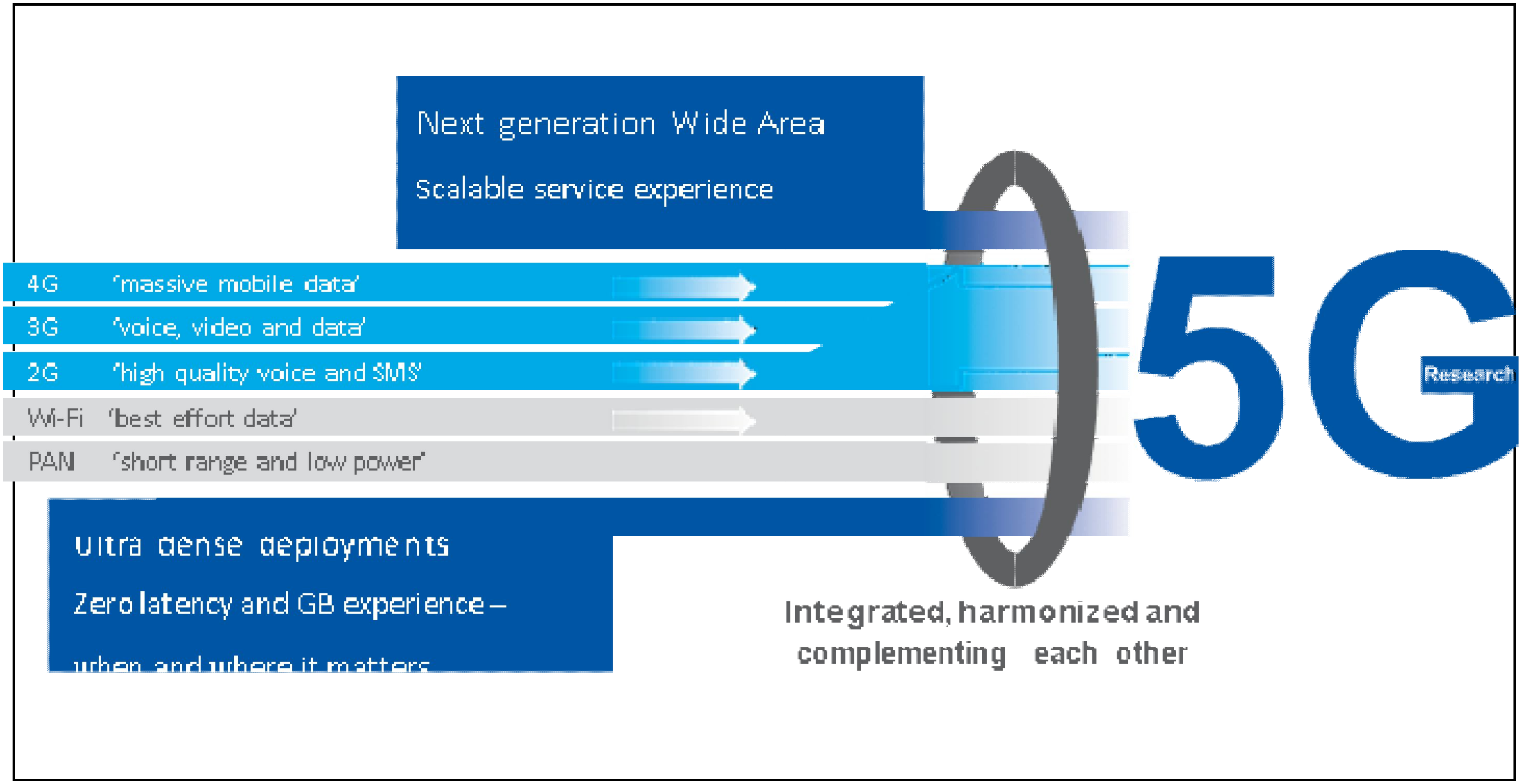
Unit No 1: Introduction to 5G

The continuing growth in demand from subscribers for better mobile broadband experiences is encouraging the industry to look ahead at how networks can be readied to meet future extreme capacity and performance demands. Although the path towards 2020 has already been set out in our Technology Vision 2020.

From historical point of view, each of the cellular standards has evolved around a set of key use cases:

In the last four decades, mobile phones, more than any other technology, have quietly changed our lives forever.

- 1G, the first generation of telecom networks (1979), let us talk to each other and be mobile
- 2G digital networks (1991) let us send messages and travel (with roaming services)
- 3G (1998) brought a better mobile internet experience (with limited access)
- 3.5G brought a truly mobile internet experience, unleashing the mobile apps ecosystem
- 4G (2008) networks brought all-IP services (Voice and Data), a fast broadband internet experience, with unified networks architectures and protocols
- 4G LTE (for Long Term Evolution), starting in 2009, doubled data speeds
- 5G networks (2019) expand broadband wireless services beyond mobile internet to IoT and critical communications segments.



Next generation Wide Area
Scalable service experience
4G 'massive mobile data'
3G 'voice, video and data'
2G 'high quality voice and SMS'
Wi-Fi 'best effort data'
PAN 'short range and low power'
Ultra dense deployments
Zero latency and GB experience –
when and where it matters
Integrated, harmonized and complementing each other
5G
Research

Comparison between 4G-LTE and 5G

The key differences between 4G vs. 5G network architecture include the following:

- latency
- potential download speeds
- base stations
- OFDM encoding
- cell density

4G vs. 5G: What's the difference?

	4G	5G
LATENCY	60 to 98 ms	Less than 5 ms
POTENTIAL DOWNLOAD SPEED	1 Gbps	20 Gbps
BASE STATIONS	Cell towers	Small cells
OFDM ENCODING	20 MHz channels	100 to 800 MHz channels
GOAL FOR CELL DENSITY	200 to 400 users per cell	100 times greater than 4G

ILLUSTRATION: FEODORA CHIOSEA/ADOBE STOCK

Comparing latency, speed and bandwidth

Latency. The biggest difference between 4G and 5G is latency. 5G promises low latency under 5 milliseconds, while 4G latency ranges from 60 ms to 98 ms. In addition, with lower latency comes advancements in other areas, such as faster download speeds.

Potential download speeds. While 4G introduced various VoIP capabilities, 5G builds upon and enhances those promises of quick potential download speeds. 4G's download speeds hit 1 Gbps, and 5G's goal is to increase that tenfold for maximum download speeds of 10 Gbps.

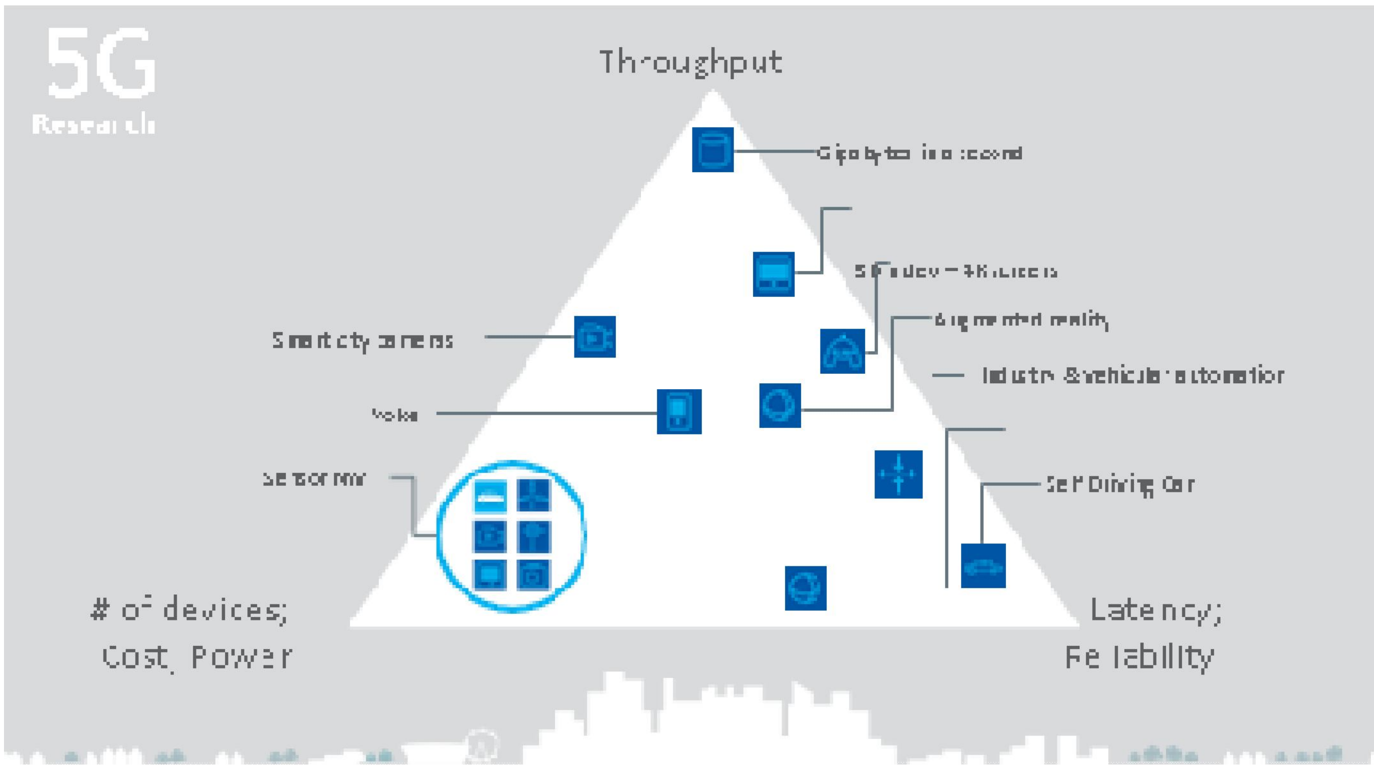
Base stations. Another key difference between 4G vs. 5G is the most common base station required to transmit signals. Like its predecessors, 4G transmits signals from cell towers. However, 5G uses small cell technology, due to its faster speeds and mmWave frequency bands, so carriers will deploy high-band 5G in small cells about the size of pizza boxes in multiple locations. 5G will still use cell towers for its lower frequency spectrums as well.

Carriers must deploy small cells in various areas due to the mmWave frequency. While the frequency is higher than cellular technology has seen so far, mmWave has weaker signals that travel across shorter distances. Small cell stations must be placed frequently in 5G-capable areas to ensure the signals reach users and businesses.

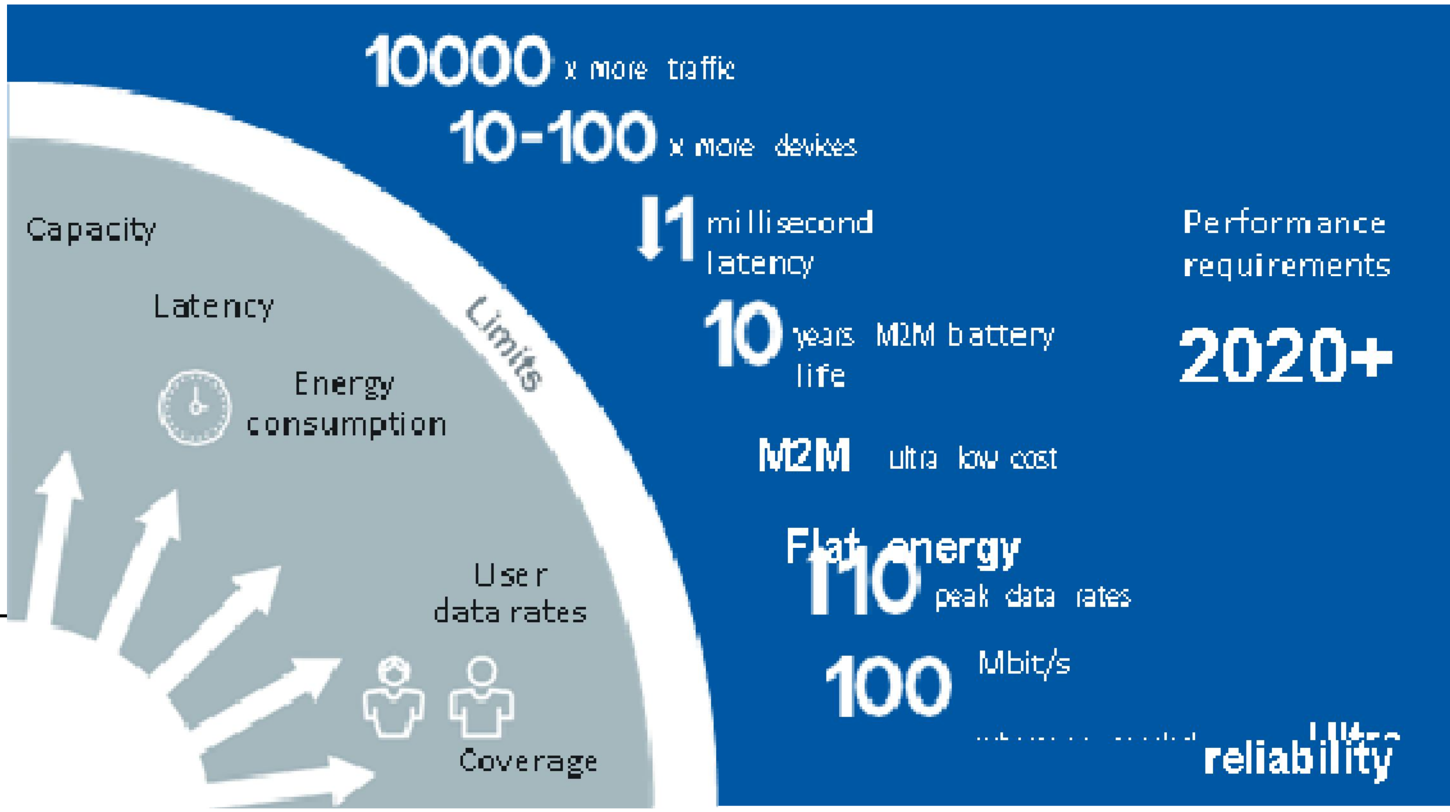
OFDM encoding. OFDM is used to split different wireless signals into separate channels to avoid interference, which also provides greater bandwidth. Because OFDM encodes data on different frequencies, this can bolster 4G and 5G download speeds, as these networks would have their own signal channels rather than a shared one between them. 4G uses 20 MHz channels, while 5G will use 100 MHz to 800 MHz channels.

Cell density. Small cell technology enables 5G to provide more cell density and enhance network capacity. While these were also promises of 4G, 5G will hopefully succeed where its predecessor falls short, as 4G never completely met its high goals for general speeds. With 5G, networks will be denser, which means they have more capacity to support more users and connected devices leading to increased mobile device and connection capacity.

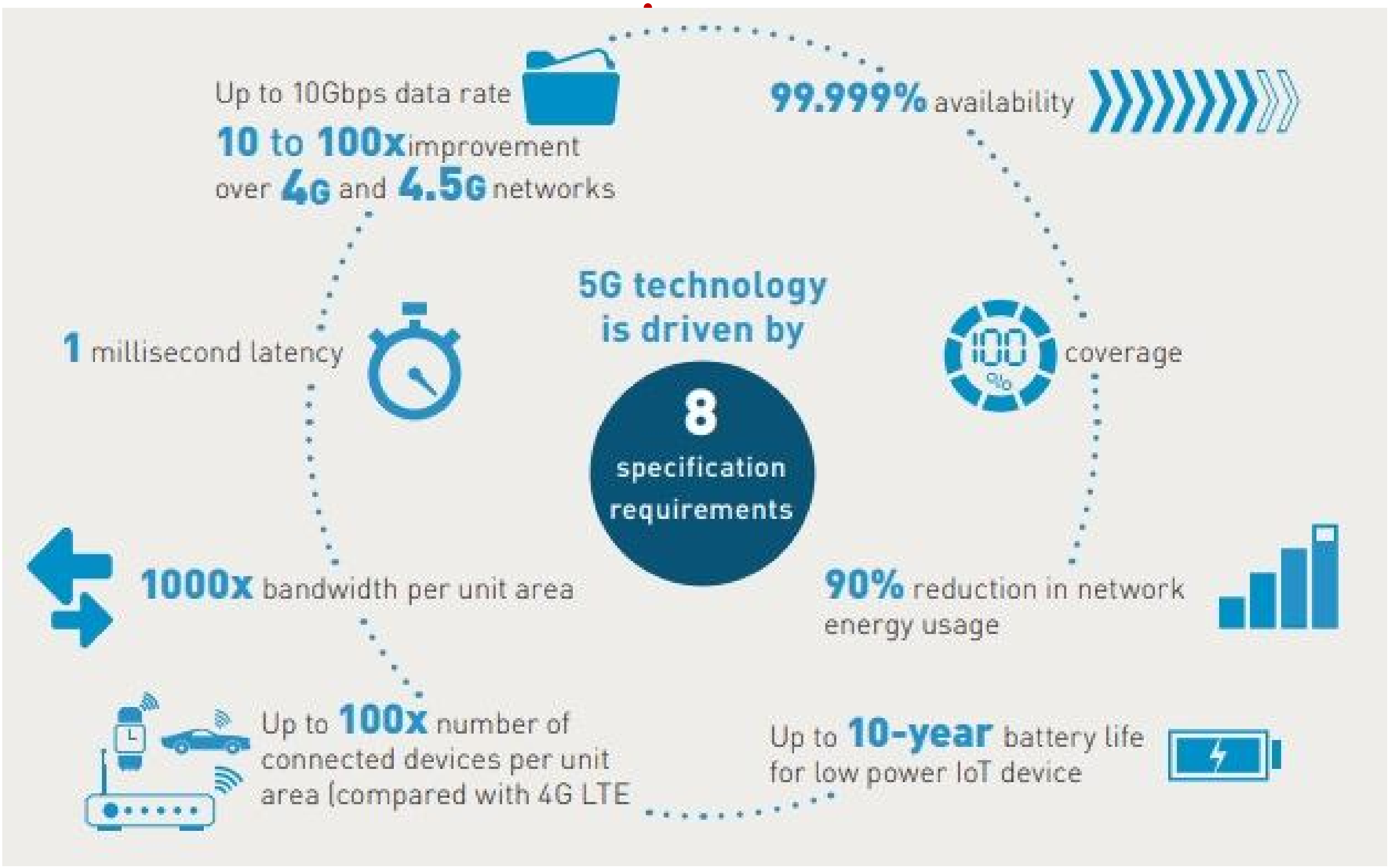
New services and use cases are envisioned for 5G and will likely be the driver for the technology.



The use cases, key design principles and vision of the 5G system lead to requirements that the future mobile broadband system will need
to meet.



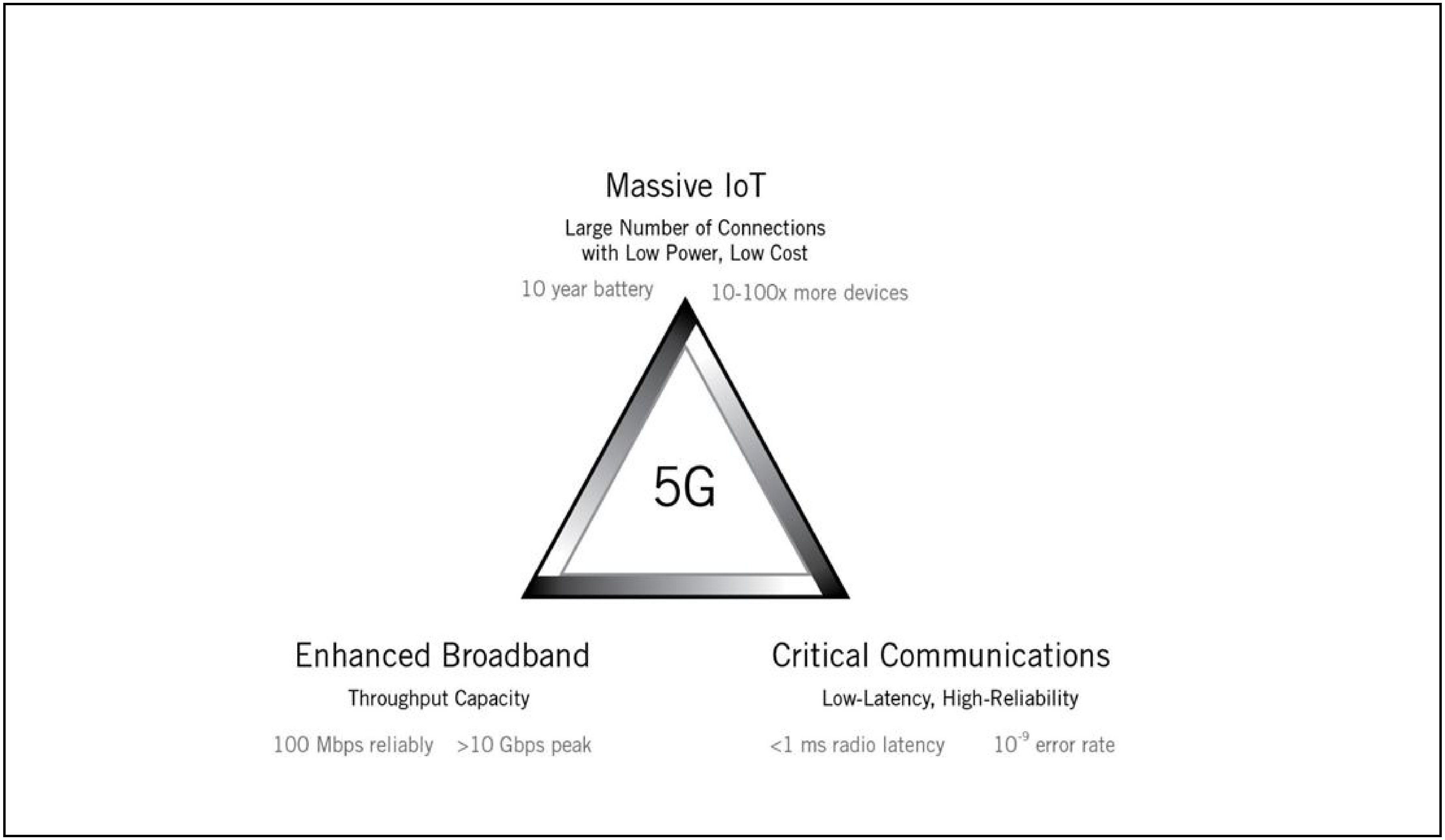
5G technology is driven by 8 specification



Current Challenges

While 4G was designed largely with mobile broadband in mind, 5G allows engineers to look at the horizon of new uses. Different use cases put different demands on the network, and impact different sectors of the economy. 5G must consider, for example, the various networking requirements of industrial automation, precision agriculture, and augmented reality. Where demands push up against the boundaries of what is currently possible with 4G networks, researchers start to consider leaps to whole new technologies instead of incremental additions to the LTE specification.

Development of 5G is driven by the fundamental challenges that existing networks face. The challenges can be roughly divided into whether they are primarily for human users or for machine users. Perhaps more helpfully, the uses cases that necessitate the development of 5G can be grouped under three general headings: enhanced mobile broadband; Internet of Things (IoT); and critical infrastructure or public safety.


Massive IoT
Large Number of Connections
with Low Power, Low Cost
10 year battery
10-100x more devices
5G
Enhanced Broadband
Throughput Capacity
100 Mbps reliably
>10 Gbps peak
Critical Communications
Low-Latency, High-Reliability
<1 ms radio latency
10^{-9} error rate

Main objectives for 5G are:

- 1,000 times higher mobile data volume per area,
- 10 to 100 times higher typical user data rate,
- 10 to 100 times higher number of connected devices,
- 10 times longer battery life for low-power devices,
- 5 times reduced end-to-end (E2E) latency, reaching a target of 5 ms for road safety applications.

Challenges to meet above requirements:

The key challenge is to meet these goals at a similar cost and energy consumption as today’s networks. From the point of view of 5G, a complete redesign of the Internet is discarded. Since the current Internet has become so large, the implementation of new architectura principles is impractical due to the commercial and operational difficulties it poses. Some concepts such as information-centric networking (ICN) are considered unrealistic, although some of its fundamentals, as the universal caching, have to be taken into account in order to efficiently distribute the traffic load in the network.

Deal with the Challenges

In this challenging task, has defined a set of five essential points to be consolidated into a single 5G system concept. These points are:

- direct device-to-device communications (D2D),
- massive machine communications (MMC),
- moving networks (MN),
- ultra dense networks (UDN), and
- ultra-reliable communications (URC)

Deal with the Challenges …….

To address these challenges, new flexible air interfaces, new possible waveforms, and new multiple access schemes, medium access control (MAC), and radio resource management (RRM) solutions and signaling protocols must be investigated to discard the idea that physical layer improvements are already close to their upper limit.

The key supporting enablers include:

- ***Dense and dynamic RAN*** providing a new generation of dynamic radio access networks (RANs). The term RAN 2.0 could be also used referring to this flexibility of the RAN.
- ***The spectrum toolbox*** contains a set of enablers (tools) to allow 5G systems to operate under different regulatory and spectrum sharing scenarios.
- ***Flexible air interface*** incorporating several radio interface technologies operating as a function of the user needs.
- ***Massive MIMO***, in which the number of transmit and receive antennas increase over an order of magnitude.
- ***New lean signaling/control information*** is necessary to guarantee latency and reliability, support spectrum flexibility, allow separation of data and control information, support large variety of devices with very different capabilities, and ensure energy efficiency.
- ***Localized contents/traffic flows*** allow offloading, aggregation, and distribution of real-time and cached content.

Basic (Key) Building blocks for 5G Networks Architecture

The fundamental building blocks for 5G Network Architecture are:

- ***Evolved mobile broadband (eMBB)*** will provide high data rates and low latency communications improving quality of experience (QoE) for the users
- ***Massive machine communications (MMC)*** will provide up- and down-scalable connectivity solutions for tens of billions of network-enabled devices, where scalable connectivity is vital to the future mobile and wireless communications systems.
- ***Vehicle to Vehicle, Device and Infrastructure (V2X) and driver assistance services*** require cooperation between vehicles and between vehicles and their environment in order to improve road safety and traffic efficiency in the future.
- ***Ultra-reliable communications (URC)*** will enable high degrees of availability. It is required to provide scalable and cost-efficient solutions for networks supporting services with extreme requirements on availability and reliability.

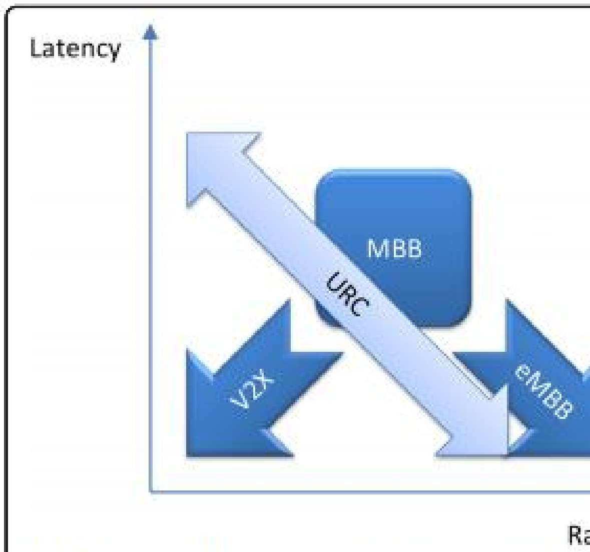


Figure 1 Extension of requirements as compared with curr MBB technologies.

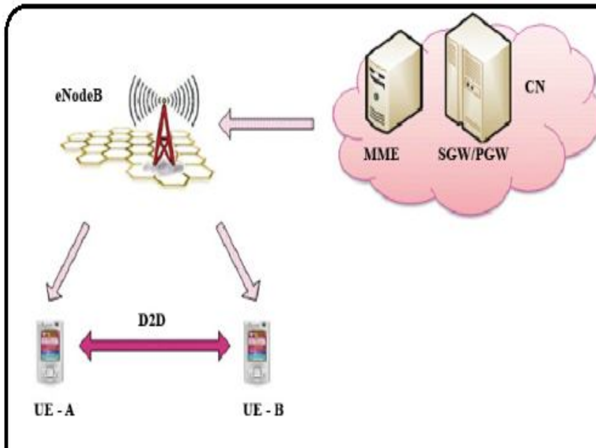


Figure D2D communication structure.

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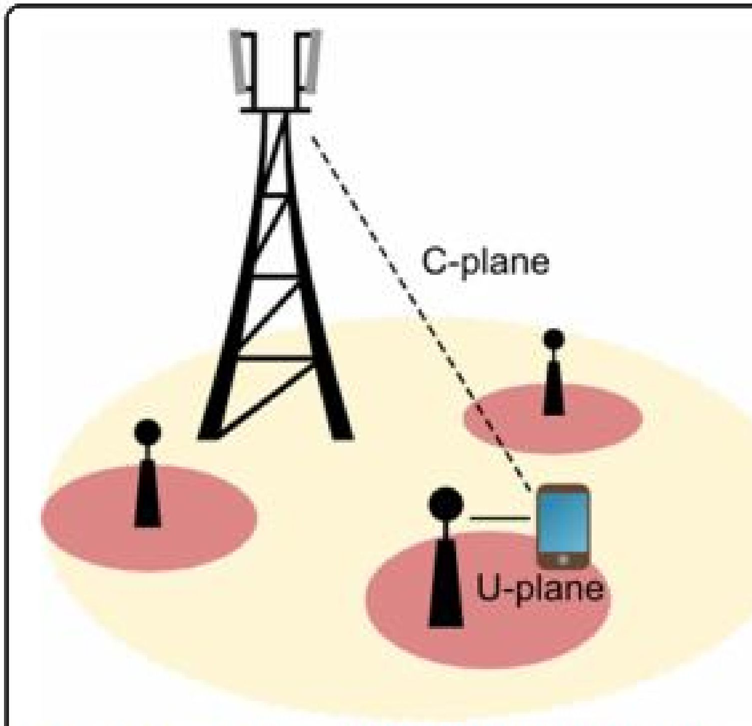
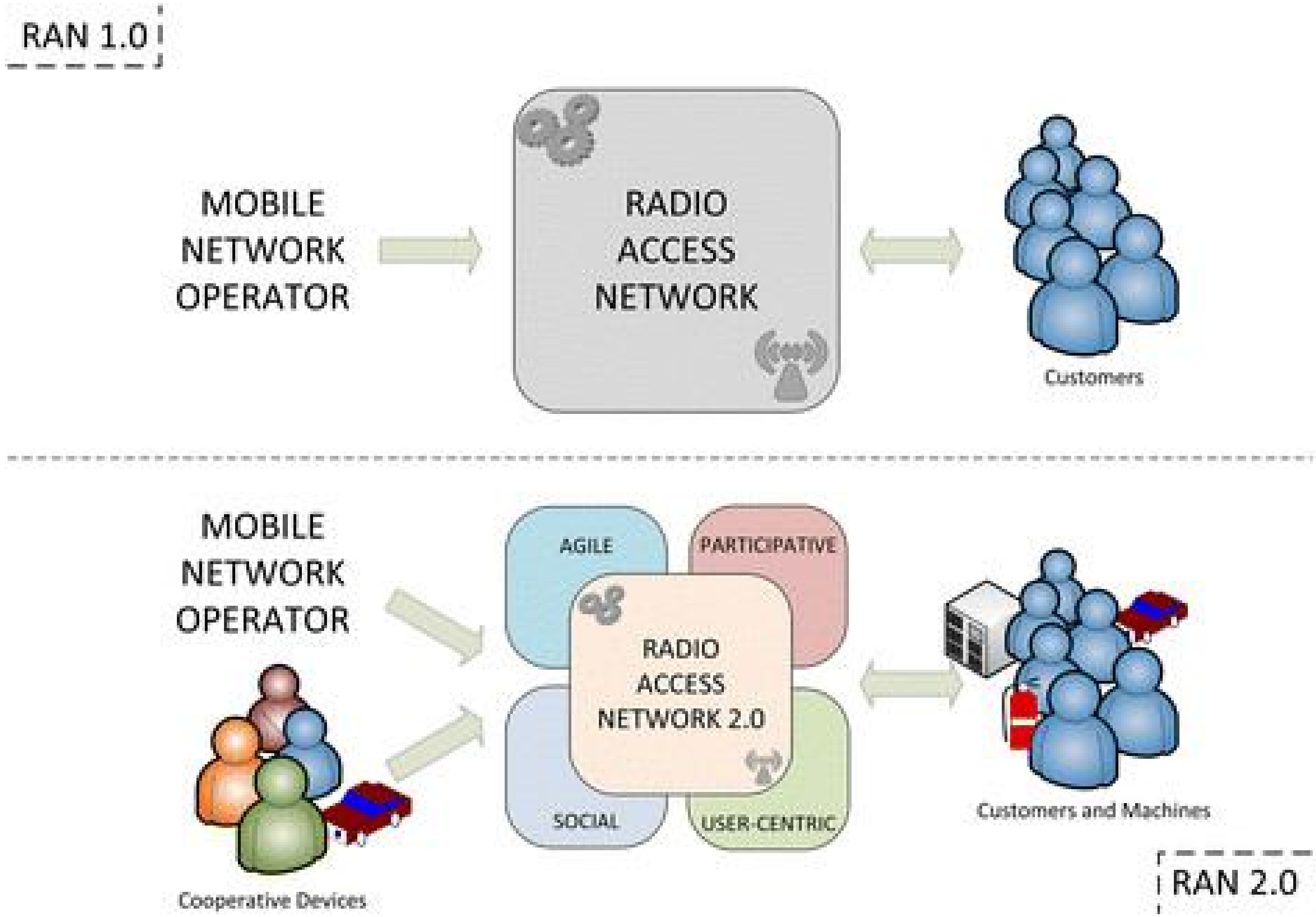
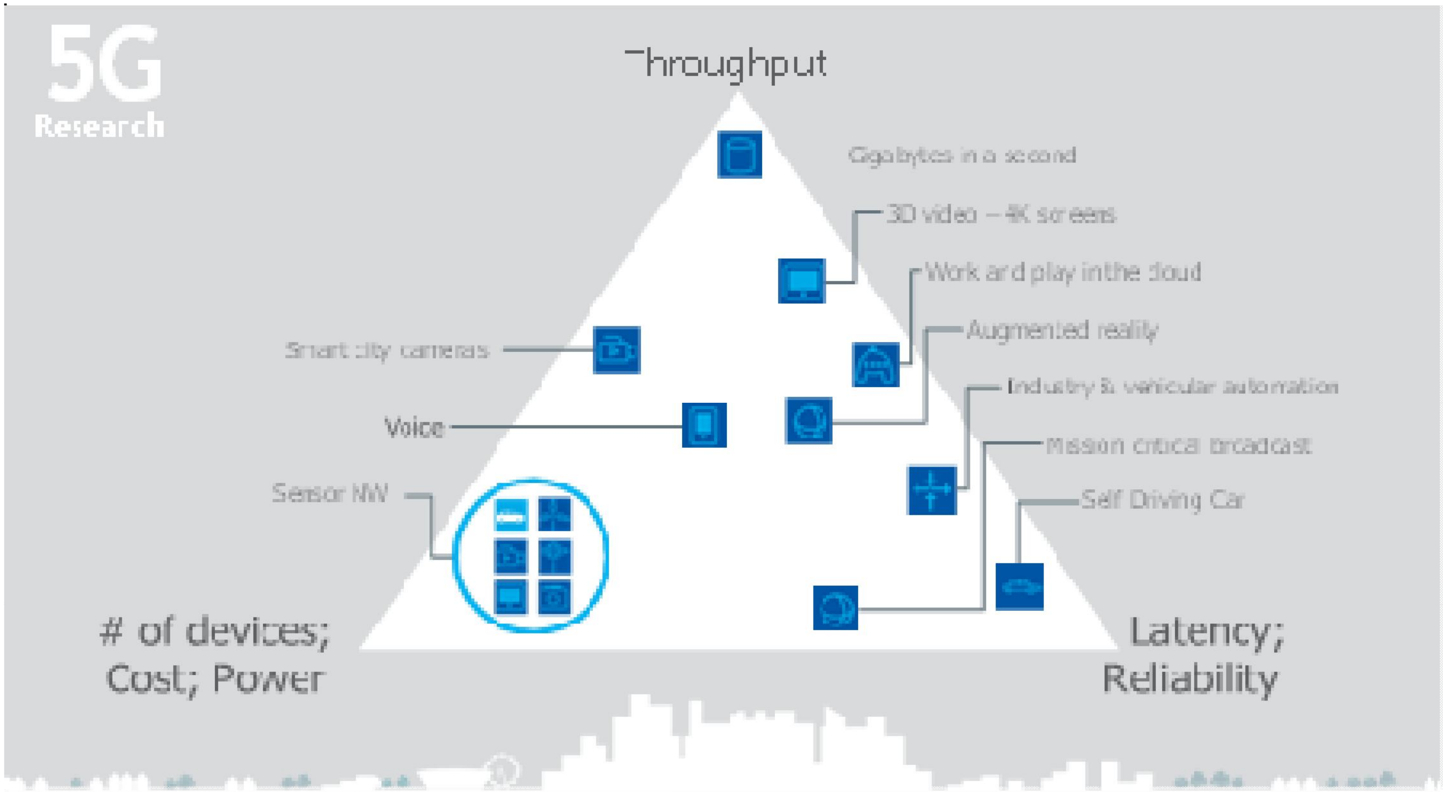


Figure 2 Decoupling of control and user plane in UDN.


RAN 1.0
MOBILE NETWORK OPERATOR
RADIO ACCESS NETWORK
Customers
MOBILE NETWORK OPERATOR
AGILE
PARTICIPATIVE
RADIO ACCESS NETWORK 2.0
SOCIAL
USER-CENTRIC
Cooperative Devices
Customers and Machines
RAN 2.0

There are three main requirement dimensions: Throughput/capacity, number of devices/low cost and latency/reliability. Some use cases may require multiple dimensions for optimization while others focus only on one key performance indicator (KPI).



Top 10 5G Use Cases

1. Autonomous Vehicles
2. 5G Drone Technology
3. Sports Broadcasting
4. Smart Cities & Infrastructure
5. Online-Streaming Quality
6. Improved Communication
7. Agriculture Technologies
8. Healthcare Sector
9. Improved Home Internet
10. Retail & Logistics

Mobile connectivity beyond 2020 : Every thing on wireless

: Extended and enriched wireless services

1. Mission critical services (Ultra reliable & low latency communication)

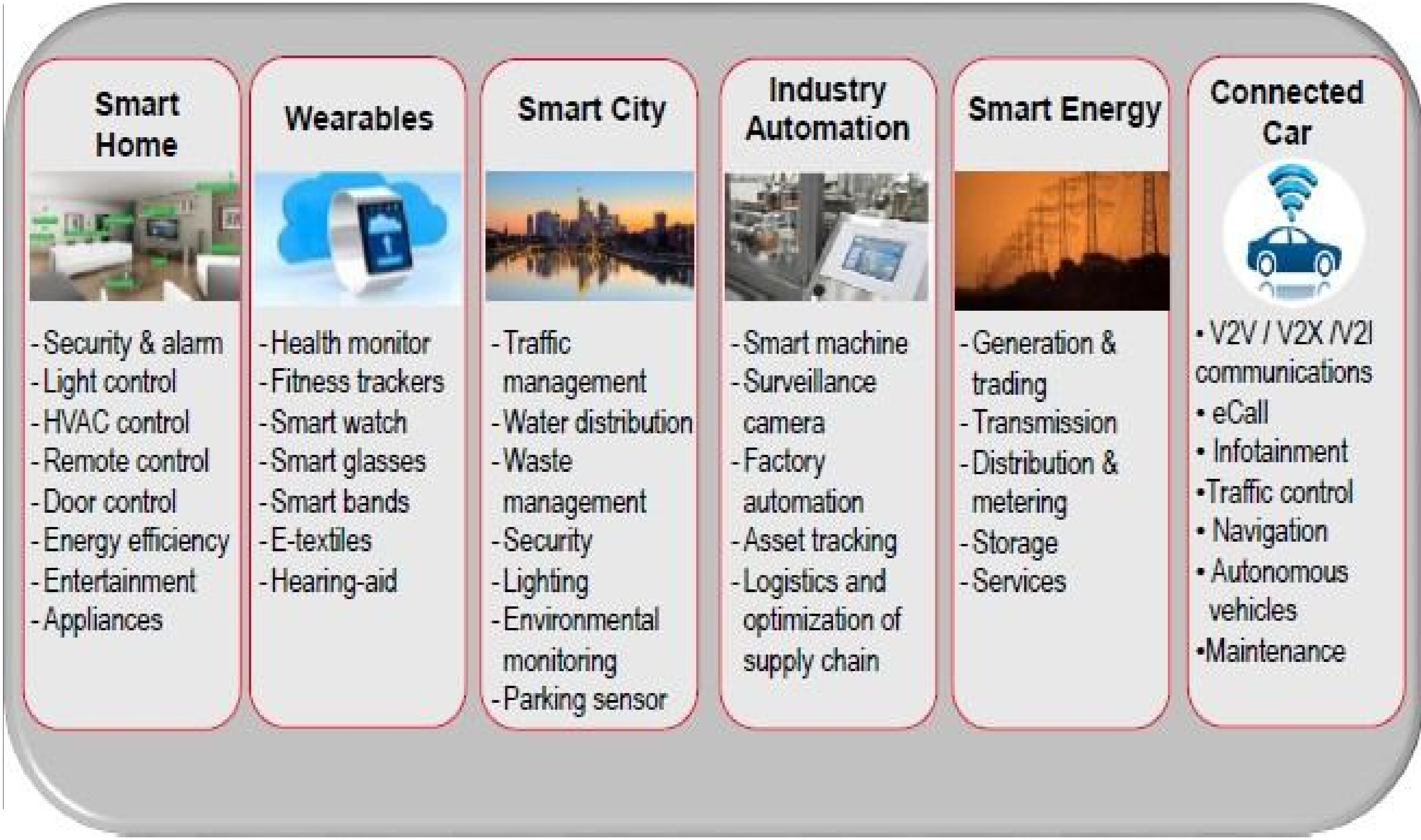
- Industrial Automation,
- e-health, hazardous environments, rescue missions, etc.
- Self-driving vehicles
- Drones
- Vehicular communication (V2V, V2I, V2P)

2. Massive Machine type communication / Massive IoT

- Smart home
- Smart city

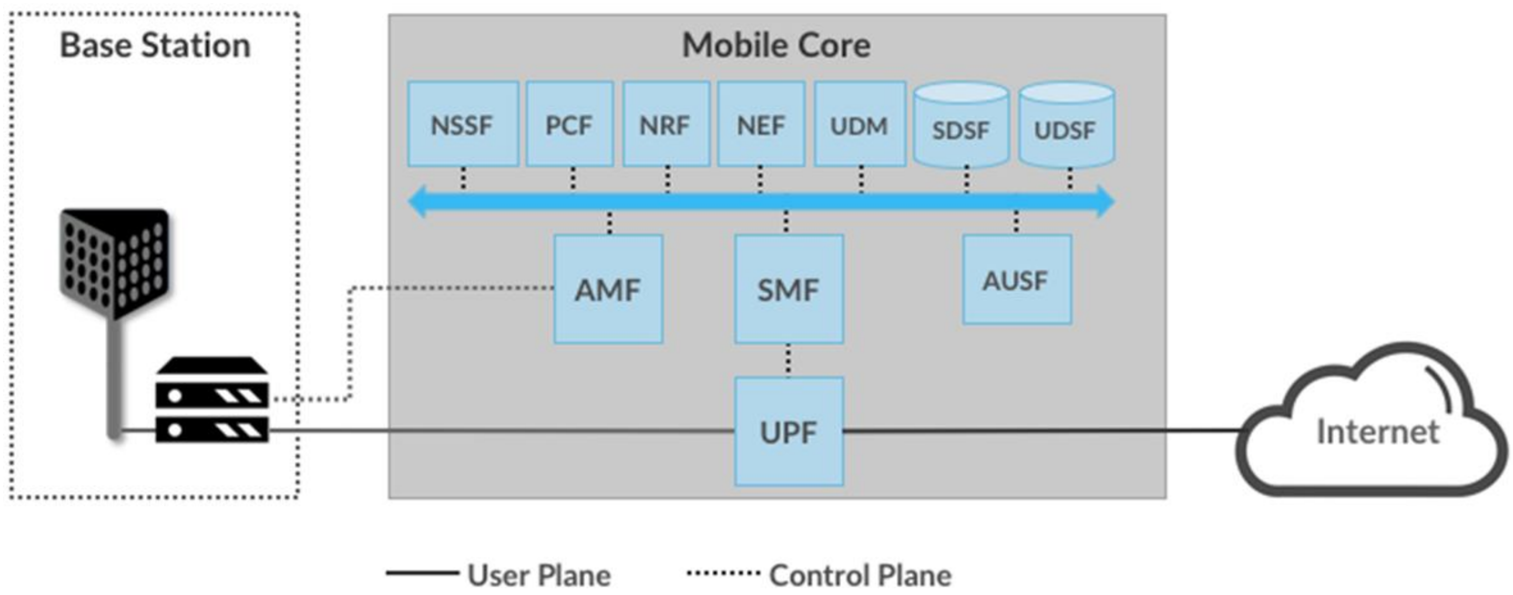
3. Enhanced Mobile broadband

- UHD video (4K, 8K) 3D video
- Virtual Reality (VR), Augmented Reality (AR),
- Tactile Internet, Cloud gaming, Broadband kiosks,
- Real time simulation & training
- Remote class room, Hologram



Smart Home
- Security & alarm
- Light control
- HVAC control
- Remote control
- Door control
- Energy efficiency
- Entertainment
- Appliances
Wearables
- Health monitor
- Fitness trackers
- Smart watch
- Smart glasses
- Smart bands
- E-textiles
- Hearing-aid
Smart City
- Traffic management
- Water distribution
- Waste management
- Security
- Lighting
- Environmental monitoring
- Parking sensor
Industry Automation
- Smart machine
- Surveillance camera
- Factory automation
- Asset tracking
- Logistics and optimization of supply chain
Smart Energy
- Generation & trading
- Transmission
- Distribution & metering
- Storage
- Services
Connected Car
• V2V / V2X /V2I communications
• eCall
• Infotainment
•Traffic control
• Navigation
• Autonomous vehicles
•Maintenance

. 5G Architecture



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- PCF (Policy Control Function): Manages the policy rules that other CP functions then enfor Roughly corresponds to the EPC’s PCRF.
- UDM (Unified Data Management): Manages user identity, including the generation of authentication credentials. Includes part of the functionality in the EPC’s HSS.
- AUSF (Authentication Server Function): Essentially an authentication server. Includes part functionality in the EPC’s HSS.

The second group also runs in the Control Plane (CP) but does not have a direct counterpar the EPC:

- SDSF (Structured Data Storage Network Function): A “helper” service used to store structu data. Could be implemented by an “SQL Database” in a microservices-based system.
- UDSF (Unstructured Data Storage Network Function): A “helper” service used to store unstructured data. Could be implemented by a “Key/Value Store” in a microservices-based system.

- NEF (Network Exposure Function): A means to expose select capabilities to third-party services, including translation between internal and external representations for data. Could be implemented by an “API Server” in a microservices-based system.
- NRF (NF Repository Function): A means to discover available services. Could be implemented by a “Discovery Service” in a microservices-based system.
- NSSF (Network Slicing Selector Function): A means to select a Network Slice to serve a given UE. Network slices are essentially a way to partition network resources in order to differentiate service given to different users. It is a key feature of 5G that we discuss in depth in a later chapter.

The third group includes the one component that runs in the User Plane (UP):

- UPF (User Plane Function): Forwards traffic between RAN and the Internet, corresponding to the S/PGW combination in EPC. In addition to packet forwarding, it is responsible for policy enforcement, lawful intercept, traffic usage reporting, and QoS policing.

Of these, the first and third groups are best viewed as a straightforward refactoring of 4G's EPC, while the second group—despite the gratuitous introduction of new terminology—is 3GPP's way of pointing to a cloud native solution as the desired end-state for the Mobile Core. Of particular note, introducing distinct storage services means that all the other services can be stateless, and hence, more readily scalable.

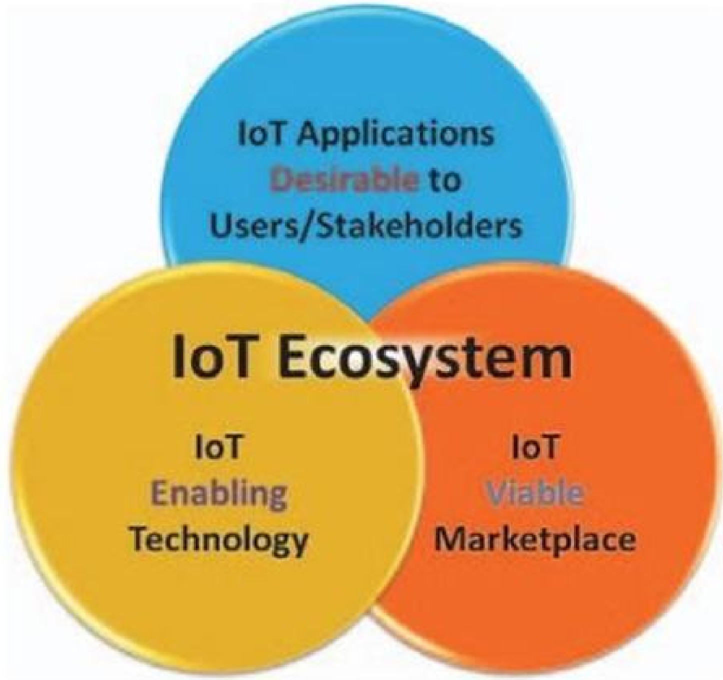
INTRODUCTION TO IoT

Today the Internet has become ubiquitous, has touched almost every corner of the globe, and is affecting human life in unimaginable ways.

We are now entering an era of even more pervasive connectivity where a very wide variety of appliances will be connected to the web.

One year after the past edition of the Cluster book 2012 it can be clearly stated that the Internet of Things (IoT) has reached many different players and gained further recognition. Out of the potential Internet of Things application areas, Smart Cities (and regions), Smart Car and mobility, Smart Home and assisted living, Smart Industries, Public safety, Energy & environmental protection, Agriculture and Tourism as part of a future IoT Ecosystem (Figure below) have acquired high attention.

IoT Ecosystem



We use these capabilities to query the state of the object and to change its state if possible.

- In common parlance, the Internet of Things refers to a new kind of world where almost all the devices and appliances that we use are connected to a network.
- We can use them collaboratively to achieve complex tasks that require a high degree of intelligence.
- For this intelligence and interconnection, IoT devices are equipped with embedded sensors, actuators, processors, and transceivers.
- IoT is not a single technology; rather it is an agglomeration of various technologies that work together in tandem.
- Sensors and actuators are devices, which help in interacting with the physical environment.

- The data collected by the sensors has to be stored and processed intelligently in order to derive useful inferences from it.
- Note that we broadly define the term *sensor*; a mobile phone or even a microwave oven can count as a sensor as long as it provides inputs about its current state (internal state + environment).
- An *actuator* is a device that is used to effect a change in the environment such as the temperature controller of an air conditioner.
- The storage and processing of data can be done on then edge of the network itself or in a remote server.

- The storage and processing capabilities of an IoT object are also restricted by the resources available, which are often very constrained due to limitations of size, energy, power, and computational capability.
- As a result the main research challenge is to ensure that we get the right kind of data at the desired level of accuracy.
- Along with the challenges of data collection, and handling, there are challenges in communication as well.
- The communication between IoT devices is mainly wireless because they are generally installed at geographically dispersed locations.
- The wireless channels often have high rates of distortion and are unreliable.
- In this scenario reliably communicating data without too many retransmissions is an important problem and thus communication technologies are integral to the study of IoT devices.
- We can directly modify the physical world through actuators or we may do something virtually. For example, we can send some information to other smart things.

- The process of effecting a change in the physical world is often dependent on its state at that point of time. This is called *context awareness*. Each action is taken keeping in consideration the context because an application can behave differently in different contexts.
- For example, a person may not like messages from his office to interrupt him when he is on vacation. Sensors, actuators, compute servers, and the communication network form the core infrastructure of an IoT framework. However, there are many software aspects that need to be considered.
- First, we need a middleware that can be used to connect and manage all of these heterogeneous components. We need a lot of standardization to connect many different devices.
- The Internet of Things finds various applications in health care, fitness, education, entertainment, social life, energy conservation, environment monitoring, home automation, and transport systems.

IOT NETWORKING CONSIDERATIONS AND CHALLENGES

When you consider which networking technologies to adopt within your IoT application, be mindful of the following constraints:

- Range
- Bandwidth
- Power usage
- Intermittent connectivity
- Interoperability
- Security

Role of IoT in 5G

- Direct Device-to-Device Communication
- Massive Machine Communication
- Networks in Motion
- Ultra Dense Networks
- Ultra Reliable Communication

Native support for machine-to-machine (M2M) communication

- Support of a massive number of low-data-rate devices, sustaining a minimal data rate in virtually all circumstances, and very-low-latency data transfer.
- Requires new methods and ideas at both the component and architectural levels.

Device to Device (D2D)

- D2D will play multiple roles in 5G and improve reliability, latency, throughput per area, spectralefficiency,
- Extending machine-type access
- Extended coverage in D2D
  - multi-hopping
  - network coding
  - cooperative diversity
- Low power uplink
  - Underlay operation in the same spectrum