
  - Supervisory Control And Data Acquisition (SCADA)

Industrial IoT (2/2)

- Example applications:
  - smart factories (Industry 4.0)
  - construction
  - cyber-physical systems
  - 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 (or NR-Lite)

- 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 MBB / URLLC / mMTC classes.
- The features 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

Connected Vehicles (1/2)

- 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)

Connected Vehicles (2/2)

- 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 (1/2)

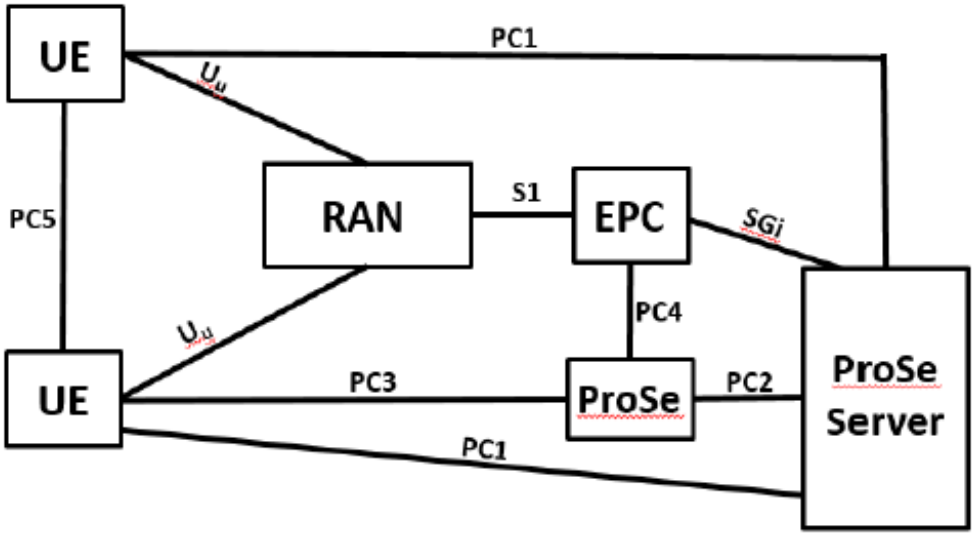
- Current V2X communication technologies are based on
  - WiFi (802.11p Wireless Access in Vehicular Environments)
    - based on Dedicated Short Range Communication
    - supports V2V and V2I
    - Toyota introduced DSRC in Japan in 2016
    - and GM/Cadillac introduced DSRC in the US in 2017
  - Cellular (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

5G-V2X (2/2)

- Comparative studies show 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
- C-V2X transmission results in higher level of accident avoidance and reduction in injury

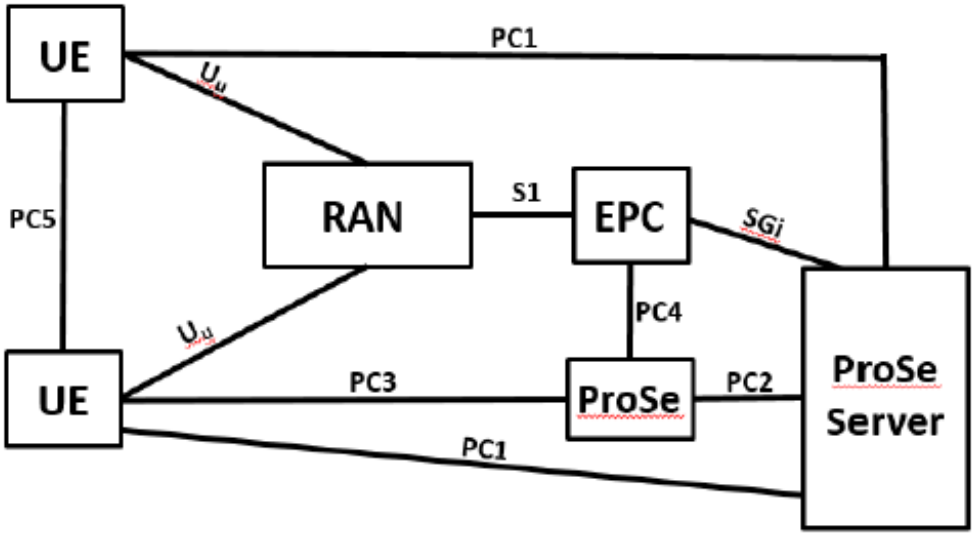
PC5 interface (1/2)

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



PC5 interface (2/2)

- PC5 was introduced in LTE for cases such as first responders and Push-To-Talk (walky-talky)
- The R12 architecture allows direct and EPC-aided discovery
- 5G will extend the PC5 interface for the V2V use case



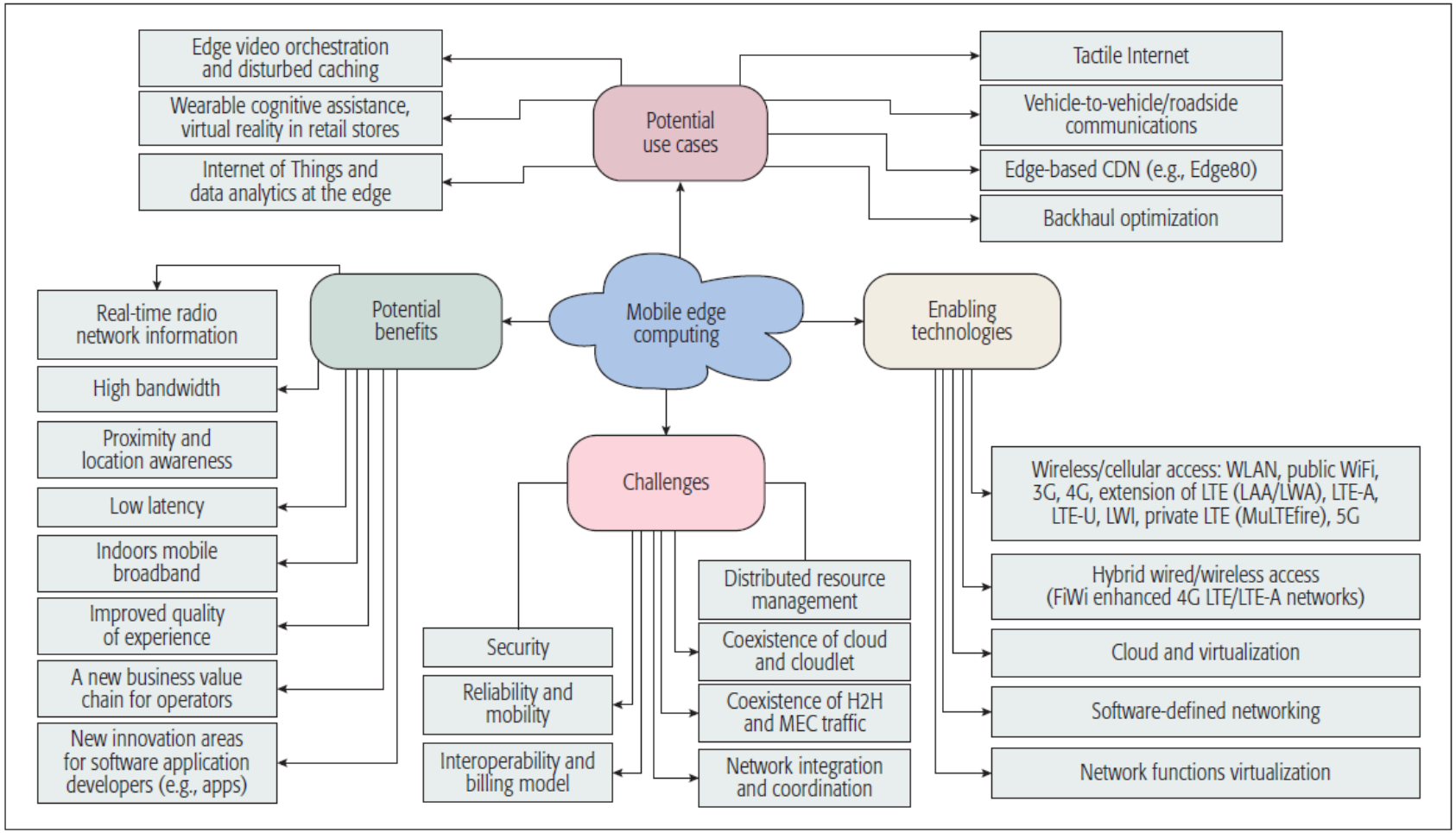
eHealth / Telemedicine (1/2)

- 5G will improve/enable new use cases, including
  - remote monitoring of health or wellness data
  - cloud connected pacemakers
  - tele-pharmacy 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
  - tele-rehabilitation (remote audiology, occupational/physical therapy)

eHealth / Telemedicine (2/2)

- eHealth / Telemedicine Requirements
  - very low delay
  - ultra high reliability
  - strict security requirements

Overview of Mobile Edge Computing



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Possible Use Cases

- Edge computing can resolve several issues in various scenarios
  - real-time image processing
  - Gaming
  - smart grid
  - smart traffic lights
  - connected vehicles,
  - smart building control
  - smart health environment

Real-Time Image Processing

- Peter, a foreign visitor in Japan, wants to know the details on the food listed in a hotel menu written in Japanese. Thus, he takes a snapshot of the menu to process it using a character recognition application. The execution of the application is compute-intensive. Therefore, he is unable to run the application on his mobile phone. In this context, he can execute his application on the edge server available inside
- the hotel network. He registers with the edge server and migrates the application to the server. The results are then sent back to him upon completion of the task.

Gaming

- Peter’s son, who is fond of computer games, wants to play a high definition 3D game from his mobile phone on a train while traveling from Seoul to Pohang-si, South Korea. He finds an available edge server on the train that provides the services to passengers of the train to run their applications. The game engine is migrated to the edge server where the actual business logic of the game will run. The game interface is the only component that runs on the mobile device. The execution of the business logic on the edge server extends the battery life of the mobile device and enables game execution on the resource-constrained mobile device.

Smart Grid

- Energy load balancing applications running on smart meters and micro grids enable automatic switching to alternative energies, such as wind and solar energy after considering the lowest price, energy demands, and availability. The data generated by grid devices and sensors are processed by the edge collector at the edge network. Edge devices process the
- delay-sensitive data in the edge network and send the rest of the data to the cloud server. In a smart grid environment, the lowest tier stores temporary data, whereas the highest tier stores the semi-permanent data.

Smart Transportation

- Edge computing can also contribute to improving the functionalities and services provided by smart transportation. Smart lights that can serve as edge devices can take sensing information of the flashing lights of an ambulance from a video camera and consequently open lanes for the ambulance. Similarly, smart street lights take information from sensors to detect the presence of bikers and pedestrians and then turn the lights on or off depending on when movement is detected or traffic has passed.

Real-Time Big Data Analytics

- Big data processing has been a hot research area for computer science researchers. Real-time big data analytics in cloud computing is a challenging process because of the enormous volume of data and large WAN latency. Edge computing furnishes on-demand resources for processing huge amounts of real-time big data. Processing big data in the edge network reduces the traffic in the network and the workload on the cloud server.

Real-Time Big Data Analytics

- Edge computing can complement the services provided by cloud computing. For instance, in a large-scale environment monitoring system, regional and local data can be collected and mined at edge servers, thereby enabling timely responses in emergency cases. Compute-intensive tasks such as detailed analysis can be performed in the cloud server. Such edge computing-based big data analytics can be useful for the Internet of Things (IoT) and smart cities where sensor devices continuously generate enormous amounts of data.

Case Studies

- **Case Study I**: Joint Resource Allocation and Computing
- **Case Study II**: Proactive vs. Reactive Computing
- **Case Study III**: AR-Enabled Self-Driving Vehicles
- **Case Study IV**: Service-oriented HybrId access Network and Cloud ArchitecturE (SHINE)