Study and Design of 5G Network for Smart Water Meter IoT Applications

Capstone Project MINT 709

by

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Abstract

10 March 1876 is the historical day in telecommunication history when first successful practical telephone call had been made by Alexander Graham Bell. Since then, the concept of communication using a telephone has evolved and Motorola made first mobile phone in 1973. 1G or first-generation analog network evolved in 1979 in Japan, 2G or the second-generation digital cellular network based on GSM technology in 1991, 3G or third-generation of wireless mobile telecommunications technology based on UMTS and CDMA in 2001, 4G or fourth generation based on LTE standard in 2009.

Nowadays, with the new developments in mobile telephony, the use of mobile phone is not just limited to phone calls. Mobile phone has myriad of features which include camera, music, video and most importantly internet. With the increase in usage of the mobile phone the requirement of higher bandwidth of internet emerges and the next generation mobile communication technology comes in picture termed as 5G or fifth generation telecommunication technology.

With the increase in number of mobile connections and continuous growth of mobile data, the use of mobile will be different of what we are using today. 5G is the next generation network which gives higher data speed, ultra-low latency and extremely robust system and act as an enabler for IoT. Internet of Things is a network where different appliances, systems and machines are connected in a network and communicate without human interaction with the help of several sensors. 5G overcomes challenges of providing a low latency network that consumes less power and operates at higher frequencies (lower wavelengths) for a wide machine to machine network which were not provided by the 4G technology.

The main objective of this project is study and design 5G and its enabled IoT applications. We have studied smart water meter IoT application which uses NB IoT in detail and compared existing communication technologies such as LoRa with NB-IoT and discussed which one is best suitable for different IoT applications. At the end we discussed how NB-IoT will act as foundation for Massive IoT and what Massive IoT will bring to us. We have also discussed how we are moving towards 5G from current in market technologies such as LTE and NB-IoT.

Acknowledgment

In the first place, I want to thank God Almighty for giving me the strength, the knowledge, the ability and the opportunity to undertake and complete this project successfully. This would not have been possible without his blessings.

I'm delighted to thank my mentor **Mr. Juned Noonari**, who always supported and guided me and gave me valuable inspiration and suggestions in my search for knowledge. He gave me the freedom to study my project while still making sure that I stay on course and do not deviate from the core of my subject. This thesis would not have been possible without his knowing guidance.

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1. Introduction

1.1 Evolution of Wireless Technologies

The ability to communicate with people while moving has evolved remarkably since Guglielmo Marconi first showed radio ability to communicate with ships continuously. The wireless mobile has evolved over a very short period of time. Mobile cellular communications have generations as shown in the figure.

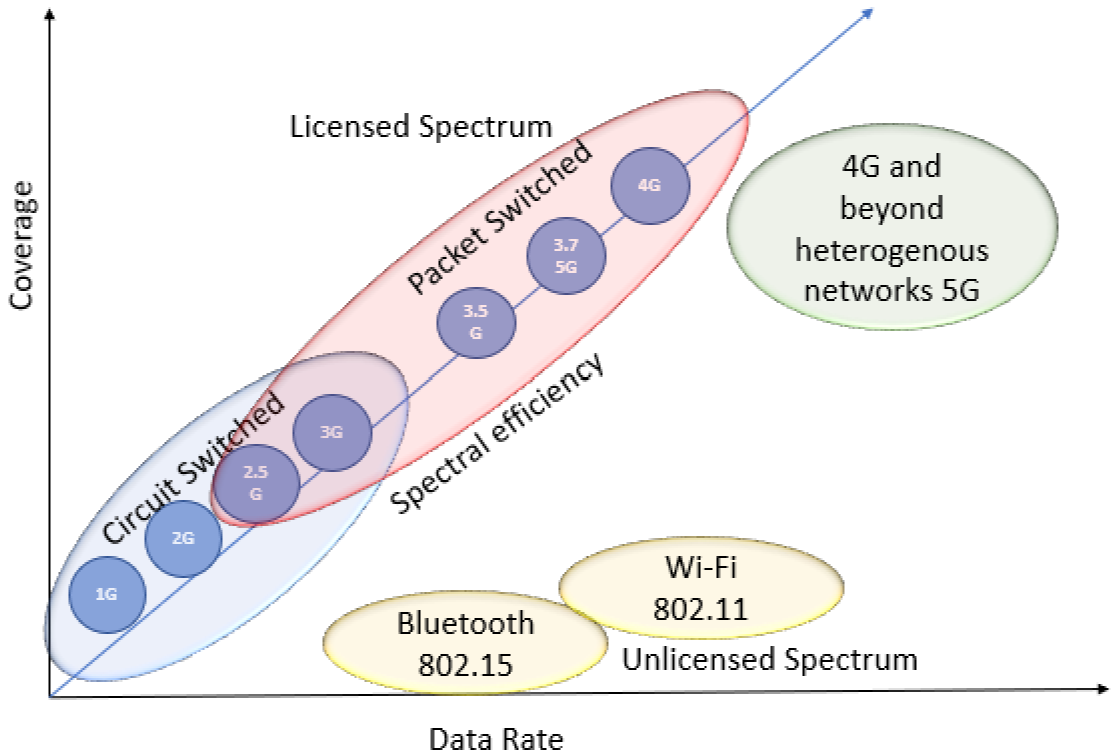


Figure 1: Evolution of wireless network.

Figure 1. shows the evolving generations of wireless technologies in terms of data rate, mobility, coverage and spectral efficiency.

With the growth of wireless technologies, data rate, mobility, coverage and spectral efficiency are increasing. It also shows that 1G and 2G technologies use circuit switching, while 2.5G and 3G use both circuit and packet switching, i.e. the next 3.5G generation. 5G are using packet switching technology. In addition to these factors, the licensed spectrum differs from the unlicensed spectrum. All developing generations use the licensed spectrum while the unlicensed spectrum is used by WiFi, Bluetooth and WiMAX.

1.1.1 1G AMPS/TACS/NMT

In the early 1980s, the first generation was announced. It's up to a data rate of 2.4kbps. Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT) and the Total Access Communication System (TACS) were the main subscribers. It has many disadvantages, such as below par capacity, reckless handoffs, inferior voice associations and no security, since voice calls have been stored and played in radio towers, which increases the vulnerability of these calls from unwanted eavesdropping by third parties.

1.1.2 2G Global Systems for Mobile communications (GSM)/CDMA

In late 1990s, the second generation was introduced. Digital technology is used in mobile phones of the second generation. Global Mobile Communications Systems (GSM) was the first system of the second generation, mainly used for voice communication with a data rate of up to 64 kbps. 2G mobile handset battery lasts longer due to low power radio signals. It also offers services such as short messaging (SMS) and email. GSM, Code Division Multiple Access (CDMA) and IS-95 were key technologies.

1.1.2.1 2G/GSM Architecture

The architecture of the GSM network comprises three main subsystems:

- Mobile Station (MS) – ME (Mobile Equipment) + SIM
- Base Station Subsystem (BSS)
- Network and Switching Subsystem (NSS)

The wireless interface between the MS and the Base Transceiver Station (BTS) is Um, which is part of the BSS system. The Base Station Controller (BSC) controls many BTSs. BSC is connected to the NSS via Mobile Switching Center (MSC).

Mobile Station: MS communicates through the air interface with a base station transceiver in the same cell in which the mobile equipment is located. The Mobile Equipment (ME) is the physical device, which consist of transceiver, digital signal processors, and the antenna. The second element of the MS in the GSM is the Subscriber Identity Module (SIM). The SIM card is completely unique to the GSM system.

Base Station Subsystem: A base station subsystem consists of a base station controller (BSC) and one or more base transceiver station (BTS). Each Base Transceiver Station defines a single cell.

- Base Station Controller: A Base Station Controller is connected with a BTS. It controls multiple BTS units and hence multiple cells inside those BTS's. A-bis interface connects a BTS to a BSC. The interface between the BSC and the MSC is called the A interface, which is standardized within GSM.

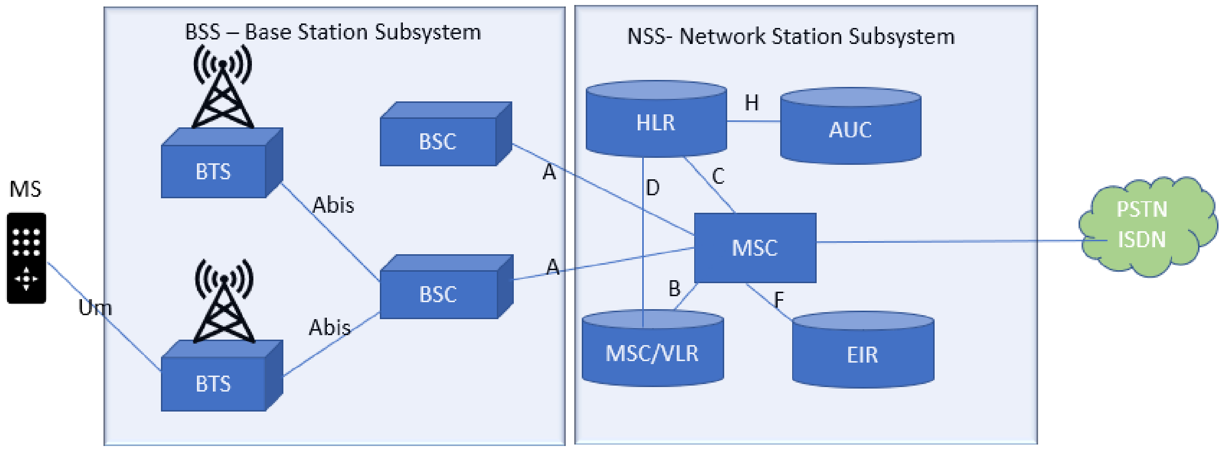


Figure 2: 2G Network Architecture Model

Network and switching subsystem (NSS): NSS support network operation part. It connects cellular network and the Public switched telecommunication Networks (PSTN or ISDN or Data Networks). The NSS controls handoffs between cells in different BSSs, authenticates the user and validates their accounts. It has many functions such as enabling worldwide roaming of mobile subscribers. In particular the switching subsystem consists of:

- **Mobile Switching Center (MSC):** MSC performs the telephony switching functions for the network and controls calls to and from other telephone, data communications networks, Public Switched Telephone Networks (PSTN), Integrated Services Digital Networks (ISDN), Public Land Mobile Networks (PLMN) and Public Data Networks (PDN).
- **Visitor Location Register (VLR):** VLR is a database that contains all temporary subscriber information needed by the MSC to serve visiting subscribers who are temporarily in the area of the MSC.
- **Home Location Register (HLR):** This database stores and manages user subscriptions. It contains all permanent subscriber information including their service profile, location information and activity status.
- **Authentication Center (AUC):** The AuC is used for authentication and encryptions of the mobile subscribers that verify the mobile user’s identity and ensure the confidentiality of each call. The AuC has the authentication and encryption keys for all the subscribers in both the home and visitor location register.
- **Equipment Identity Register (EIR):** The EIR is a database that stores the information about the identity of mobile equipment for example: International Mobile Equipment Identity (IMEI) that reveals the details about the manufacturer, country of production, and device type. This information is used to prevent calls from being misused, to prevent unauthorized MSs, to report stolen mobile phones.

1.1.2.2 Advantages

- 2G cellphones were smaller than 1G. Since, they emitted less radio power
- The battery life of 2G handset lasts longer due to low power radio signals
- 2G also offered additional service such as email and SMS
- Handsets are safer to use because of lower power emission
- Improved Privacy

1.1.2.3 Disadvantages

- GSM does not support high data rate
- Inefficient usage of bandwidth and resources
- Unable to handle complex data
- Reduce range of sound
- Weaker digital signal

1.1.3 2.5G General Packet Radio Services (GPRS)

It is described as a 2nd generation cellular system merged with General Packet Radio Services (GPRS). A 2.5G system generally uses 2G system frameworks, but it applies packet switching along with circuit switching. It can assist data rate up to 144kbps.

1.1.4 2.75G (EDGE)

GSM network evolved to EDGE (Enhanced Data Rates for GSM Evolution) network when 8PSK encoding is introduced. While the symbol rate stayed same at 270.833 samples per second, each symbol rate carries 3 bits instead of one. Hence, EDGE is significantly faster with a download speed of up to 384Kbps

1.1.5 3G WCDMA/UMTS

The 3rd generation was established in late 2000. It provides the ability to transfer voice and data over the same network simultaneously. It imparts transmission rate up to 2Mbps. Third generation (3G) systems clubs high speed mobile access to services based on Internet Protocol (IP). Apart from transmission rate, unconventional improvement of maintaining QoS, additional amenities like global roaming and improved voice quality made 3G as a remarkable generation. It provides broadband capacity, supports huge number of voice and data customers. 3G uses Circuit switching for voice and Packet switching for Data Communication.

Maximum data transfer rates supported by 3G:

- 2.05 Mbps for stationary devices.

- 384 Kbps for slow-moving devices.
- 128 Kbps for high speed devices.

The main drawback for 3G devices is that they need more power than most 2 G models. This 3G network is more expensive than 2G. Since 3G involves the introduction and use of the Multiple Access (WCDMA) Wideband Code Division, Universal Mobile Telecommunications Systems (UMTS) and Multiple Access (CDMA) 2000 technology, the evolving technologies such as High Speed Uplink/Downlink Packet Access (HSUPA/HSDPA) and Evolution-Data Optimized (EVDO) come up with an intermediate wireless generation between 3G and 4G named as 3.5G with improved data rate of 5-30 Mbps.

1.1.5.1 3G/UMTS Architecture

3G network consists of Mobile station, Core and RAN network (UTRA).

Mobile Station: It is a data and voice-enabled mobile phones, tabs or computers which could be used as an end user.

RAN (Radio Access Network): It consists of base stations **(NodeB)** and radio network controller (RNC's) which bridges the gap between Mobile Station and Core Network. In addendum, it controls and manages the air interface for the whole network.

CN (Core Network): It processes and manages the subsystems. The 3G UMTS network Architecture is migrated from GSM with some enhancements in core network elements such as voice and data are separated with circuit switched and packet switched domain respectively.

Circuit Switched Domain: It uses a circuit switched network which provides a dedicated link or channel for a specific time slot for a set of users. It's made of

- MSC – Mobile Switching Centre that manages circuit switched calls.
- GMSC – Gateway MSC acts as a gateway between external and internal networks.

Packet-switched domain: It uses the IP network in which IPs transmit and receive data between two or more devices.

- SGSN (Serving GPRS Support Node): SGSN handles mobility management, session management, billing, communication with other areas of the network.
- GGSN (Gateway GPRS Support Node): It handles the internal operations between the external packet switched networks and UMTS packet switched network.

IMS (IP Multimedia Subsystem): it is an architectural framework that provides IP multimedia services

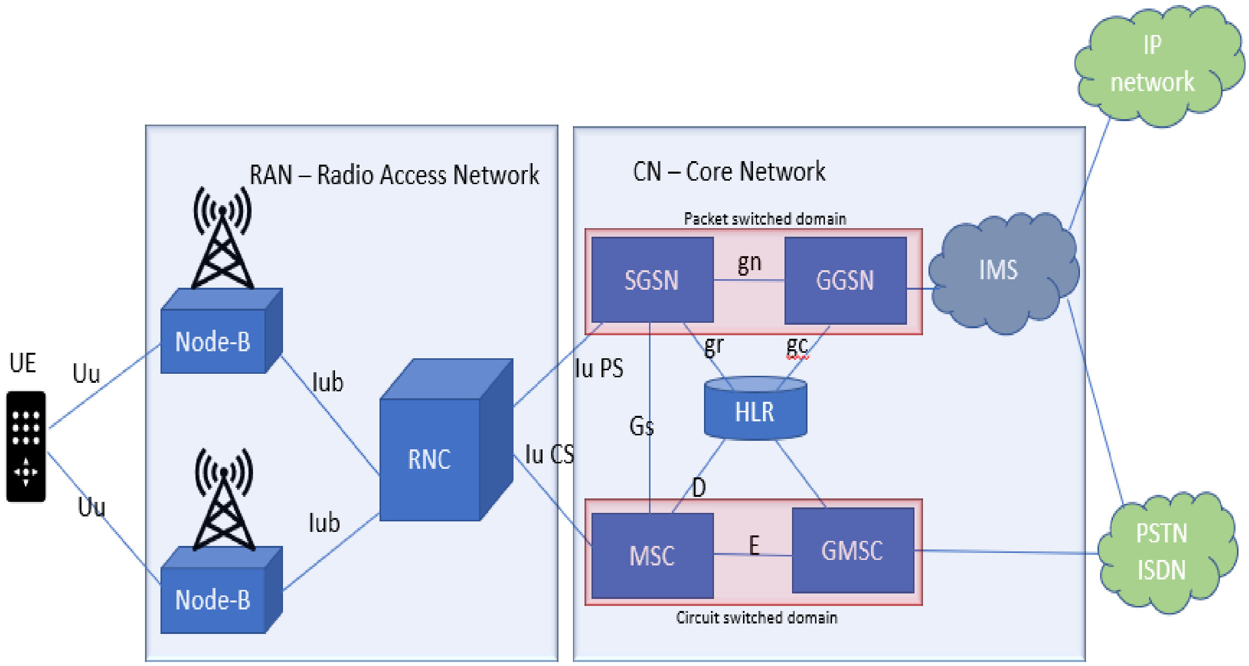


Figure 3: 3G Network Architecture Model

1.1.5.2 Advantages

- Adaptive antenna arrays are implemented to the 3G base station and with the help of these we can adaptively adjust the power, lower the system self-interference and enhance receiver sensitivity and increase the system capacity
- Downlink transmission increased with the help of closed loop power control technology.
- It supports multimedia applications such as video and photography.
- It supports Value-added services like mobile television, GPS, video call and video conference.
- High speed mobile internet access.
- Faster Data rate and increased capacity.

1.1.5.3 Disadvantages

- 3G compatible handsets required.
- The 3G device upgrade cost is expensive.
- High power consumption.
- 3G requires more expensive, closer base stations.

1.1.6 3.75G LTE/WiMAX

The future of mobile data services is Long-Term Evolution Technology (LTE) and Fixed Worldwide Interoperability for Microwave Access (WiMAX). LTE and Fixed WiMAX have the potential to complement the network capacity and provide a large number of users with access to a wide range of high-speed services, such as video on demand, peer-to-peer file sharing and composite web services. In addition, an additional spectrum is accessible that accredit operators manage their network very efficiently and offer better coverage with improved performance at lower costs.

1.1.7 4G LTE Advanced

4G is usually referred to as the 3G and 2G standards descendant. It offers features such as scalability, flexibility, efficiency, self-governance, security to support interfacing with different types of networks and a multitude of new and existing services.

It offers completely converged customized services such as voice, data and multimedia at data rates of up to 100 Mbps for:

- High-resolution mobile television
- IP telephony
- Gaming services
- Video conferencing
- 3D television

4G LTE 's main objective was to achieve high mobility and worldwide connectivity.

The IP Core Network is further developed to provide more efficient support for high data rates, advanced application services and IP and radio management.

The 3G’s spread spectrum radio technology was replaced by:

- OFDMA (Orthogonal Frequency Division Multiple Access) for multi-carrier transmission.
- FDE (Frequency-Domain Equalization).

As a result, it transfers very high bit rates without being affected by multipath radio propagation.

For MIMO (Multiple-Input Multiple-Output) communications, peak bit rate is enhanced further with the help of smart antenna arrays. Higher order modulation up to 64 QAM and MBMS (Multimedia Broadcast Multicast services) is used for broadcasting.

1.1.7.1 4G Network Architecture

4G consists of UE, E-UTRAN and EPC.

User Equipment (UE): Any device capable of establishing communication functions such as mobile phones, tabs, computers, etc.

Evolved UMTS Terrestrial Radio Access Network (E-UTRAN): It controls radio communication between user equipment and Core network (EPC). LTE mobile can connect with just one cell and with more cells in one base station at a time.

eNodeB: LTE UE is connected to eNodeB and the main operations performed by EBS (Evolved Base Station) which is also known as **eNodeB:**

- Analog and digital processing of LTE air interface
- Transmit and receive of radio transmission to all the LTE-enabled devices.
- Handles signaling messages and commands as low level operation.

Evolved Packet Core (EPC): It connects and communicates with internal and external packet data networks and IP multimedia subsystem (IMS). It comprises of following blocks:

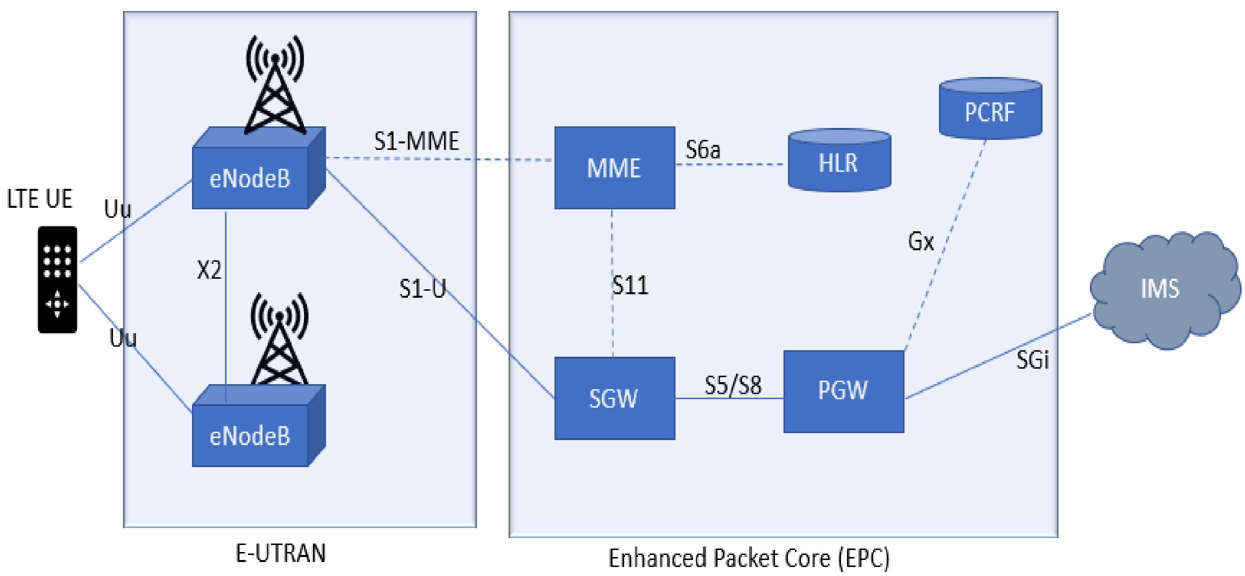


Figure 4: 4G Network Architecture Model

- **HSS:** Home Subscriber Server stores all the information about all the network operator’s subscribers in a central database.
- **MME:** The Evolved Packet Core (EPC) is the main component of the SAE architecture. In the LTE EPC architecture, Mobility Management Entity (MME) plays a major role. Actually, MME is the EPC 's main signaling node. LTE MME initiates the paging and

authentication of the mobile device. MME keeps location information for each user at the level of the tracking area and during the initial registration process, select the appropriate gateway. MME connects to the node b (eNB) via the S1-MME interface and connects via the S11 interface to the S-GW. In a pool, multiple MMEs can be grouped to meet the increased signaling load in the network. MME also plays an important role in the transmission of signals between LTE and the 2G/3G network.

Main functions of MME are:

- Network access control
- Radio resource management
- Mobility management
- UE- Reachability
- Roaming management
- Tracking area management
- Lawful Intercept
- Load balancing of the SGW's

- **S-GW:** Serving GW is the gateway that terminates the E-UTARN interface. For each EU associated with the EPS, there is a single Serving GW at a given time. SGW is responsible for transferring data to neighboring eNodeB, including data transfers in all packets throughout the user plane. Its tasks include taking care of the mobile interface for other networks like 2G/3G.

  Main Functions of S-GW are:

  - Lawful Intercept
  - Packet routing and forwarding
  - Marking of transport level packet in both uplink and downlink
  - Accounting for inter-operator charging
  - Anchor point for inter eNodeB handover
  - Mobility anchoring for inter 3GPP mobility

- **P-GW:** The PGW is the gateway that ends the SGi to PDN interface. If UE accesses multiple PDNs, there may be more than one PGW for that UE, but a mix of S5/S8 connectivity and Gn / Gp connectivity is not supported for that UE simultaneously. PGW is responsible for acting as a mobility anchor between 3GPP and non-3GPP. PGW supplies EU connectivity to external PDN being the UE's entry or exit point of traffic. The PGW manages policy enforcement, user package filtration, charging and LI support.

  PGW Functions includes:

  - User-based packet filtering
  - Lawful interception
  - UE IP address allocation

- Inter-operator charging
- Packet screening

- **PCRF:** The Policy and Charging Rule Function is responsible for controlling flow-based charging in the Policy Control Enforcement Function (PCEF) and policy control decision-making.

1.1.7.2 Advantages

- Reduced delays in connection and latency of transmission.
- Higher user Data Throughput.
- Higher cell edge bit rate.
- Enhanced spectral efficiency.
- Simplified network architecture.
- Seamless mobility between various radio access technologies.
- Mobile device reasonable power consumption.

1.1.7.3 Disadvantages

- Limited voice calls and services can be handled a time.
- Location coordination and resource coordination to add new devices is not adequate.
- It requires a wide bandwidth as a concentrated data service.

2. 5G network

With the exponential increase in user demand, 4G is easily replaced by 5G. It will also make room for the thousands of Internet devices that enter our daily world. 5G is the fifth mobile cellular communications generation. 5G performance targets high data rate, lower latency, energy saving, lower cost, higher system capacity and high device connectivity. It uses advanced and improved data coding / modulation technology. It provides a full mobility of about 100 Mbps and 1 Gbps with low mobility. It uses intelligent antenna techniques to increase data rates and coverage. These features are expected to allow many new use cases which cannot be performed using older network standards.

5G enabled mobile phones to be used with a greater bandwidth. It uses CDMA, Beam Division Multiple Access (BDMA), Filter Bank Multiple Access (FBMC) and Millimeter Wave (Wireless Backhaul). In this communication, an orthogonal beam is assigned to each mobile station and the BDMA technique divides the antenna beam into mobile station locations for multiple access to the mobile stations, thus increasing the capacity of the system.

2.1 5G vs 4G

In late 2000s, the fourth generation of mobile connectivity began to create waves. 4G made mobile internet speeds up to 500 times faster than 3G and allowed support for HD TV on mobile, high-quality video calls and fast mobile browsing. The development of 4G was a major feature for mobile technology, in particular for smartphones and tables.

4G is now common worldwide, but things are changing again. The Internet of Things is now a real possibility, and 4G will not be able to manage the huge number of connections on the network.

It is anticipated that by 2020 there will be more than 20 billion connected devices, all of which require a high capacity connection. 5G comes into force here.

An idea to move to 5G is based on current drifts, it is commonly assumed that 5G cellular networks have to deal with six challenges that 4G does not address effectively. Higher capacity, higher data rate, lower latency, end to end massive connectivity of the device, reduced costs and consistent quality of service provisioning. The table below compares 4G vs 5G technologies and mentions the difference between 4G and 5G.

The table below compares 4G vs 5G technologies and mentions the difference between 4G and 5G.

Specifications	**4G**	**5G**
Peak Data Rate	1Gbps	10 Gbps
Data Bandwidth	200 Mbps to 1Gbps	1Gbps and higher as per need

Spectral Efficiency	30 b/s/Hz	120 b/s/Hz
TTI (Transmission Time Interval)	1 ms	Varying (100 µs (min.) to 4ms (max.)
Latency	10 ms (radio)	<1 ms (radio)
Mobility	350 Kmph	500 Kmph
Frequency Band	2 to 8 GHz	3 to 300 GHz
Multiple Access	CDMA	CDMA, BDMA, FBMC
Technologies	Unified IP, seamless integration of broadband LAN/WAN/PAN and WLAN	Unified IP, seamless integration of broadband LAN/WAN/PAN/WLAN and advanced technologies based on OFDM
Core network	All IP network	Flatter IP network, 5G network interfacing(5G-NI)
Handoff	Horizontal and vertical	Horizontal and vertical

2.2 Usage Scenarios

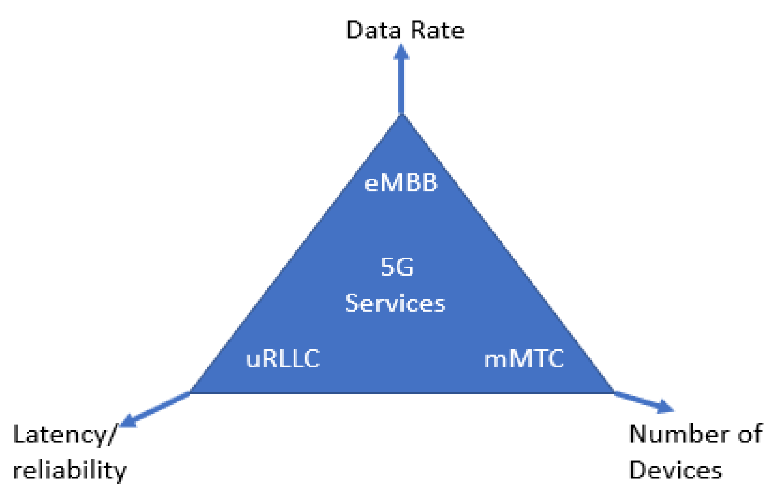


Figure 5: 5G generic services

Enhanced Mobile Broadband (eMBB): The volume of mobile data traffic has increased due to the increase in the number of smartphones and other data-consuming devices combined with enhanced multimedia applications. By 2020, the network delivery capacity must be increased to 100-1000 times as data traffic increases. 5G will enhance performance and provide a more seamless user experience with multimedia content for human-centric communications.

Massive machine-type communications (mMTC): In the next few years, the interest in machine-to-machine communication and the Internet of Things (IOT) will increase. Wireless networks connect and manage thousands of objects every day. The main challenge for the 5G network is therefore to integrate traffic in human and machine types. 5G will provide improved network coverage, long device operational lifetime and a high density of connections. This is also known as MIoT (Massive IoT), Mobile IoT, LPWA (Low power wide area)

Ultra- reliable and low- latency communications (uRLLC)/ Critical IoT: In the 5G system, performance metrics such as peak rate, coverage, spectral efficiency and latency are enhanced to provide improved service quality (QoS). 5G Will provide high performance, ultra-reliable, low latency industrial IoT and mission-critical applications.

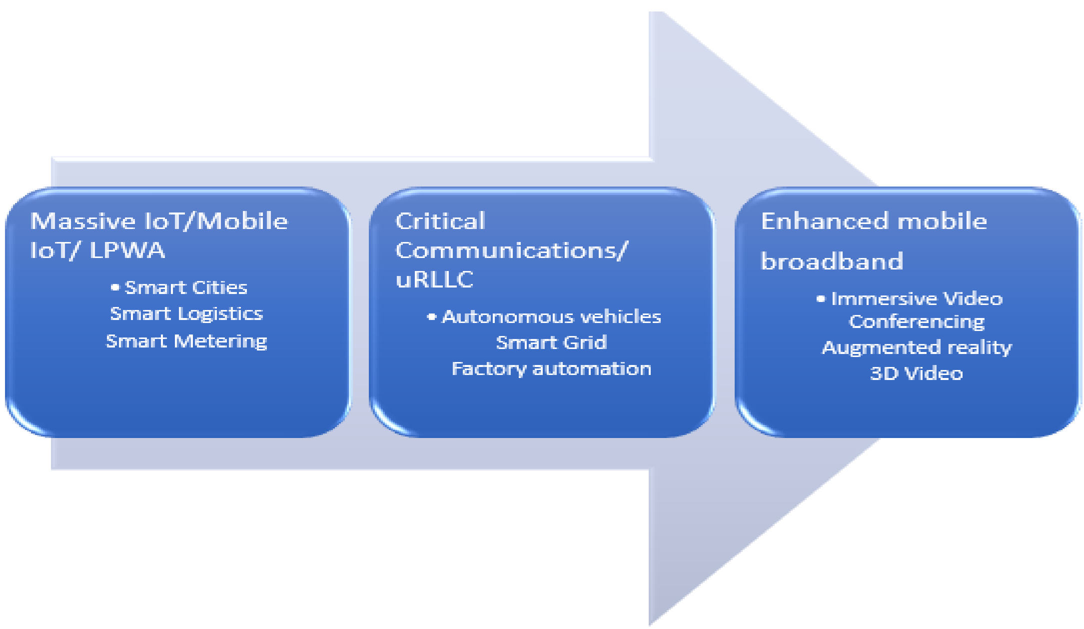


Figure 6: 5G usage scenarios

2.3 5G Key Capabilities

The following eight parameters are key capabilities for IMT-2020 5G:

Capability	Description	5G target	Usage scenario
Peak data rate	Maximum achievable data rate	20 Gbit/s	eMBB
User experienced data rate	Achievable data rate across coverage area	1 Gbit/s	eMBB
Latency	Radio network contribution to packet travel time	1 ms	URLLC
Mobility	Maximum speed for handoff and QoS requirements	500 km/h	eMBB/URLLC
Connection density	Total number of devices per unit area	10^6/km^2	MMTC
Energy efficiency	Data sent/received per unit energy consumption (by device or network)	Equal to 4G	eMBB
Spectrum efficiency	Throughput per unit wireless bandwidth and per network cell	3–4x 4G	eMBB
Area traffic capacity	Total traffic across coverage area	1000 (Mbit/s)/m^2	eMBB

Figure 7: 5G key capabilities. *(Ref: https://en.wikipedia.org/wiki/5G)*

2.4 The driving force behind network architectural transformation

The current network architecture was designed to meet requirements for voice and conventional mobile broadband services which is not capable to support 5G diverse services due to various factors such as multiple 3GPP upgrades, a large number of network elements (NE's) and complex interfaces.

- **Complex network that incorporate multiple services, standard and site types**
  The 5G network should be able to support the coexistence of multiple standards such as LTE, Wi-Fi and various site types (Nano, micro, macro, Pico base stations).

- **Coordination of multi-connectivity technologies**
  5G needs to coexist with LTE and Wi-Fi by incorporating multi-connectivity technologies and a new 5G air interface for an extended period of time. Multi-connectivity technologies should be coordinated based on the requirements of UE traffic and mobility to provide sufficient throughput and continuity.

- **On-demand deployment of service anchors**
  The architecture of the 5G network will be based on the access sites and three-layer data centers (DC). Based on the various requirements, the availability of fiber optic cables and network resources, real-time and non-real-time network resources can be deployed on the website or on the cloud access site. This also requires that the service gateway be deployed on the core website or on the cloud access site.

- **Flexible orchestration of network functions**
  Various network functions have various service requirements. URLLC requires a high scheduling throughput, low latency and high reliability. Network must be flexibly organized to simplify network functions and increase network efficiency.

- **Shorter period of service deployment**
  The rapid deployment of new services requires new and improved processes for network design, service deployment and O&M.

2.5 Moving to 5G and its challenges

Only the evolution of current networks is not sufficient to meet the demanding requirements, but both the radio access network and the core network need to be revolutionized. 5G has certain requirements and challenges that use a variety of technologies to be met and solved.

The challenges faced by the 5G are

- Increased Capacity
- High data rate
- Low latency
- Huge number of connections
- Low cost
- Quality of service

In order to meet these requirements or, in other words, to solve these challenges, certain technologies were used to enable the 5G. These are the following technologies:

A wireless software-defined network (SDN), network function virtualization (NFV), millimeter wave spectrum, massive MIMO (multiple input multiple output), ultra-densification, big data and mobile cloud computing, scalable Internet of Things (IoT), device-to-device connectivity with high mobility (D2D), green communications, and new radio access techniques.

The 5G is expected to meet certain requirements in order to serve the different types of equipment and applications. Each of these requirements is discussed below:

2.5.1 High Data Rate

With the enormous increase in applications requiring fast Internet communication, the need for high data rates is rapidly increasing. The achievement of high data rates in the wireless networks is one of the most important factors in the evaluation of performance. LTE has provided a data rate of up to 15 Mbps, however, new applications such as ultra-HD video streaming require higher data rates (up to 25 Mbps) than the data available. The data rate depends on two main network metrics, the cellular data rate and the area capacity.

The data rate at the cell edge indicates where the connection is weak. In order to achieve a high data rate for the entire system, the cell-edge data rate should be improved. In addition, if a user is close to the cell edge of a network, the interference is high and the signal is weak. On the other hand, when a user is near the center of the cell, the interference is low, leading to a strong signal. The goal is to improve the cell edge data rate to improve the user experience. One of the most efficient ways of doing this is by using small cells. The use of small cells enhances the coverage and capacity of cellular networks.

The second metric affecting the area capacity is the data rate. The area capacity indicates the total data rate per unit area that a network can serve. In 5G, the data rate for cell-edge data is expected to be 10 Gbps and 100 Mbps.

The enabling solutions/technologies that have been used to gain high data rate are

- MIMO
- Relays
- Small Cells
- Millimeter Wave Communication
- Wireless SDN.

2.5.2 Reduced Latency

Latency is the time needed to transfer data through a network from source to destination. The importance of reducing network latency derives from the application that is greatly affected by delays such as gaming. In fact, the LTE RTT (Round Trip Time) latency is approximately 15 milliseconds and is expected to be reduced to 1 ms in order to meet 5G requirements. The reason for this need to reduce latency within 5G is the growing use of real-time interactions in many applications, which did not require a delay in improving user experience. The idea of the Internet of things and machine type communication where everything is connected, and delay is not acceptable.

The enabling technologies that have been used to reduce latency are

- D2D communication
- All-optical networks
- Big data and mobile cloud computing

2.5.3 Low Energy and Power Consumption

One of the enabling technologies supported by 5G is IoT, where devices are connected to a base station using sensors without having to connect always. This scenario shows that these devices are switched on only when they need to. This means that 5G needs to reduce energy and does not support synchronization. It is necessary in 5G to reduce energy consumption 1000 times per bit by improving massive machine type communications. The technologies used to reduce electricity consumption are:

- D2D communications
- Green communications

- Ultra-densification

2.5.4 High Scalability

When designing LTE and 5G wireless networks, account should be taken of the increase in the number of mobile devices. By 2020, the number of devices connected to a mobile network is projected to increase to 50 billion. The service and handling of this number of devices requires an efficient network. Providing cellular networks with a high scalability requires sufficient frequency spectrum resources and efficient media control.

The enabling technologies that have been used to provide higher scalability are:

- Massive MIMO
- Wireless software-defined networking
- Mobile cloud computing.

2.5.5 Improved connectivity and reliability

In addition to the above requirements, coverage and transfer efficiency should also be improved for a better user experience, especially when the millimeter wave spectrum is used. With the increase in the number of connected devices and the density of the base stations, as well as the introduction of femto cells and pico cells, the number of handovers to be handled by the base station will increase. To handle this, new handover algorithms and techniques that provide improved coverage in cell edge areas are required.

Authentication and privacy concerns related to the handover are another related matter. The delay in contacting the authentication server for each handover will be hundreds of milliseconds, which for 5G applications would be intolerable. In addition, the transmission range of signals is greatly reduced due to the use of higher frequency bands in the millimeter wave. The maintenance of connectivity is therefore a major challenge for 5G. The requirements for both high reliability and connectivity should always be guaranteed for mission-critical services.

The enabling technologies that have been used to improve connectivity are

- Ultra-densification
- D2D communications
- Wireless software-defined networking.

2.5.6 Improved Security

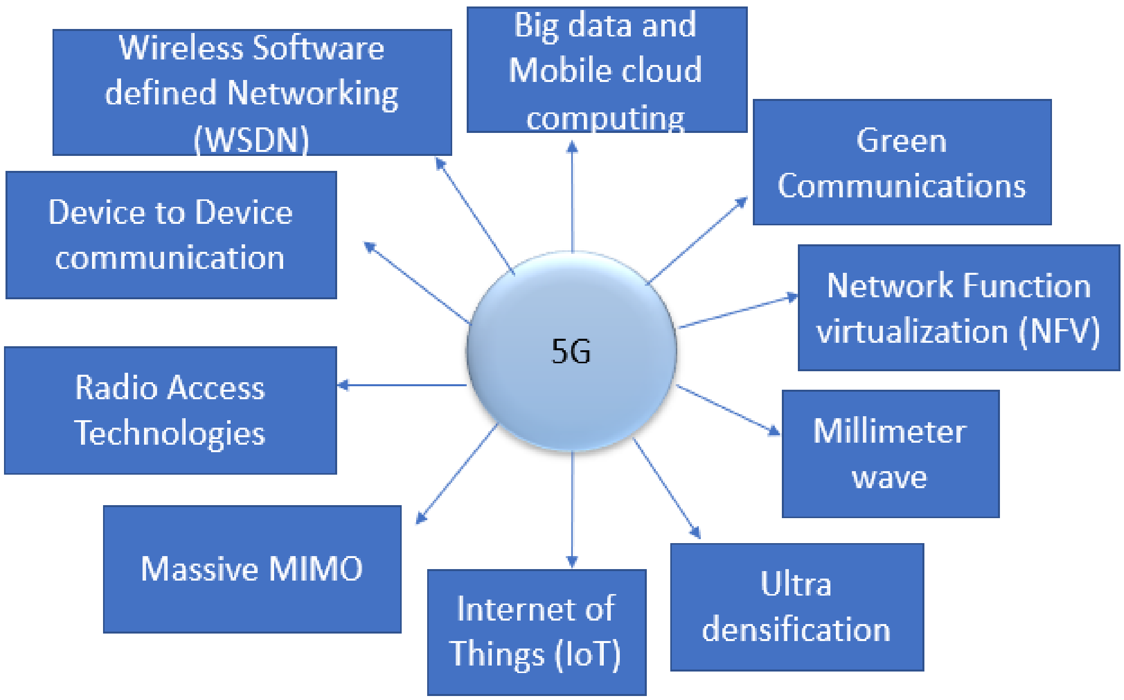
Nowadays, security not only provides users with reliable connectivity, but also improves security across the entire network, addresses authentication, authorization and accounting concerns, develops new encryption protocols and safeguards cloud computing and management activities. For example, security concerns are growing since the introduction of a near-field communication

(NFC) technique that not only allows proximity data transmission but can also lead to identity leaks. The 4G networks could not develop a unified standard for protecting the personal information of users, which is fully addressed in the 5G networks.

In 5G, standardization on authentication, authorization and accounting is required. In particular, because the IoT will reach its peak in 5G networks, authentication, authorization and accounting (AAA) processes for interconnected devices with fine-grained protective mechanisms should be granted. Network operators, device manufacturers and standardization bodies should work together to develop services, products and protocols that can be referenced substantially.

3. Enabling Technologies of 5G

To meet the requirements of coverage, high data rate, capacity and scalability, some technologies are used from 5G. These technologies are discussed below.



3.1 Wireless Software-Defined Network (WSDN)

SDN is one of the most important cellular 5G enable technology. SDN has emerged primarily for data center networks, and its main idea for the next generation of the Internet is to separate the data plane from the control plane, which increases network performance flexibility. By dividing the control plane from a user or data plane, capacity and data rates can be increased by reducing the overhead in the control plane.

In the SDN network, a network engineer or administrator can shape traffic at a centralized level (using the SDN controller) without touching individual network switches. The SDN controller directs the switches to operate and deliver the services wherever necessary without a network connection between the server and the devices.

3.1.1 SDN Architecture

A typical representation of the SDN architecture consists of network infrastructure layer, control layer and application layer.

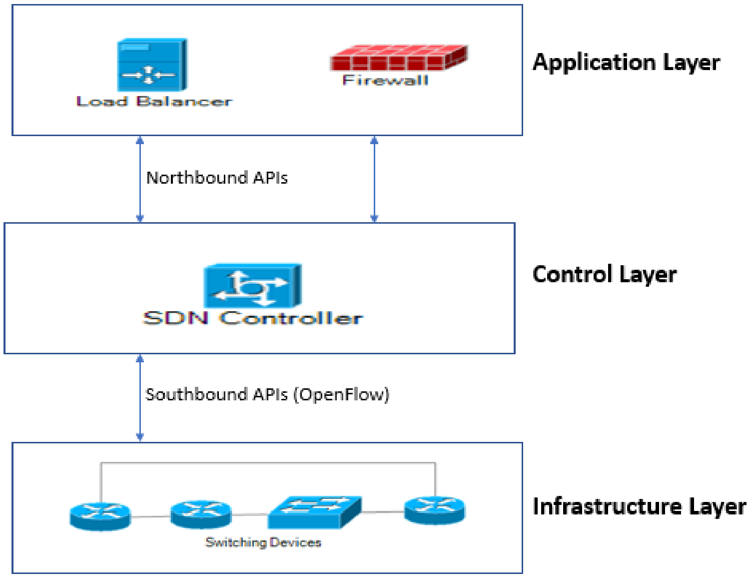


Figure 8: SDN architecture.

Application Layer:

It contains network applications or functions including load balancers, firewalls or system for intrusion detection. However, SDN replaces physical load balancers or firewalls that we use in traditional networks with an application that manages data plane behavior using the controller.

Control Layer:

The control layer consists of the centralized software of the SDN controller, which acts as the brain of the software network. This controller is located on a server and manages traffic policy and flow across the network.

Infrastructure Layer:

The layer is made up of the physical switches in the network.

These three layers communicate using respective northbound and southbound application programming interfaces (APIs). For example, applications talk to the controller via its northbound interface, while the controller and switches communicate via southbound interfaces like OpenFlow.

3.1.2 How SDN works

SDN consists of different types of technologies, including functional separation, network virtualization and programming automation. A packet arrives at a network switch in a classic SDN scenario and packet handling rules are sent from the centralized controller to the switch. Switch forward the packet based on these rules. The switch is also a data plane device. It can request guidance from the controller whenever needed and provide the controller with traffic information. The switch sends every packet going to the same destination along the same path and treats all packets exactly the same way.

Software-defined networking uses adaptive or dynamic mode of operation, in this mode a switch issues a route request to a controller for a packet that has no route. This process is separate from adaptive routing, which issues routing requests via routers and algorithms based on network topology and not via a controller.

The SDN virtualization uses the virtual overlay concept, which logically separates the physical network. Users can implement end-to-end overlays to abstract the network and network traffic underlying the segment. This micro-segmentation is particularly useful for service providers and operators with multi-tenant cloud environments and cloud services, as it can provide each tenant with a separate virtual network with specific policy.

3.1.3 Benefits of SDN

- SDN allows traffic load management by the administrator in a flexible and efficient way. Network administrators can prioritize, deprioritize, or even block certain packet types. This traffic control is very useful in a multi-tenant cloud computing architecture.

- SDN improves network management and provides end- to- end visibility. The network administrator must deal with a centralized controller to distribute policies to the connected switches instead of configuring multiple devices.

- SDN contributed to the development of software-defined wide area network (SD-WAN) technology.

- SDN virtualizes hardware and services that have been dedicated to the hardware before. In the end, this reduces hardware footprints and reduces operating costs.

3.1.4 Challenges with SDN

- Safety is both an advantage and a concern about SDN technology. The centralized SDN controller has a single failure point and can be detrimental to the network if targeted by an attacker.
- Adaptive rapid on-demand growth.
- Addressing dynamic real-time change.

3.2 Network Function Virtualization

Network Function Virtualization NFV is a complementary SDN concept. Several virtual machines on different operating systems work on different hardware in NFV. NFV offers greater scalability and flexibility and reduces the capital expenditure (CAPEX) required to purchase hardware devices and saves operating expenditure (OPEX) by adding resources to virtual network functions running on a centralized server pool.

3.2.1 NFV Architecture

According to ETSI, NFV 's overall architecture consists of four key elements: NFV infrastructure (NFVI), virtual network functions (VNFs), hypervisors and orchestration and management (NFV MANO). NFV 's main component is VNFs, which are network software implementations running on a general cloud infrastructure, as shown below.

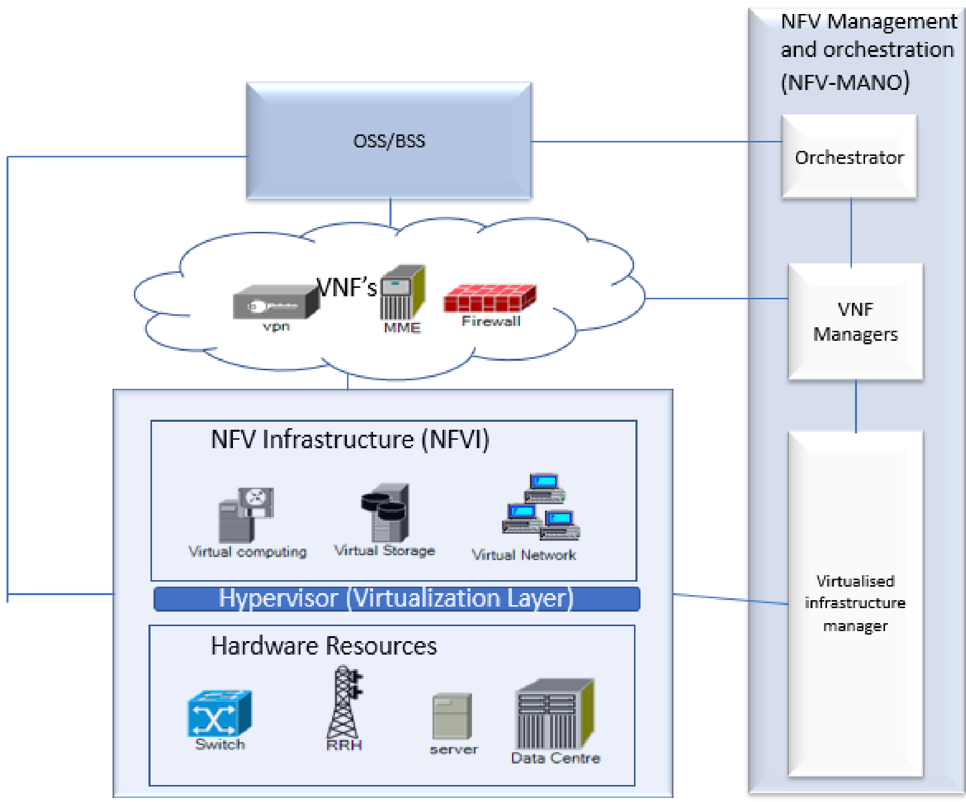


Figure 9: Overall architecture of NFV

VNFs are deployed on top of the NFVI which comprises of virtual computing, virtual storage and virtual network resources. The virtual resources created by hypervisors bring virtualization into the network over physical hardware resources. The hardware resources include networking infrastructures (switches and RRHs), computing (server) and storage infrastructures (data center).

The NFV MANO framework controls the provisioning and configuration of VNFs, and the NFVI.

3.2.1.1 NFV Infrastructure (NFVI):

NFV is the infrastructure for the building and deployment of VNFs. As shown in the diagram above, NFVI is the collection of hardware and software resources for virtual computing, storage and network. NFVI can be distributed at various locations, including customer premises and data centers. The network connectivity between the two sites is therefore also considered to be part of NFVI.

3.2.1.2 Virtual Network Functions (VNFs):

VNF is implementation of network function with software that is separated from the hardware underlying it. Some network function examples include DHCP servers, firewalls, NAT, gateways and MME.

3.2.1.3 Hypervisors

A computer software, firmware or hardware that creates and operates virtual machines is a hypervisor or virtual machine monitor (VMM). A computer with one or more virtual machines running a hypervisor is called a host machine and each virtual machine is called a guest machine. The hypervisor provides a virtual operating platform for the guest operating systems and manages the execution of the guest operating systems. Virtualized hardware resources can be shared by multiple instances of a variety of operating systems: for example, Linux, Windows and macOS instances can all run on a single physical x86.

Hypervisors set up the virtualization layer that provides virtual machines (e.g. virtual computing and storage) and virtual networks through physical computing, storage and networking. It also links network infrastructure logically to virtual networks for efficient management.

3.2.1.4 NFV Management and Orchestration (NFV MANO):

The NFV MANO provides the management and orchestration framework for all infrastructure resources. It provides VMs, configures VMs, manages VM and physical infrastructure resources. The MANO contains three functional blocks: the NFV orchestrator, the VNF manager and the virtual infrastructure manager.

- *NFV orchestrator* handles on-boarding new network services and VNFs, manages global resources, and validates and authorizes NFVI resource requests.
- *VNF manager* manages the life-cycle of VNF instances and coordinates the configuration and event reporting between NFVI and network management software.
- *Virtual infrastructure manager* controls and manages the compute, storage, and network resources of NFVI.

3.2.2 Challenges with NFV

- *Security and Privacy:* VNFs could run on several third-party servers, service providers have no direct data control, which raises new data privacy and security concerns.

- *Performance and portability:* NFV virtualizes service components and the support for OSS / BSS is maintained the same. In particular, VNFs will be run on a generic industry standard server and these NFVI servers must be manufactured without the knowledge of future function types. These severs must offer a service similar to that on specialized hardware. To solve this, it is necessary to select a balance between flexibility and performance by implementing some high-performance functions on hardware while virtualizing other network functions.

3.3 Millimeter Wave

Millimeter frequency bands are one of the promising technologies that have a significant impact on mobile communications capacity and throughput. Frequency bands are between 30 and 300 GHz in the mm-wave. In addition, mm-wave carrier frequencies increase the data rates through the allocation of large bandwidth.

3.3.1 Spatial Multiplexing and Beamforming

The atmospheric attenuation effect in millimeter wave bands is less but still more than the microwave frequencies, making them only feasible for small-scale deployments. In order to compensate for the high atmospheric attenuation of the millimeter wave, large antenna arrays should be used at the base station. Instead of the omnidirectional antennas used by traditional wireless communication systems, 5G deploys a large set of directional narrow-beam antennas that can be identified simultaneously by multiple users. Large antenna arrays are therefore essential to serve a wide variety of users in dense areas.

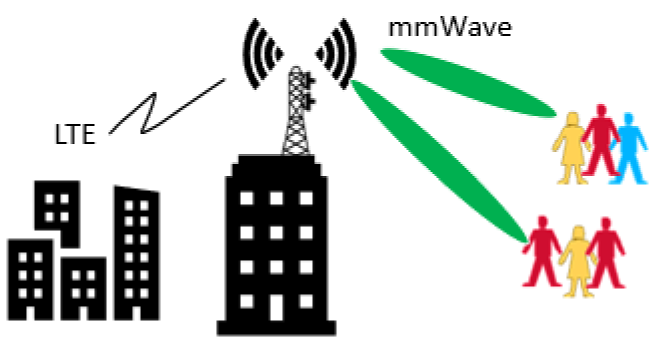


Figure 10: Urban environment with high user density using mmWave

3.3.1.1 Spatial multiplexing

In spatial multiplexing, multiple antenna elements are used to transmit multiple separated and independent encoded data streams. Each data stream travels through different propagation channels and receivers with multiple antennas can receive and reconstruct the original transmitted data with better spectral efficiency. Spatial multiplexing is most effective when multiple data streams can be supported by the propagation paths and when the channel has a high signal-to-noise ratio (SNR) which does not affect the signal strength when the original signal has to be divided into several data streams.

3.3.1.2 Beamforming

Beamforming combines antenna array elements adaptively at the base station and uses the multiplied beamforming weights on each element to control the directions to which data streams are transmitted. Specific users thus receive the data, while others are not interfered with. Beamforming works well if the channel has a low or limited SNR power.

3.4 Device to Device Communication (D2D)

Device-to-Device communication (D2D) allows two devices to communicate with each other without an intermediate base station (BS) that controls the communication. D2D uses licensed spectrum rather than unlicensed spectrum used by technologies such as Wi-Fi and Bluetooth. This type of communication provides high data rate, improves QoS and provides low latency due to the efficient and direct communication between the two connected devices.

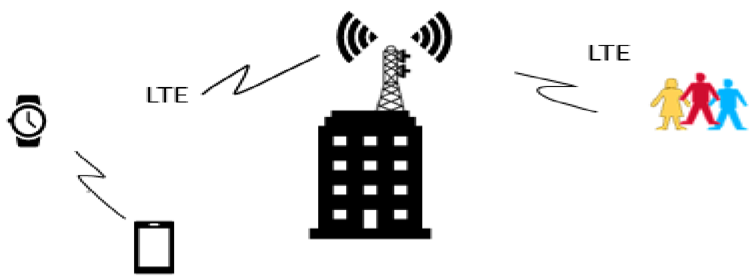


Figure 11: Device-to-device communications

D2D communication provides better user experience especially when the capacity of a BS is reached because of data traffic. D2D communications can be used as a foundation for many technologies such as machine type communication (MTC) and vehicle-to-vehicle communications (V2V).

3.4.1 Types of D2D communication

1. Device relaying with BS controlled link establishment.
2. Device relaying with device controlled link establishment.
3. Direct D2D communication with BS controlled link establishment.
4. Direct D2D communication with device controlled link establishment.

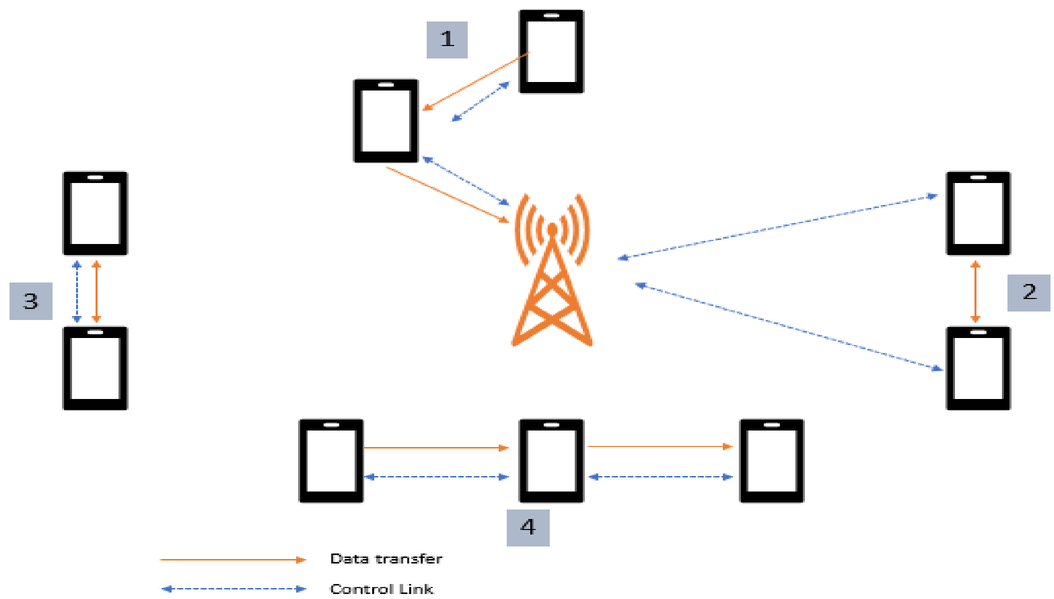


Figure 12: Device-to-device communications

3.5 Massive MIMO

In addition to millimeter wave communications and D2D communications, a massive MIMO solution for 5G networks is also proposed. It is quite different from the multi-user MIMO (MU-MIMO) installed in the 4G system, where only several tens of antenna components are built on base stations and user terminals, and where massive MIMO designs hundreds of antennas at base stations to increase capacity and system throughput, thereby increasing independence too.

Massive MIMO uses spatial multiplexing (discussed in Section 3.3.1) and time-division duplexing (TDD) to serve multiple users on the time-frequency resources.

3.5.1 Types of Layout of Massive MIMO

There are three possible layout types of massive MIMO antenna arrays, such as linear, rectangular and cylindrical arrays, at the base station. The various deployment scenarios use different types of massive MIMO layout. For example, the linear and rectangular antenna arrays can be installed outside high-rise buildings to serve indoor and outdoor users on different floors. The rectangular antenna array can also be used by spatial multiplexing techniques for multiple users. The cylindrical arrays can be used to track the moving routes of the users for moving users.

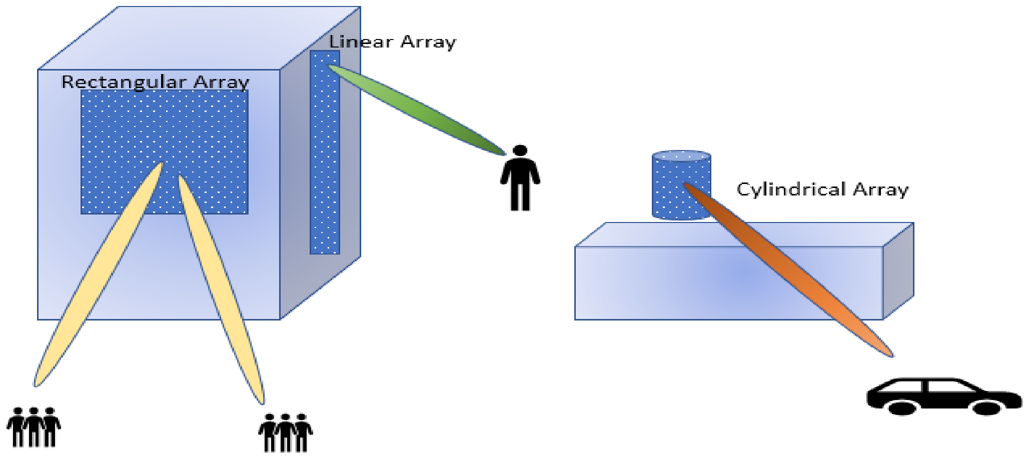


Figure 13: Massive MIMO base station antenna layouts

3.6 Ultra-Densification

The traditional macro-cell network architecture serves the basic network architecture of the 4G system. The use of new smartphones, tablets, wearable devices and other types of new devices requiring network access and connectivity for data roaming and video streaming increases the mobile data traffic worldwide gigantically. The traditional high-tower base stations cannot, however, keep pace with this increase. Two major solutions have been provided to solve this problem, namely spatial densification and spectral aggregation, which can create more cell layers and wisely manage the shared spectrum resources to increase capacity.

3.6.1 Spatial Multiplexing

Spatial densification covers the heterogeneous network (HetNet) idea used in the 4G LTE system. HetNets comprises picocells, femtocells and distributed antenna elements that will help improve system performance.

3.6.2 Spectral aggregation and spectrum sharing

In addition to spatial densification, where users are associated with different cells to increase network capacity, the spectral aggregation offers an alternative to network condensation through the management of spectrum resources. Spectral aggregation addresses the challenges of aggregating non-continuous fragments in the bandwidth resource and uses spectrum sharing to coordinate both the licensed and unlicensed spectrum to achieve higher spectrum usage.

3.7 Internet of Things (IoT)

The Internet of Things (IoT) is the key concept in the landscape of 5G cellular networks. IoT is an everyday network of physical objects, vehicles, equipment, devices, buildings, etc. These devices sense some information, and it is passed on to a remote server, mainly via the Internet. The server can also remotely issue device control commands. The data collected on the server is then processed to get information about the underlying process. This processed data is further used to build smarter systems like smart homes, smart cities, intelligent transport systems, healthcare systems, etc.

Please refer to section 5 for more details.

4. 5G Network Architecture

4.1 The evolution of network architecture

5G must be more flexible and scalable compared to 4G to allow for a wider range of scenarios and services. To meet the challenges of 5G requirements, a new architecture with technical innovation and evolution is expected to support wider scenarios, increase the user data rate and reduce latency.

For the core network, it will be reconstructed based a more convenient and flexible framework having the following characteristics:

1. Virtualization and NF modularization;
2. Unified service-based architecture and interface;
3. Separation of user plane and control plane;
4. Decoupling of mobility management and session management function;
5. New QOS architecture for introducing the new services.
6. Network slicing for supporting the new business domains.

The 5G system network architecture is designed to support data connectivity and services enabling deployments to use Network function virtualization and software-defined networking.

The 5G architecture is defined in two ways:

- A service-based representation:

In this representation, network functions such as AMF within the control plane allow other network functions to access their services. This representation also includes point to point representation wherever necessary.

Note: 5G Core follows the Service Based Architecture approach

- A reference point representation:

This shows the interaction between the NF services in the network functions described by the point to point reference point between any two network functions (e.g. AMF and SMF)

4.2 Network Functions and Entities

The elements of the 5GC are also called network functions to facilitate the enabling of various data services and requirements. The architecture of the 5G system consists of the following network functions (NF), the majority of which are 5GC.

The functional description of these network functions is specified in section 3.4.

- Authentication Server Function (AUSF)

- Access and Mobility Management Function (AMF)
- Data Network (DN), e.g. operator services, Internet access or 3rd party services
- Unstructured Data Storage Function (UDSF)
- Network Exposure Function (NEF)
- Network Repository Function (NRF)
- Network Slice Selection Function (NSSF)
- Policy Control Function (PCF)
- Session Management Function (SMF)
- Unified Data Management (UDM)
- Unified Data Repository (UDR)
- User Plane Function (UPF)
- Application Function (AF)
- User Equipment (UE)
- (Radio) Access Network ((R)AN)
- 5G-Equipment Identity Register (5G-EIR)
- Security Edge Protection Proxy (SEPP)
- Network Data Analytics Function (NWDAF)

4.3 Network Function Functional description

4.3.1 AMF- Access and Mobility Management function

The Access and Mobility Management (AMF) function supports: NAS signaling termination, NAS ciphering & integrity protection, registration management, connection management, mobility management, authentication and authorization of access, security context management and network slicing support. AMF is part of the EPC 's MME functionality.

4.3.2 SMF- Session Management function

Session Management Function (SMF) supports: session management (session establishment, modification, release), UE IP address allocation & management, DHCP functions, termination of NAS signaling related to session management, DL data notification, UPF traffic steering configuration for proper traffic routing. SMF has some of the EPC MME and PGW features.

4.3.3 UPF- User plane function

User plane function (UPF) supports: packet routing & forwarding, packet inspection, QoS handling, acts as an external PDU interconnection session point for Data Network (DN) and is an anchor point for intra-RAT and inter-RAT mobility. UPF is part of EPC world's SGW & PGW functionality.

4.3.4 PCF- Policy Control Function

The Policy Control Function (PCF) supports: a unified policy framework, providing policy rules for CP functions, accessing policy decisions in UDR subscription information. PCF functionality is similar to EPC world PCRF functionality.

4.3.5 NEF- Network Exposure function

Network Exposure Function (NEF) supports: exposure of capabilities and events, secure provision of external application information to the 3GPP network, internal / external information translation. Not present in the world of the EPC)

NOTE: The NEF can access the UDR located in the same PLMN as the NEF.

The NEF resides in the HPLMN for external exposure of services related to specific UE(s). The NEF in the HPLMN may have interfaces with NF(s) in the VPLMN, depending on the operator agreements.

4.3.6 NRF- NF Repository function

NF Repository Function (NRF) supports: service discovery, maintenance of NF profile and NF instances available. (Not present in EPC)

4.3.7 NSSF- Network Slice Selection Function

Network Slice Selection Function (NSSF) supports: selecting the Network Slice instances to serve the EU, determining the permitted NSSAI, determining the AMF set to serve the UE. (not in the EPC world)

4.3.8 UDM- Unified Data Management

Unified Data Management (UDM) supports: authentication and key agreement(AKA) credentials generation, handling of user identification, authorization of access, subscription management. UDM is part of the EPC world HSS functionality.

4.3.9 AUSF- Authentication Server Function

Authentication Server (AUSF) function acts as a server for authentication. AUSF is part of the EPC world HSS.

4.3.10 AF- Application Function

Application Function (AF) supports: application influence on traffic routing, access to NEF, interaction with policy framework for the purpose of policy control. (Like AF in EPC world).

4.4 5G Core architecture

4.4.1 Non-Roaming reference architecture

- The 5GC control plane network functions use service-based interfaces to interact with each other.
- One or more NF services may be provided by a control plane network function
- An NF service consists of operations based either on a request-response or a subscriber notification model.

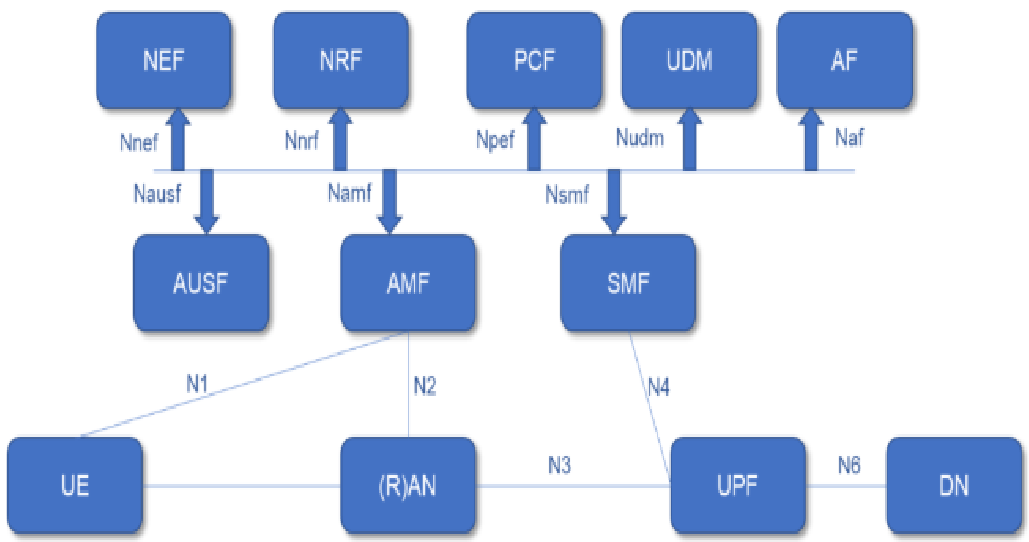


Figure 14: Non-roaming 5G System Service-based architecture. *(Ref:3GPP TS 23.501 V15.3.0 (2018-09))*

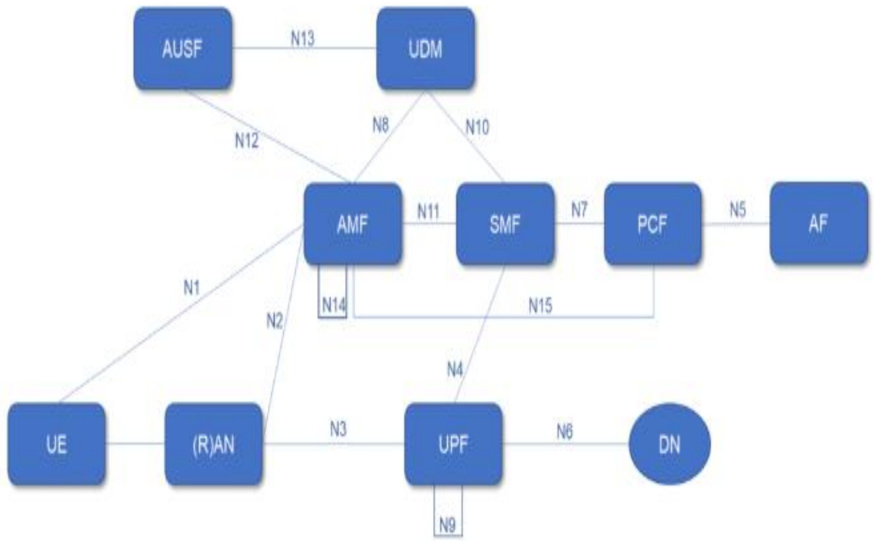


Figure 15: Non-Roaming 5G System Architecture in reference point representation *(Ref: 3GPP TS 23.501 V15.3.0 (2018-09))*

4.4.2 Roaming reference architecture

The figure below shows the core network architecture in which users have to access the UPF home network services. There is a N9 interface between the visited network's UPF and the home network's UPF for service forwarding.

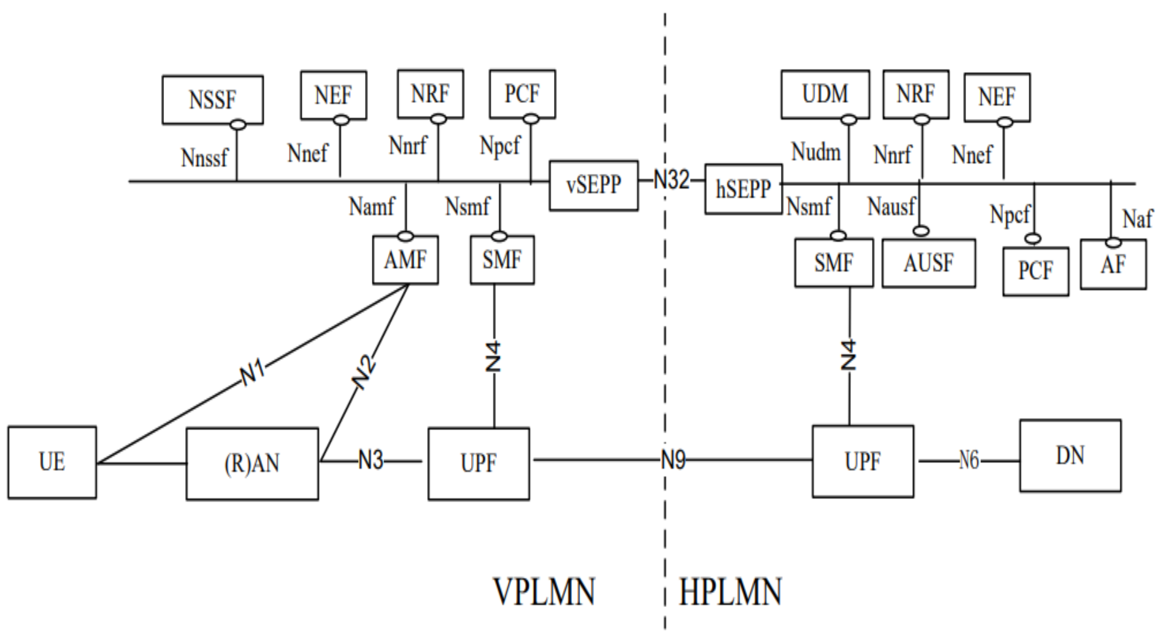


Figure 16: 5G Core Service Based architecture (Home routed roaming) *(Ref: 3GPP TS 23.501 V15.3.0 (2018-09))*

The figure below shows the core network architecture in which users access the services of the visited network UPF.

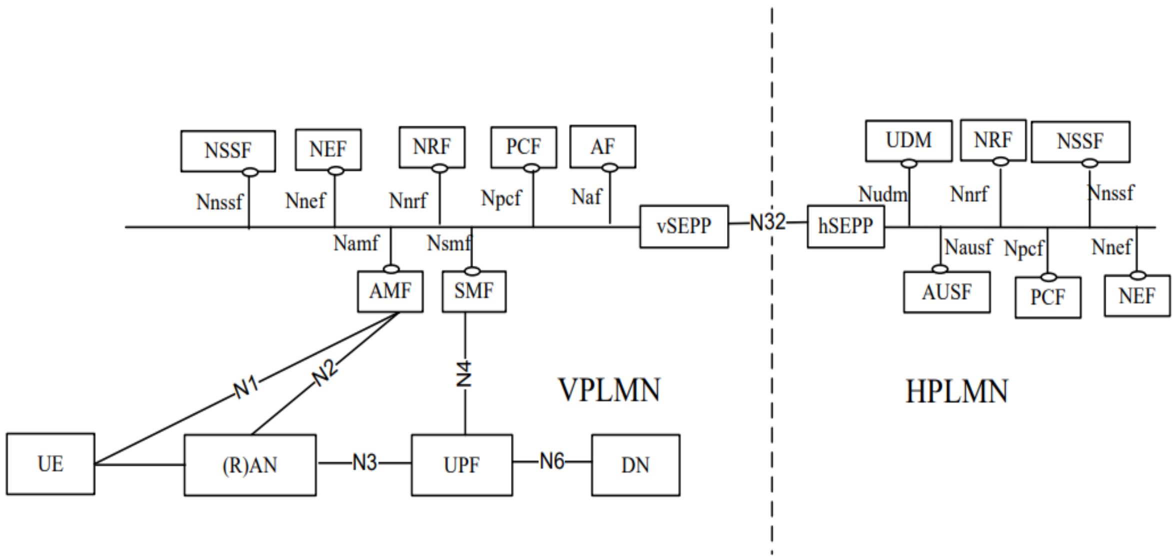


Figure 17: 5G Core Service Based architecture (Local Breakout Roaming) *(Ref: 3GPP TS 23.501 V15.3.0 (2018-09))*

4.5 5G RAN architecture

4.5.1 NG RAN – NextGen RAN Architecture

The next generation radio access network is part of the NextGen 3GPP 5G system. The architecture as a whole is shown in the following figure. This is specified in 3GPP TS 38.300

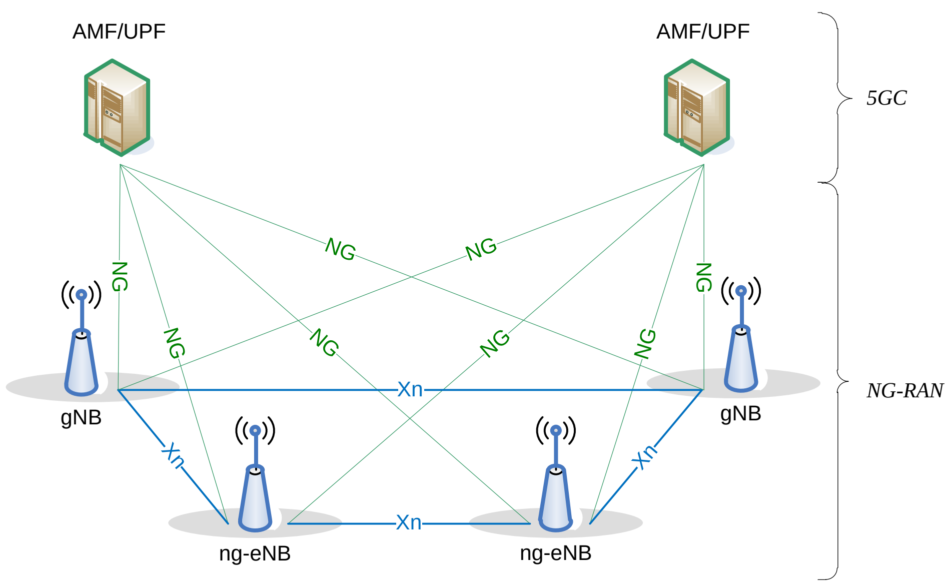


Figure 18: NG-RAN in relation to the 5G system *(Ref: 3GPP TS 38.300 V15.3.1 (2018-10))*

NextGen RAN represents the newly defined radio access network for 5G. It provides NR (New Radio) access and LTE radio access.

A NG-RAN node is either gNB or ng-eNB.

gNB: Provides NR user plane and control plane services towards UE.

ng-eNB: provides LTE/E-UTRAN services towards the UE.

The gNBs and ng-eNBs are interconnected via the Xn interface. gNBs and ng-eNBs are also connected to the 5GC through the NG interfaces, in particular the AMF (Access and Mobility Management Function) via the NG-C interface and the UPF (User Plane Function) via the NG-U interface.

gNB and ng-eNB has the following functions:

- Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic resource allocation to the UEs in both uplink and downlink (scheduling);
- IP header compression, encryption and data integrity protection;
- Selection of an AMF at UE attachment when no routing to an AMF can be determined from the information shared by the UE;
- Routing of the data from User Plane towards UPF(s);
- Routing of the data from Control Plane towards AMF;
- Connection setup and release;
- Scheduling and transmission of the paging messages;
- Scheduling and transmission of the system broadcast information which is originated from the AMF or OAM;
- Reporting and measuring configuration for mobility and scheduling;
- Transport level packet marking in the uplink;
- Session Management;
- Network Slicing Support;
- QoS Flow management.
- Data radio bearers mapping;
- Support of UEs in RRC_INACTIVE state;
- NAS messages distribution function;
- Radio access network sharing;
- Dual Connectivity;

4.5.2 Network interfaces

4.5.2.1 NG interface

NG User Plane

The NG-U interface is defined between gNB/ng-eNB node and the UPF. The transport network layer is built on IP transport and GTP-U is used on the top of UDP/IP to carry the user plane traffic PDUs between NG-RAN and the UPF.

NG-U provides the unreliable delivery of the user plane PDUs between NG-RAN and the UPF. The user plane protocol stack of the NG interface is shown below:

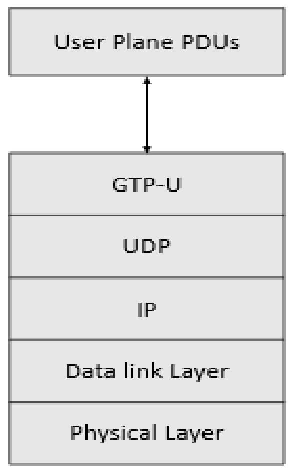


Figure 19: NG-U Protocol Stack

NG Control Plane

The NG-C interface is defined between NG-RAN and the AMF. As per the control plane stack provided in 3GPP TS 38.300, The transport network layer is built on IP transport and SCTP is used on top of IP layer for reliable delivery of signaling PDUs from NG-RAN to AMF. Application layer signaling protocol is referred as a NGAP (NG -Application protocol). SCTP guarantees delivery of application layer signaling PDUs and in transport, IP layer ensures point to point transmission for delivery of signaling.

This interface provides NG interface management, UE context management, UE mobility management, Paging, session management, Transport of NAS messages and warning messages handling.

The control plane protocol stack of the NG interface is shown below:

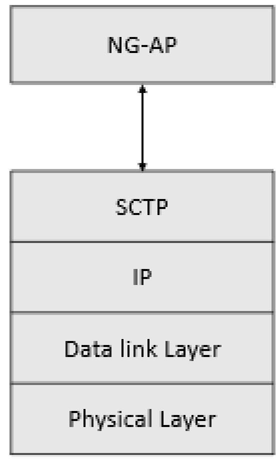


Figure 20: NG-C Protocol Stack

4.5.2.2 Xn Interface

Xn User Plane

The Xn-U interface is similar to NG-U interface except it is used between two NG-RAN nodes. Xn-U provides non-guaranteed delivery of user plane PDUs and supports data forwarding and flow control.

Xn Control Plane

The Xn-C interface is like NG-C interface except it is used between two NG-RAN nodes. Xn-C ensures delivery of signaling PDUs and supports Xn interface management, UE mobility management, RAN paging and dual connectivity.

4.5.3 Deployment Scenarios and Migration Paths

One of the characteristics of NG RAN is the ability to operate both in the "Stand-Alone "(SA) and the "Non-Stand-Alone "(NSA) operations.

5G NR standalone (SA) mode refers to the use of 5G cells both for signaling and for transferring information. GNB is connected to the 5G Core Network (5GC) in SA operation; it includes the new 5G Package Core architecture rather than the 4G Evolved Package Core. This means that 5G could be deployed without an LTE network. Lower costs, better efficiency and support in the development of new use cases are expected.

5G NR Non-Standalone (NSA) mode refers to the 5G NR deployment option, which depends on the control plane of the existing LTE network for control functions, while 5G NR focused exclusively on the user. NR and LTE are closely integrated and connect to the existing 4G core network (EPC) using dual connectivity (DC) to the terminal. A Master Node (MN) and a

Secondary Node (SN) simultaneously provide radio resources to the terminal for enhanced end user bit rates in a dual connectivity architecture.

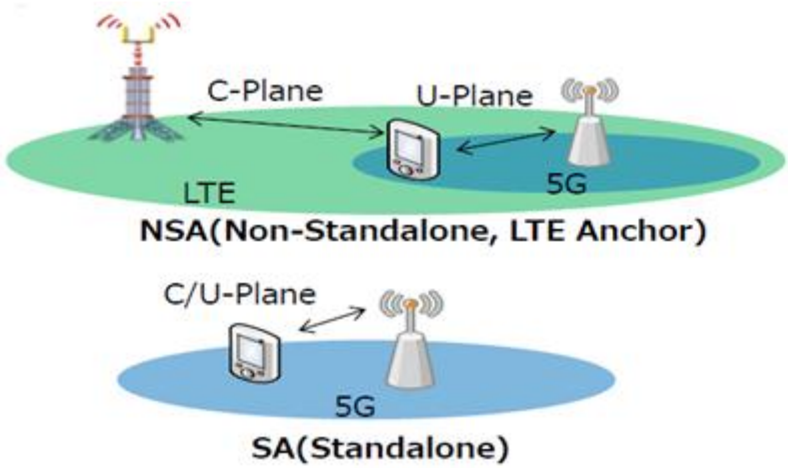


Figure 21: 5G SA/NSA operation

Many different configuration options can be derived from the overall architecture, each of which represents a viable network operator deployment option. These architecture options can be found in the following sub-sections.

4.5.3.1 NR-gNB connected to the 5GC (Option 2)

In this option the gNBs are connected via the NG interface to the 5G core network (5GC). The gNBs interconnect via the Xn interface.

4.5.3.2 Multi-RAT DC with EPC (option 3)

In this option, commonly referred to as EN-DC (LTE-NR Dual Connectivity), a UE is connected to an eNB acting as an MN and an en-gNB acting as an SN, see Figure 22. An en-gNB is different from gNB because it implements only part of the functionality of the 5G base station required to perform SN functions for EN-DC.

The eNB is connected to the EPC through the S1 interface and the X2 interface to the en-gNB. The en-gNB can also be connected to the EPC through the S1-U interface and the X2-U interface to other en-gNBs. The architecture shown below is shown in figure 22. Note that the en-gNB can send UP directly to the EPC or via the eNB.

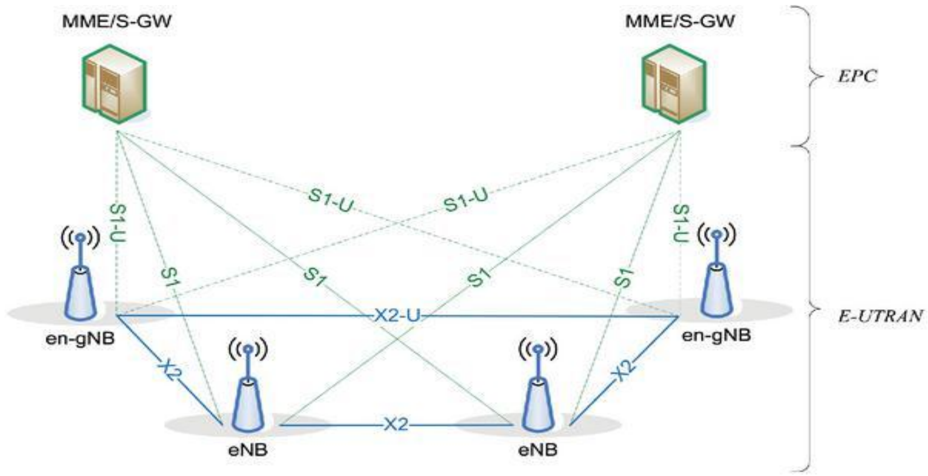


Figure 22: Overall LTE (E-UTRAN)-NR DC architecture

4.5.3.3 Multi-RAT DC with the 5GC, with NR as master (Option 4)

In this option, a UE is connected to gNB acting as an MN and a ng-eNB acting as a SN. This option requires the deployment of the 5G core. The gNB is connected to 5GC and ng-eNB via the Xn interface is connected to the gNB. The ng-eNB can send UP directly or through the gNB to the 5G core.

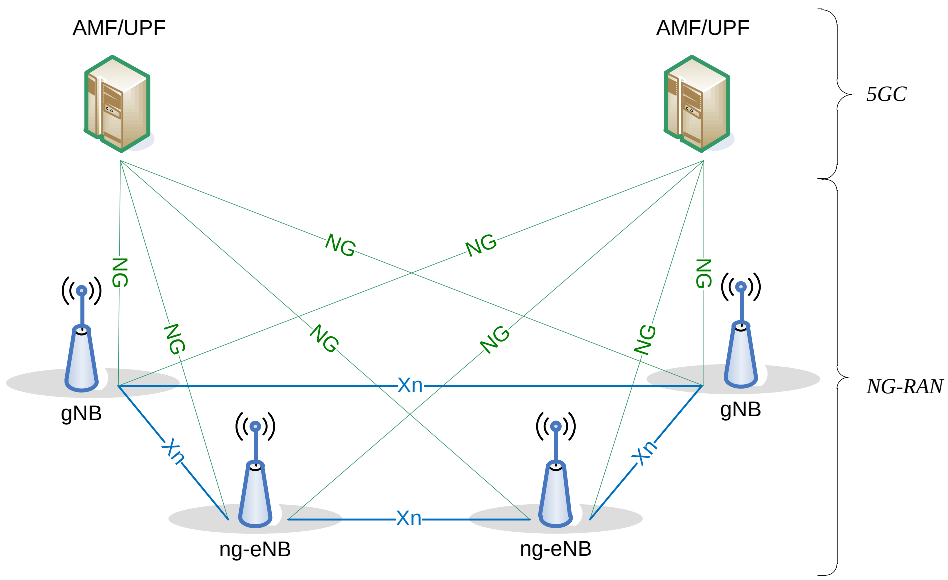


Figure 23: Overall LTE (E-UTRAN)-NR DC architecture

4.5.3.4 LTE ng-eNB connected to the 5GC (Option 5)

In this option ng-eNBs are connected via the NG interface to the 5G core network (5GC). The Ng-eNBs connect via the Xn interface. This option essentially enables the existing LTE radio infrastructure (by upgrading to the eNB) to be connected to the new 5G Core.

4.5.3.5 Multi-RAT DC with the 5GC, E-UTRA as Master (Option 7)

In this option, a UE is connected to a ng-eNB acting as a MN and a gNB acting as a SN. The ng-eNB is connected to the 5GC and the gNB through the Xn interface is connected to the ng-eNB. gNB can send UP directly to the 5GC or through the ng-eNB.

4.5.4 Migrations Considerations

When 5G is first deployed with NR, it is likely that NR is deployed at higher frequencies than with LTE. In this case, NR coverage is usually much smaller than LTE coverage, with frequencies above 6 GHz in particular. It is then desirable to use the existing LTE coverage to provide continuous national coverage and mobility while enhancing NR user planning capacity in target areas with high traffic loads. Option 3 allows operators to launch the NR service in this way and build on their existing E-UTRAN and EPC investments.

When operators decide to introduce the 5G core, this will "unlock "a new set of possible deployment scenarios, including support for NR as a standalone Radio Access Technology (RAT) (Option 2), while using the LTE nodes deployed as secondary nodes through Dual Connectivity (DC) (Option 4) at the same time. Another way to introduce 5G Core is to keep LTE as the main anchor, connecting it to the 5G Core (Option 5) while still using NR as a secondary node through DC (Option 7)

The choice between deploying NR with 5GC as an anchor and keeping LTE as an anchor with the new 5GC usually depends on each operator's business decision. It depends on various factors, including the deployed LTE network density, the availability of new frequencies, the demand for end-user traffic and the business case of new functions, such as slicing, which only new networks will provide.

4.5.5 5G NR gNB architecture

The 4G RAN architecture was based on a monolithic building block (eNB), a simple architecture with very few interactions with the logical nodes. In the earlier phase of NR research, it is therefore felt that splitting the gNB (the logical NR node) between the central units (CUs) and the distributed units (DUs) would bring further benefits. Some advantages of this division are given below:

- A Flexible hardware implementation enabling cost-effective and scalable solutions

- A split architecture allows coordination of performance, load management and optimization of real-time performance.
- It also enables virtualized deployments.

The choice of how NR functions can be divided into the architecture depends on the deployment of radio network scenarios, constraints and services envisaged. It depends, for example, on the need to support specific QoS settings for each service offered (for example. Low latency, high performance, special user density and demand for load).

Theoretically you can split at any layers in the protocol stack. However, 3GPP decided to use split between centralized PDCP/RRC and decentralized RLC/MAC/PHY. The prime reason for this split is dual connectivity.

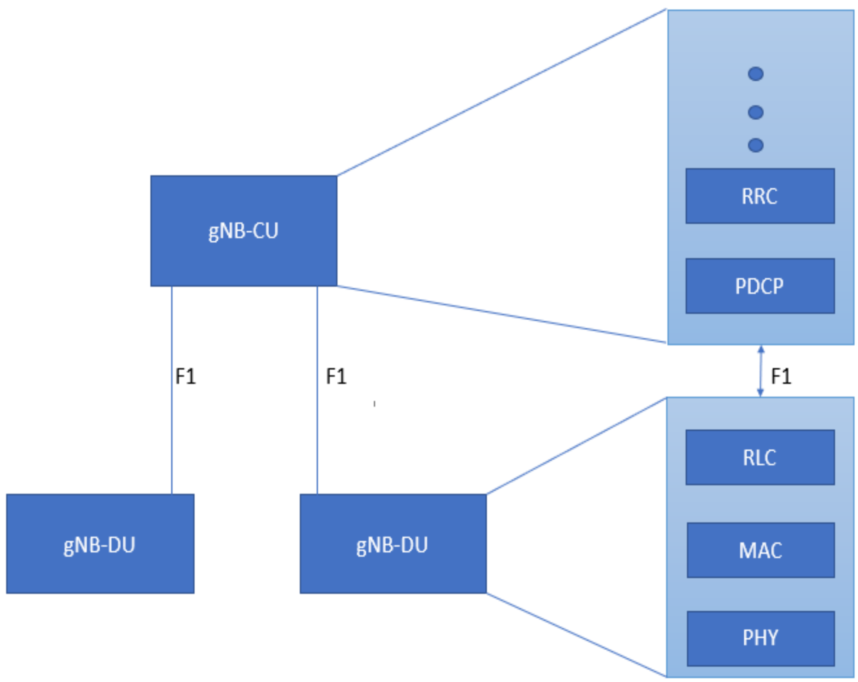


Figure 24: NG-RAN functional split

This option allows for the centralization of traffic aggregations from NR and E- UTRA transmission points and can facilitate load management. This split allows for the NG- RAN part to be virtualized. We can put higher layer protocol stack (PDCP and above) into an open hardware and software-based protocol stack.

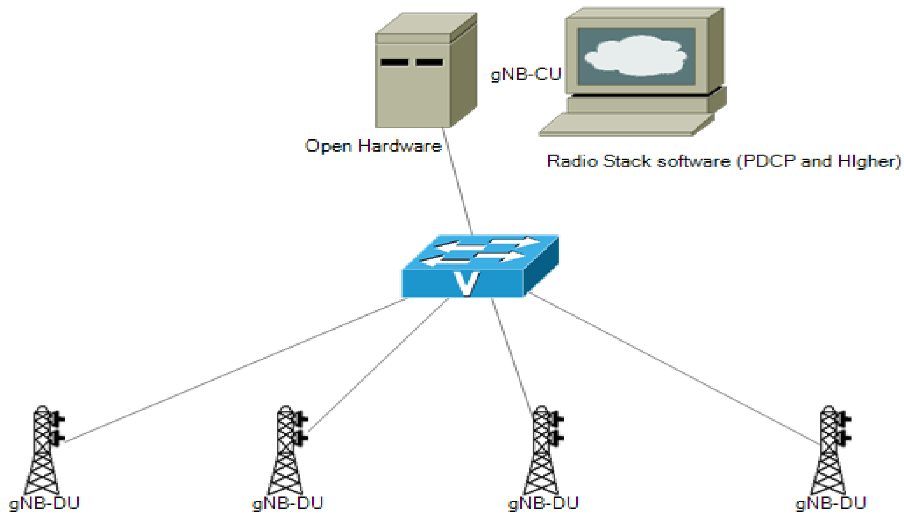


Figure 25: NG-RAN functional split

4.5.6 Higher layer split (HLS) of gNB (Overall Architecture)

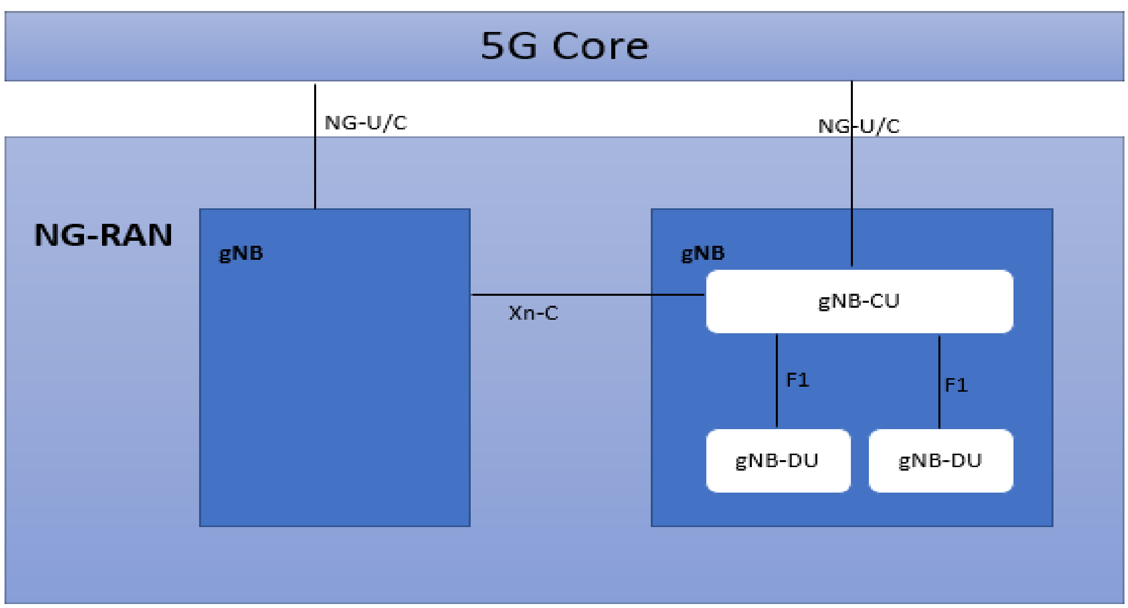


Figure 26: Higher layer split (HLS) of gNB (Overall Architecture)

NG-RAN consists of a group of gNBs that are interconnected via the Xn and to the 5G core via the NG interface. GNB supports dual mode operation: FDD mode and TDD mode are supported. The internal structure of gNB is divided into two parts called the CU (Central Unit) and the DU (Distributed Unit) and the new interface called F1 connects these two entities. NG, Xn and F1 are logical interfaces. A gNB can consist of a gNB-CU and one or more gNB-DU(s). The maximum number of gNB-DUs linked to a gNB-CU is limited only through implementation. In 3GPP standard, only one gNB-DU connects to one gNB-CU, but implementations that allow multiple gNB-CUs to connect to one gNB-DU, for example. for added resiliency, are not excluded. One gNB-DU can support one cell or more. The internal structure of the gNB is not visible to the core network and other RAN nodes, so that the gNB-CU and the gNB-DU connected are only visible to other gNBs and the 5GC as gNB.

The F1 interface supports signaling exchange and data transmission between the endpoints, separates Radio Network Layer (RNL) and Transport Network Layer (TNL), and enables the exchange of UE-associated and non-UE-associated signaling. F1 interface functions are also divided into the functionsF1-C and F1-U.

4.5.6.1 F1-C (Control Plane) Functions:

F1 Interface Management Functions: These include F1 setup, gNB-CU Configuration Update, gNB-DU Configuration Update, error indication and reset function.

System Information Management Functions: The gNB-DU is responsible for the scheduling and broadcasting of the system information. The encoding of NR-MIB and SIB1 is performed by the gNB-DU, for system information transmission while the encoding of other SI messages is performed by the gNB-CU. The F1 interface also supports the delivery of SI on demand, allowing UE to save energy.

F1 UE Context Management Functions: The establishment and modification of the UE context is the responsibility of these functions. The establishment of the F1 UE context is initiated by the gNB-CU and the gNB-DU can accept or reject the establishment on the basis of admission control criteria (e.g., if resources are not available, the gNB-DU can reject a context setup or a request for modifications). In addition, either gNB-CU or gNB-DU can initiate a F1 UE context modification request. The receiving node may accept or deny the modification. The F1 UE context management function can also be used to establish, modify and release Data Radio Bearers (DRBs) and Signaling Radio Bearers (SRBs).

RRC Message Transfer Function: This function transfers RRC messages from the gNB-CU to the gNB-DU and vice versa.

4.5.6.2 F1-U (User Plane) Functions:

Transfer of User Data: This function is responsible for transferring user data between gNB-CU and gNB-DU.

Flow Control Function: This function enables the downlink user data transfer to the gNB-DU to be controlled. Several features are introduced to improve data transmission performance, such as

the rapid retransmission of PDCP, PDUs lost due to radio link failure, the dismissal of redundant PDUs, the retransmitted data indication and the status report.
In the case of CU-DU split, the following connected mobility scenarios are supported:

- Inter-gNB-DU Mobility: The UE moves from one gNB- DU to others in the same gNB-CU.
- Intra-gNB-DU inter-cell mobility: The UE moves from cell to cell within the same gNB-DU, supported by the UE Context Modification procedure (gNB-CU initiated).
- EN-DC (LTE-NR Dual Connectivity) Mobility with Inter-gNB-DU Mobility using MCG (Master Cell Group) SRB: The UE moves from one gNB-DU to another within the same gNB-CU when only MCG SRB is available during EN-DC operation.
- EN-DC Mobility with Inter-gNB-DU Mobility using SCG (Secondary cell group) SRB: The UE moves from one gNB-DU to another when SCG SRB is available during EN-DC operation.

4.5.7 Separation of CP and UP with HLS (Higher Layer Split)

GNB-CU is further divided into two parts to optimize the location of different RAN functions based on different scenarios and performance requirements: gNB-CU-CP and gNB-CU-UP (control plane and user plane). The general RAN architecture with the separation of CU-CP and CU-UP is shown below:

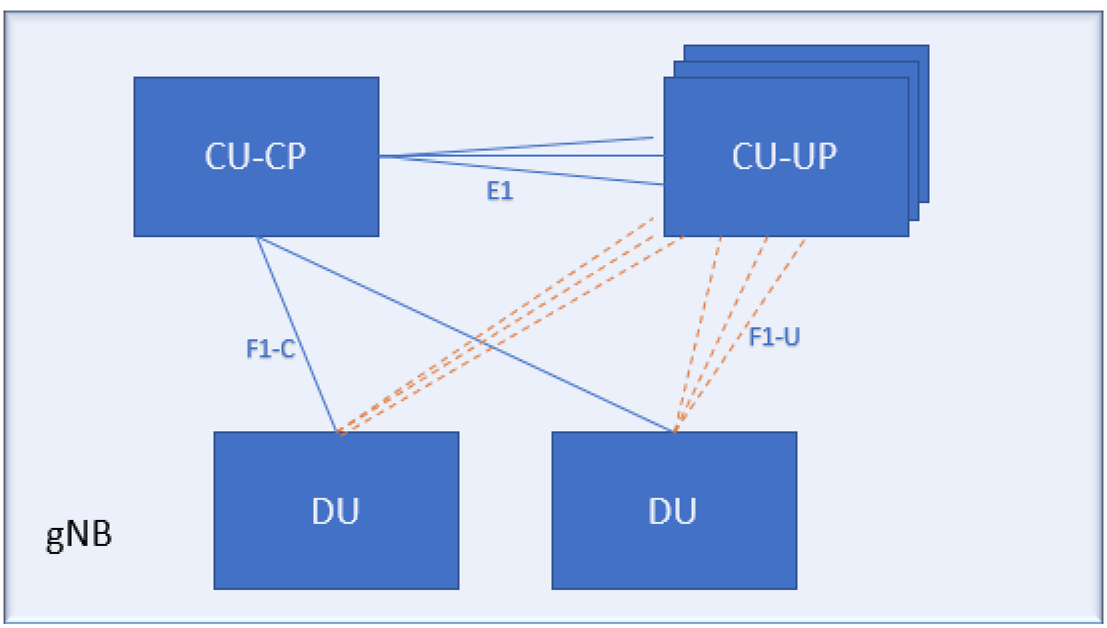


Figure 27: Overall RAN architecture with CU-CP and CU-UP separation

The interface between CU-CP and CU-UP is called E1 (control plane interface). The gNB-CU-CP hosts the RRC and the control plane part of the PDCP protocol, and also terminates the E1 interface connected to the gNB-CU-UP and the F1-C interface connected to the gNB-DU. The gNB-CU-CP hosts the user plane part of the gNB-CU PDCP protocol for an en-gNB and the user plane part of the gNB-CU PDCP protocol and the gNB-CU SDAP protocol. The gNB-CU-UP terminates the E1 interface, connected to the gNB-CU-CP and the F1-U interface connected to the gNB-DU.

A gNB may consist of a gNB-CU-CP, more than one gNB-CU-UP and more than one gNB-DU. The gNB-CU-CP is connected to the gNB-DU via the F1-C interface and the gNB-CU-UP via the F1-U interface is connected to the gNB-DU. One gNB-CU-UP is connected to one gNB-CU-CP only, but implementations allow a gNB-CU-UP to connect to several gNB-CU-CPs, for example, for added resiliency, are not precluded. You can connect one gNB-DU to several gNB-CU-UPs under the same gNB-CU-CP control. You can connect one gNB-CU-UP to several DUs under the same gNB-CU-CP control.

The E1 interface's basic functions are E1 interface management and E1 context management functions.

4.5.8 NR Radio Interface Protocol

This section provides an overview of the radio interface protocol architecture that operates between NG-RAN and the UE and details the features of each protocol. The architecture of the radio protocol consists of a user plane used for transferring user data (IP packets) between the network and the UE and a control plane used for control signaling between NG-RAN and the UE.

4.5.8.1 User Plane

The following image shows the User plane protocol stack within the UE and the gNB.

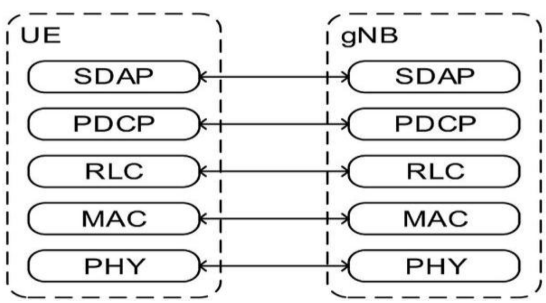


Figure 28: User plane protocol stack

Service Data Adaptation Layer (SDAP)

It is introduced to support the new flow-based 5G core network QoS model. With this new QoS model, the core network can set up various QoS requirements for different PDU session IP flows. The SDAP layer provides mapping of IP flows with different QoS requirements for radio bearers, which are configured to deliver the required QoS. The mapping between IP flows and radio carriers can be configured and reconfigured using RRC signals, but it can also be changed more dynamically without the involvement of RRC signals via a reflective mapping process.

Packet Data Convergence Layer (PDCP)

The PDCP protocol provides header compression and decompression with RoHC (Robust Header Compression), security functions including ciphering / deciphering and integrity protection, transmitted PDCP PDUs duplication and reordering and detection of duplicate PDCP PDUs. The main differences in NR PDCP compared to LTE are the introduction of duplication of data over different transmission paths to achieve extremely high reliability for URLLC (Ultra Reliable Low Latency) applications and the introduction of integrity protection for user data.

Radio Link Control Protocol (RLC)

RLC provides segmentation, in order to match the transmitted PDU size to the available radio resources, and error correction through ARQ. It does not provide concatenation of RLC SDUs as LTE RLC does. However, the equivalent functionality now provided by the MAC layer and does not provide reordering, with the protocol stack instead relying only on the reordering within PDCP.

Medium Access Control (MAC)

The main function includes multiplexing and demultiplexing of data from different radio bearers to the transport blocks that are carried by the physical layer, priority handling between data from other radio bearers, and error correction using Hybrid ARQ. A notable addition to LTE is that the MAC protocol contains control signals used for beam management.

4.5.8.2 Control Plane

The following picture shows the control plane protocol stack. It includes PDCP, RLC and MAC sublayers (terminated in gNB on the network side), RRC (terminated in gNB on the network side), and NAS control protocol (terminated in AMF on the network side).

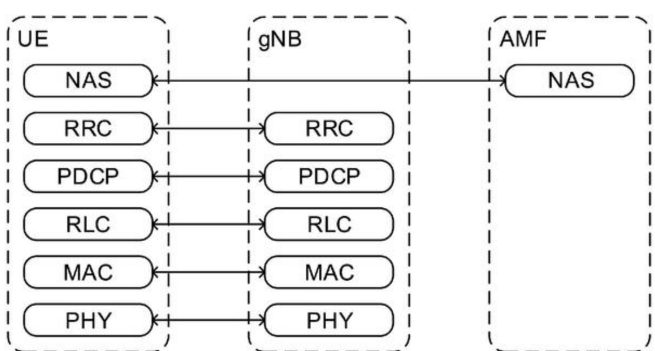


Figure 29: Control plane protocol stack

Non-Access Stratum (NAS) Protocol:

This protocol terminates in the UE and the AMF of the 5G core network and are used for core network related functions such as registration, authentication, location updating and session management. The Radio Resource Control (RRC) protocol ends in the UE and the 5G-RAN and is used to control and configure radio functions in the UE.

Radio Resource Control (RRC):

The main services and functions of the RRC sublayer includes Paging, Security functions including key management, Mobility functions including: Handover and context transfer, UE cell selection and reselection and Inter-RAT mobility. It also provides detection of and recovery from radio link failure, UE measurement reporting and control of the reporting and establishment, maintenance and release of an RRC connection between the UE and NG-RAN

The introduction of a 3-state model with the addition of the RRC INACTIVE state as shown in the figure below represents a significant difference in NR RRC compared to LTE RRC. RRC Inactive provides a state with battery efficiency similar to RRC Idle but with an UE context within the NG-RAN that allows transitions to / from RRC Connected to be faster and incur less overhead signaling.

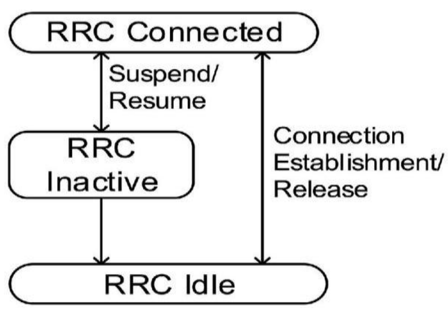


Figure 30: NR RRC state model.

The other important additions to LTE RRC are the support of an 'on demand' system information mechanism that enables the UE to request when specific system information is needed instead of the NG-RAN radio resources to provide frequent periodic system information broadcast, and the extension of the measurement reporting framework to support beam measurements for handover purposes within a high-frequency beam based deployment.

5. Internet of Things (IoT)

The Internet of Things is the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, and connectivity which enables these things to connect, collect and exchange data.

The technical concept of the IoT is to enables these objects to sense information using sensors and sends this information to a server. This server analyzes this information and translates them to certain behaviors or actions. These actions format intelligent environments such as smart homes. The evolution of the IoT enables billion of connected devices to connect to the Internet, which impact on the way people live. It is expected that the number of connected devices is expected to exceed 50 billion devices by 2020s.

5.1 Types of IoT

5.1.1 Consumer IoT (cIoT)

Consumer IoT is mainly designated for individual customer to use in homes and offices. This is mainly used for connecting individual household appliances together, and to handle various data with a centralized access. In this technology various appliances are interconnected to each other and data is positioned in the centralized position and it is accessible anytime and anywhere. Remote access is one of the key features of IoT, few examples are, turning on and off the TV with one mobile phone, same with accessing the main door and other appliances like a washing machine and air conditioner.

The objective of Consumer IoT is to improve the quality of life of people by saving time and money. It involves the interconnection of consumer electronic devices, as well as of (virtually) anything belonging to user environments such as homes, offices, and cities. cIoT communications are typically machine-to-user, and in the form of client-server interactions. In cIoT, desirable features of networked things are low power consumption, ease of installation, integration and maintenance.

5.1.2 Industrial IoT (iIoT)

The IoT 's application to the manufacturing sector is called the iIoT (or Industrial Internet). The iIoT will revolutionize manufacturing by enabling much larger amounts of data to be acquired and accessible at much higher speeds and much more efficiently than before.

Industrial IoT focuses on the integration of Operational Technology (OT) and Information Technology (IT) and on how intelligent machines, networked sensors and data analysis can improve business-to-business services across a wide range of market sectors and activities, from manufacturing to public services. It generally involves machine-to-machine interactions with a distributed control system that does not require human intervention (i.e. autonomous industrial plants) either for application monitoring or as part of a self-organized system.

Unlike cIoT, iIoT communications are typically machine-to-machine interactions used to automate and/or monitor process control.

5.2 Role of 5G in IoT

3G and 4G cellular technologies, and especially 3GPP LTE, are among the most appealing technologies in the modern IoT connectivity. They offer wide coverage, relatively low deployment costs, high level of security, access to dedicated spectrum, and simplicity of management. However, they do not support efficiently MTC (Machine Type Communication) communications.

Due to the huge data exchanged among plethora of connected devices to IoT, the need to provide extremely high capacity, high data rate and high connectivity is increased. Also, the nature of the 5G cellular network supports the heterogeneity of connected device in the IoT. In fact, the 5G could play a potential role as a foundation to facilitate the connectivity of the large amount of connected devices to the Internet. Thus, 5G wireless networks considered as a key driver for IoT.

5.3 Challenges of IoT

5.3.1 Energy efficiency

One of the main challenges for IoT is to provide efficient energy consumption. Most of the energy challenges in IoT are related to connected devices. These connected devices are usually depending on batteries or on harvesting energy systems. Also, sometimes especially on applications that required remote communication, the energy consumption can be problematic in case of requiring recharging or replacement of energy systems. IoT achieves the energy efficiency or consumption by the mean of direct communication between connected devices, which allows local connectivity among devices provided by wireless technologies.

5.3.2 Scalability

Since sensors are cheap and available, it is easy to deploy many of them to connect devices. Providing coverage to these connected devices on a reliable manner is one of the main challenges. Furthermore, the overhead of signaling and connection setup must be reduced. Due to the increase number of connected devices, the handover between cells is increased. These issues related to scalability of IoT can be handled by technologies such as SDN (Software-defined networking). (F., Nie, Lin, & Manoj.Chandrasekaran., vol. 106, 2016, pp. 17-48.)

5.3.3 Intelligence Processing and Storage

As stated previously the concept of the IoT is to have number of connected devices via several sensors, which are responsible of sending information, after sensing them from these devices, to a remote server. This remote server is responsible of translate and process this information to knowledge that represented as certain actions or behaviors. Usually these remote servers are hosted in cloud providers. Since collecting and processing all information from different devices are complex processes, the IoT cloud providers must have certain capabilities to handle these complicated tasks.

There are two ways to handle the complexity of IoT cloud providers and computational load. First, several cloud providers can be used for the same IoT network. Second, to reduce the delay that could occur because of the complexity of the processing, the computing service could be moved to the edge of the network.

5.3.4 Security

Since we have different devices based on different hardware and platform connected to each other, the communication among these devices can be hacked but providing a security mechanism that is compatible with all these different devices is a complex job. In fact, threats could come from two aspects: among communication of devices or in the communication between these devices and remote servers. (Gupta & Gupta, 2016)

5.3.5 Interoperability

One of the major challenges in IoT is interoperability, due to the diverse range of devices to be connected, the need to coordinate these different devices is increased. There are many IoT devices based on different hardware, different platform, manufactured by different vendors. There are many IoT devices that uses its own standards and interfaces in order to communicate with other devices or remote servers. This could cause a conflict when different devices are used in the same domain. The incompatibility among devices, sensors, and even interfaces of remote servers is a main reason that causes the interoperability challenge in IoT.

5.4 Characteristics of IoT

IoT is not a single technology itself. It is a concept of many integrated technologies. It has several characteristics that shape the purposes and functionalities of IoT. These characteristics are described below:

Interconnectivity: In the IoT, everything can be connected including any virtual or physical objects. The interconnectivity feature is described by the connection among these different objects and the communication infrastructure.

Things-related services: The feature provide services that can be applied to several connected things based on constraints. For example, privacy protection as a service can be applied to same things with their constraints.

Heterogeneity: The heterogeneity feature of the IoT comes from the idea of connecting different devices that are built using different hardware and run over different platforms.

Dynamic changes: IoT can handle dynamic changes that are required by different objects. Several dynamic changes could occur in term of state changes such as idle, connected and disconnected, or in term of context changes such as changing locations.

5.5 IoT Technologies

Many technologies are used to enable the IoT to communicate. There are several techniques used to communicate between IoT devices. In order to connect the devices, each device must be identified by a unique identifier. These technologies are basically used to implement the real idea of the IoT and to enable interactions between different devices. Some of these technologies and approaches are listed below:

5.5.1 Radio Frequency Identifications (RFID)

The RFID is a two-part wireless system: tags and readers. Tags are attached to connected objects or devices and contain stored information, which is normally read by readers. These tags use radio waves with different antenna frequencies to communicate between devices. These tags can also be passive when powered by a reader or when powered by batteries. (Shah & Yaqoob, 2016)

5.5.2 Near Field Communications (NFC)

NFC is based on the same RFID mechanism. The idea is, however, to include this concept in smartphones. NFC illustrates the concept of low-power wireless networks, in which all devices are connected to other mobile phones in the same domain. It allows small amounts of data to be sent between two devices under a specific domain. The typical NFC range is 20 m. NFC can be regarded as one of the most important radio technologies for enabling wireless IoT communication. Actually, this technology allows the use of smartphones as other connected objects. (Shah & Yaqoob, 2016)

5.5.3 Machine-to-Machine Communications (M2M)

The M2M concept is similar to the IoT concept. Diversity of connected objects is the key driver in M2M communications in IoT; communication between various machines, such as computers, processors, sensors and smartphones. M2M has five components: M2M Device, M2M Gateways, M2M Communication Network, M2M Area Network and M2M Applications. All technologies used to communicate M2M can be used to enable IoT. (Shah & Yaqoob, 2016)

5.5.4 Vehicle-to-Vehicle Communications (V2V)

This type of communication requires a complex network infrastructure, as it involves vehicle communication. Vehicles usually move from place to place, leading to a non-fixed topology. Two types of interactions are involved in describing V2V communication: interaction between vehicle and vehicle and interaction between vehicle and road infrastructure. (Vermesan & & Friess, 2014)

5.6 Enabling Technologies of 5G In IoT

Several technologies from 5G designs are used to enable IoT communications to meet IoT requirements such as long coverage, extremely high data rate, scalability and capacity. These technologies are D2D, Millimeter Wave Technology, Relais, WSDN and NFV communication.

D2D communication in IoT: 5G systems uses direct communication concept in D2D communications *(Please refer section 3.4)* to support many IoT applications that required such communication. Using D2D communication to enable IoT applications has a many benefit in group communications. However, several open issues need to be investigated in D2D communication including: security, discovery of resources and interference management.

Millimeter Wave Technology in IoT: For IoT applications, the use of mm-wave could enable high data rates for these kinds of applications with great capacity. *Please refer section 3.3 for more details.*

Relays: In term of IoT systems, relaying is a key technology that provides scalability for IoT applications. Instead of having traffic over one base station (BS), IoT devices can be connected to several relay stations (RSs), which in turn allow for better connectivity and coverage.

WSDN: SDN can be used in the evolution of IoT systems to highlight flexibility and interoperability challenges. In term of flexibility, SDN allows dynamic IoT architecture that can deal with the number of connected devices and data being exchanged. In term of interoperability, splitting from data plane allows for independent use of resources. In fact, SDN allows several different services having different quality of service QoS to exist in the same domain.
Please refer section 3.1 for more details.

Network Function Visualization: The goal of this technology is to virtualize several network functions. This virtualization can increase the flexibility and scalability in the IoT applications. *Please refer section 3.2 for more details.*

Mapping IoT requirements to their enabling technologies:

IoT requirements	Enabling Solutions
Coverage	Relay
Large Capacity	MM Wave
Low Latency	D2D communication
Scalability	Relay & MM wave
Flexibility	WSDN and NFV
Interoperability	WSDN and NFV

Figure 31: Mapping IoT requirements

5.7 IoT architecture

The IoT is more than Internet-connected consumer devices. It opens far more opportunities than most organizations are pursuing today. Our approach to IoT architecture is reflected in the IoT architecture diagram, which shows the building blocks of an IoT system and how data is collected, stored and processed.

Four stage IoT architecture:

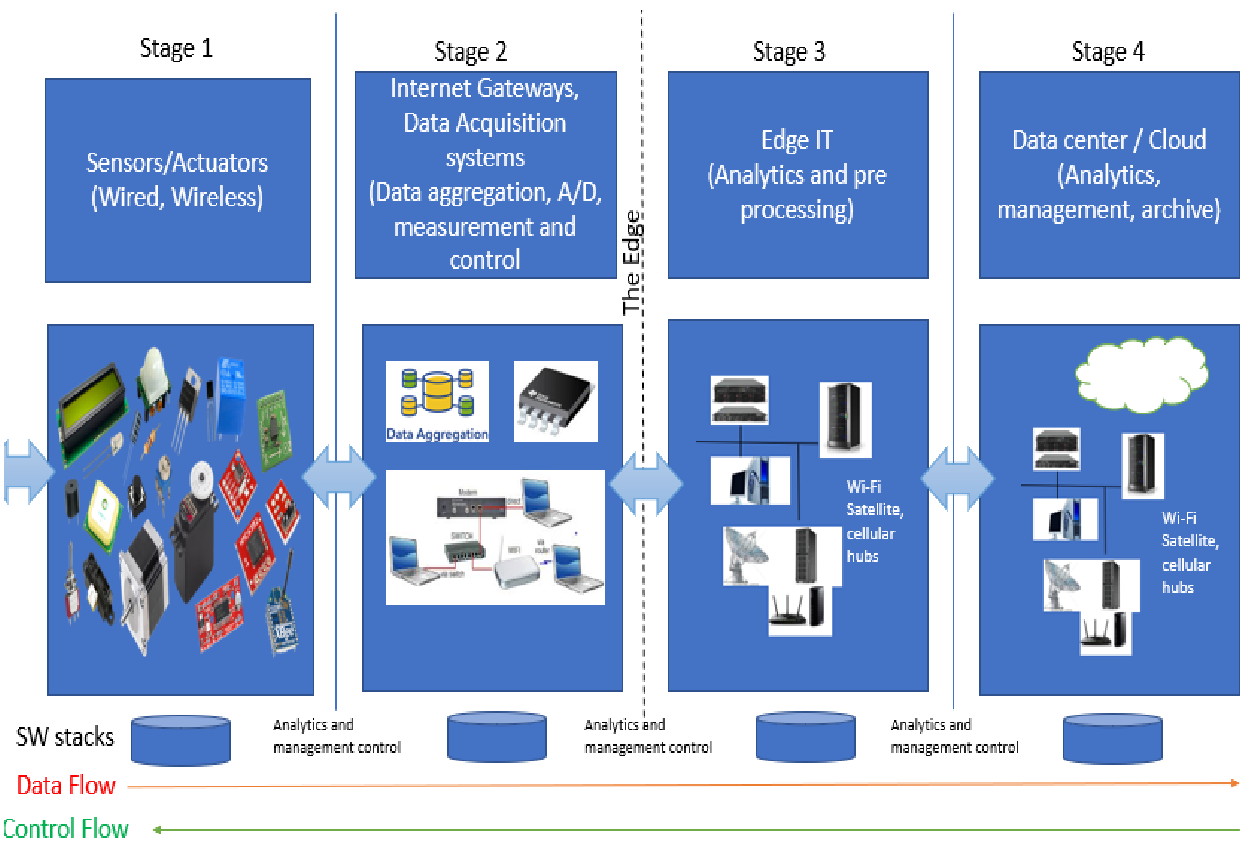


Figure 32: The four-stage architecture of an IoT system

Stage 1 of an IoT architecture comprises your connected objects, usually wireless sensors and actuators.
Stage 2 includes data aggregation systems for sensors and data conversion from analog to digital.
Stage 3 comprises edge IT systems that perform data preprocessing prior to moving to the data center or cloud.
In Stage 4, Data on traditional back-end data center systems are analyzed, managed and stored in Stage 4. Stage 1 is the operating technology (OT) professionals region, whereas stage 2,3 and stage 4 are typically IT controlled. The edge link indicates this demarcation.

Main Building Blocks of IoT system

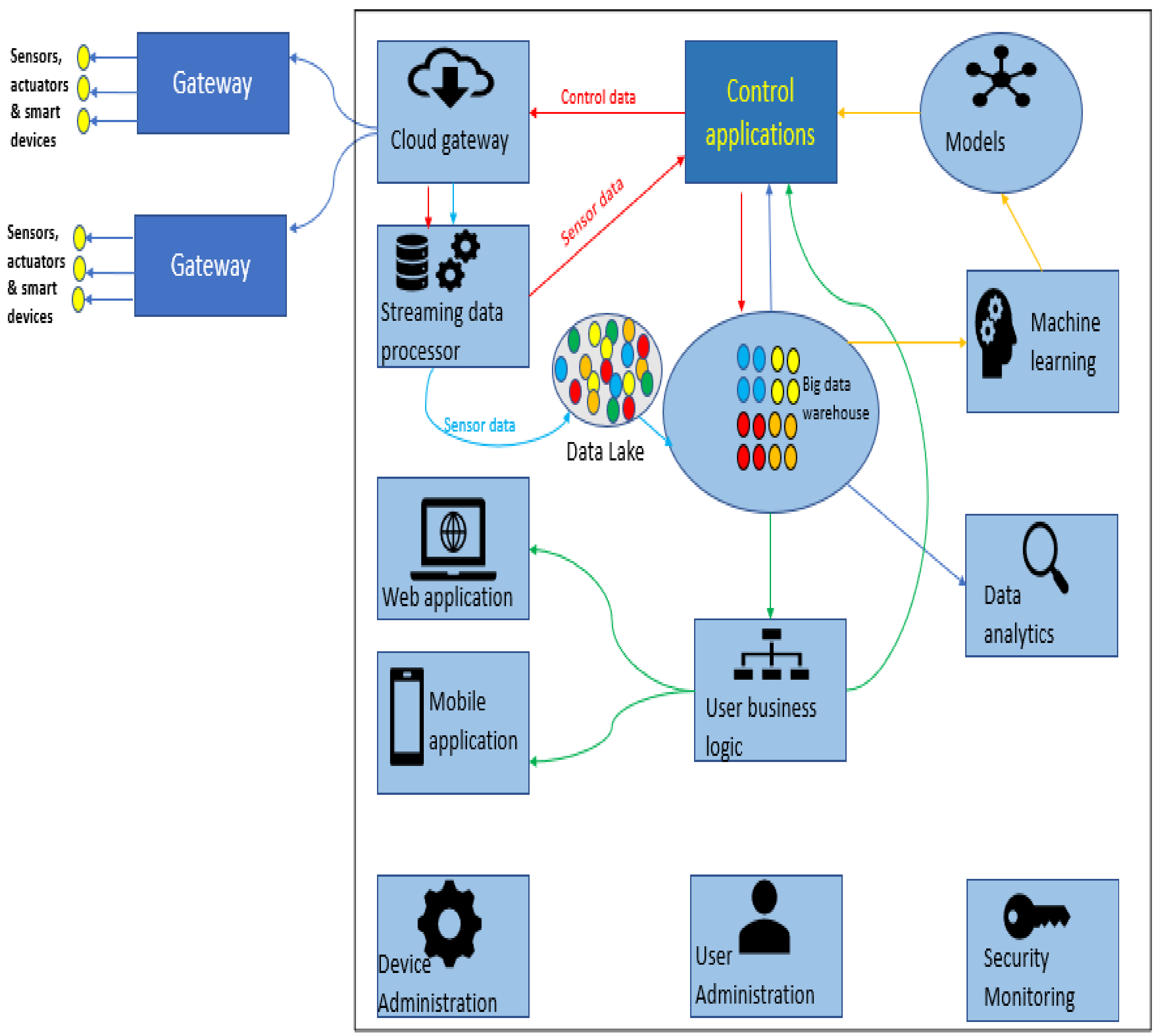


Figure 33: Basic elements of IoT architecture

5.7.1 Sensors and Actuators

5.7.1.1 Sensors

Sensors collect data from the measured environment or object and turn it into useful data. Sensors typically convert a recognized signal to a readable electrical –analog or digital–output.

5.7.1.2 Actuators

Actuators can also intervene to change the data generating physical conditions. An actuator is something that moves or actuates something. In particular, an actuator is a device which covers energy in movement or mechanical energy. An actuator is therefore a specific type of sensor that can, for example, shut off a power supply, open or close an air flow valve, increase or decrease the engine rotation speed and more. This stage consists of legacy industrial devices for robotic cameras, water-level indicators, sensors for air quality, accelerometers and heart rate monitoring, etc.

5.7.1.3 Data processing

Some data processing can take place at each of the four stages in an IoT architecture. However, while data are processed in the sensor, the processing can be limited in later stages. Data is at the heart of an IoT architecture, and attention should be paid to the immediacy and depth of insight when processing these data. The more urgent the information, the closer to the processing of the end devices. Data requiring more extensive processing must be transferred to a cloud or data center system. For example, robotic arm performing the surgery, this decision can’t simply wait, and data needs to be processed right at the sensor level at the very edge of the edge network for the fastest response.

5.7.2 The Internet Gateway

The sensor data is received in analog form and must be aggregated and converted into digital streams for further downstream processing. Data goes from things to the cloud and cloud to the things through the gateways. A gateway connects things to the cloud part of the IoT solution, allows data to be preprocessed and filtered before it moves to the cloud. Gateway communicates control commands from the cloud to things. Then commands are executed by things using their actuators.

5.7.2.1 DAS (Data acquisition systems)

DAS performs the required data aggregation and conversion functions. The DAS connects to the sensor network, adds outputs and converts from analog to digital. The Internet gateway receives aggregated and digitized data and routes it to Stage 3 systems for further processing via Wi-Fi, wired LANs or the Internet.

5.7.2.2 Data Pre-processing

Some sensors produce tens of thousands of data points per second. A gateway provides a preprocessing locally at the edge of the data before it is sent to the cloud. When data is aggregated, summarized and analyzed at the edge, it minimizes the data volume to be transmitted to the cloud, which can have a significant impact on response times and network transmission costs.

5.7.2.3 Security/filtering

Another benefit of an IoT gateway is security. The IoT network and the data it transports may provide additional security. Since the gateway manages information moving in both directions, it can protect data moving to the cloud from leaks and IoT devices from malicious external attacks with features such as detection of tampering, encryption, etc.

5.7.3 Cloud gateway

Cloud gateway enables data compression and secure data transmission between IoT cloud and field gateways. It also supports multiprotocol compatibility. The cloud gateway communicates with other gateways using different gateways protocols.

5.7.4 Streaming data processor

This processor ensures that input data is effectively transferred to a data lake and control applications. No data can be lost or corrupted occasionally.

5.7.5 Data lake

A data lake is used to store data in its natural format produced by connected devices. Big data are available in "batches "or "streams. "When information is needed for meaningful insights, it is extracted from a data lake and loaded into a Big Data warehouse.

5.7.6 Big data warehouse

Filtered and pre-processed data are extracted from a data lake to a Big Data Warehouse for meaningful insights. A Big Data warehouse only contains cleaned, structured and matched data, unlike the data lake, which contains all kinds of sensor data. In addition, data warehouse stores context information about things and sensors, for example, where sensors are installed, and stores the control applications that are sent to things.

5.7.7 Data analytics

Data analysts can use Big Data Warehouse data to find trends and gain effective insights. For example, when analyzed, device performance helps to identify inefficiencies and find ways to improve the IoT system. Data analysis helps us to make customer-oriented systems more reliable. The correlations or patterns found during the analysis may also contribute to the creation of control applications algorithms.

5.7.8 Machine learning and the models ML generates.

Machine learning is used to create more accurate and efficient control models. Models are updated regularly on the basis of the previous data collected in a Big Data Warehouse. When data analysts test and approve the application and efficiency of new models, new models are used in control applications.

5.7.9 Control applications

Control applications sends command and alerts to actuators. Some examples are mentioned below:

- Sensors can sense that soil is dry, and the water system will get the command from the control application to water the plants
- Based on weather forecast, smart home windows can receive a command to be open or close

Storing commands: The command that are send from control applications to actuators can also be stored in big data warehouse. This is required for investigation for cases such as command send by application but not performed by actuator. Secondly, storing commands from control apps may contribute to security, as an IoT system can identify strange and big commands which may evidence security breaches.

Control applications can either be rule-based (rules set by specialists) or machine learning based (timely updated automatically).

5.7.10 User applications

User applications are a software component of an IoT system that enables users to connect to an IoT system and allows them to monitor and control their smart things. Users can monitor their status with a mobile or web app, send commands to control applications and set automatic behavior options.

5.7.11 Device Management

To facilitate the interaction between devices, ensure secure data transmission and managing performance of connected devices we need device management. Device management performs below functions:

Identification: Device identification is required to establish the identity of the device to be sure that it's a genuine device with trusted software transmitting reliable data.

Monitoring and diagnostics: Ensuring smooth and secure performance of each device in a network and reducing the risk of breakdowns.

Configuration and control: To configure and control according to the purposes of an IoT system. Some parameters need to be written once a device is installed (such as unique device ID). Other settings might need updates (for example, time gap between data packets).

Software updates and maintenance: adding functionality, fixing bugs, addressing security vulnerabilities.

5.7.12 User management

Alongside with device management, it is important to provide control over the users having access to an IoT system. User management includes the identification of users, their roles, access levels and system ownership.

5.7.13 Security Monitoring

Security is the major concern in IoT because connected thing creates huge amount of data which needs to be carefully and securely transmitted and protected from cybercriminals.

To prevent such problems, it is important to log and analyze the commands sent by control applications to things, monitor the actions of users and store all these data in the cloud. Using this approach, we can address security breaches at the earliest stages and take preventive measures to reduce their occurrence in an IoT system. We can identify the patterns of suspicious behavior by comparing them with the previous logs.

5.8 IoT applications and Use cases

The following is the list of major real-world use cases of IoT.

5.8.1 Smart Home

Smart Home is a residence that has appliances such as lighting, heating, air conditioning, TVs, computers, entertainment, security, and camera systems that are capable of communicating with one another. Smart home can be controlled remotely by a time schedule, from any room in the home, as well as remotely from any location in the world by phone or internet.

5.8.1.1 Why Smart Home?

A Smart Home provides homeowners comfort, security, energy efficiency and convenience at all times, lifetime personalization regardless of whether anyone is home.

5.8.1.2 IoT architecture for Smart Home

IoT is defined as connecting various types of objects like smartphones, personal computer, tablets to internet. The main of IoT is connecting anything, anytime and anywhere. With IoT, home automation is becoming popular these days. Below is the basic IoT architecture for smart home.

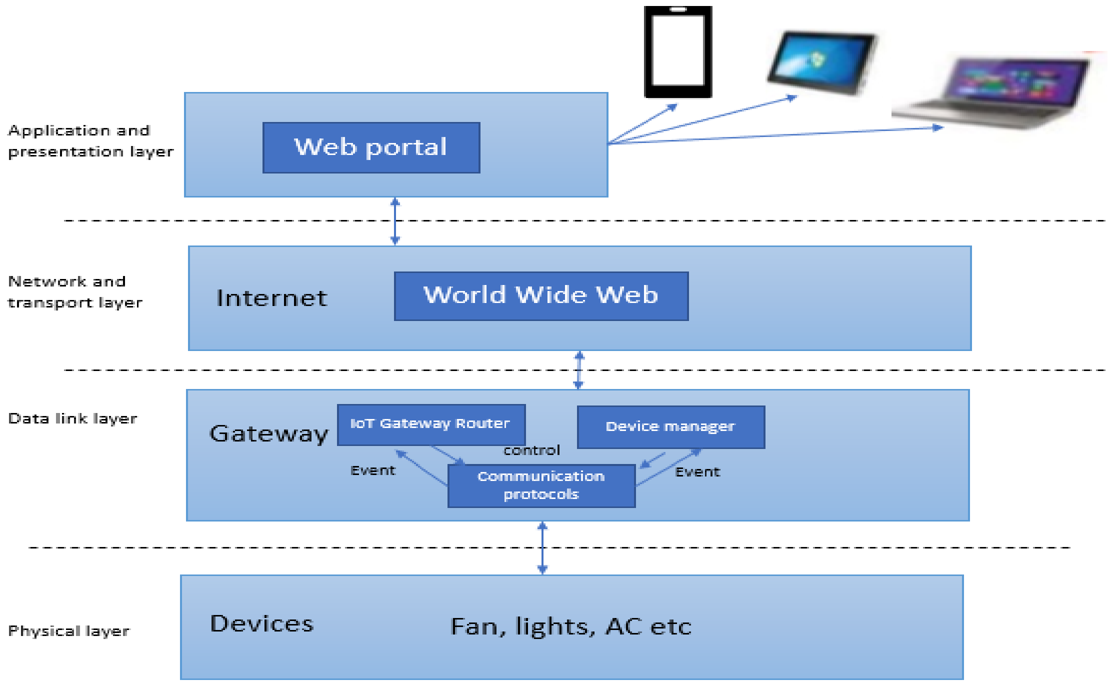


Figure 34: IoT architecture for Smart Home

The physical layer consists of the devices which needs to be controlled such as lights, heat, AC, TV.

The data link layer consists of IoT gateway router, device manager and various communication protocols

The Raspberry Pi is used as the IoT gateway which communicates to personal computer or smartphones by means internet in the *network and transport layer*

The application and presentation layer consist of web portal which will be used for designing a web page by which various appliances will be controlled. Mobile app can also be used for this purpose.

5.8.1.3 Block Diagram

It consists of Relay, PIR sensor, other detection sensors such as fire detection sensors, temperature sensor, IoT concept, Raspberry Pi/Arduino and web portal.

Relays are the switches that open and close the circuits electromechanically or electronically. Raspberry Pi/Arduino and by means of Wi-Fi and IoT concept, lights can be turn ON/OFF using the relay.

Lights and fans can be controlled using web server or through mobile app

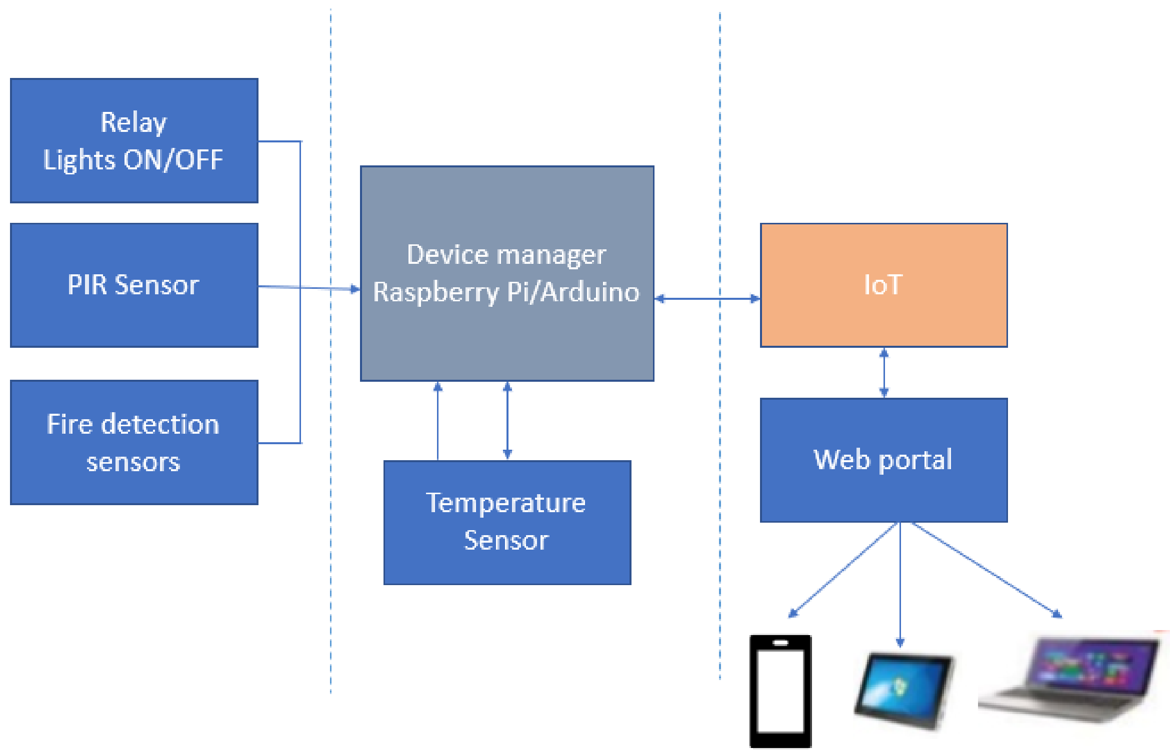


Figure 35: Block diagram for smart home automation

Relay:

An electrical switch that opens and closes a control system under an electrical circuit is called a relay. The switch is operated by an electromagnetic in the original form to open or close one or more contact sets. It controls high current AC loads from much lower circuitry of DC control. It is switched by a significantly lower voltage and a much lower current than most mechanical relays.

The PIR sensor:

A PIR sensor is an electronic sensor measuring infrared (IR) light radiating from objects in its field of view. It is used to detect the presence of people and send messages in the event of robbery. This device detects movement by receiving radiation and sends this reading to Arduino / Pi raspberry alarming the user that there is a risk in his / her home. They are small, affordable, low-power and easy to use. PIR is basically composed of a pyroelectric sensor that can detect infrared radiation levels. In addition to this sensor, there are other support circuits consisting of resistors and condensers. This chip takes the sensor output and processes it from the analog signal to emit a digital output pulse. Digital pulse 3V (motion detected) and low (motion detected) when idle. The range of sensitivity is up to 20 feet or 6 meters. Range of power supply 5V-12V.

Raspberry Pi or Arduino?

Raspberry Pi: A Raspberry Pi is a low cost, single board computer with a credit card size, usually with a Linux operating system and the ability to run multiple programs. It's more complicated to use than an Arduino. Raspberry Pi is best used when you need a full-fledged computer: driving a more complicated robot, performing multiple tasks, making intense calculations.

Arduino: An Arduino is a motherboard microcontroller. Arduino is an open source electronics platform based on hardware and software that is easy to use. You can tell the board what to do by sending the microcontroller a set of instructions. For simple repetitive tasks, an Arduino board is best used: opening and closing a garage door, reading the outside temperature, etc.

Web Portal: Various home applications can be controlled remotely with the use of the web portal. Information is stored in the embedded system and such web server type is called the embedded web server. Raspberry Pi / Arduino is used to induce server information.

5.8.1.4 Advantages

- **Savings:** Smart thermostats and smart light bulbs save energy and reduce the cost of utilities over time. Home automation technologies also monitor the use of water to avoid exorbitant bills of water.
- **Security:** security cameras offer advantages by either remote package delivery monitoring or real-time videos of residents or unwanted visitors using motion sensors such as PIR.
- **Control:** consumers also choose smart home appliances to improve home control functions. With home automation technology, you can always know what is going on in your home.
- Comfort, tranquility of mind, convenience are other benefits of home automation.

5.8.2 Wearable IoT (WIoT)/IoT in healthcare

The introduction of wearable devices has given IoT a new dimension by creating an intelligent fabric of body or near-body sensors that communicate with one another or the Internet. In other words, Wearable IoT (WIoT) is defined as a technological infrastructure that interconnects wearable sensors to monitor human factors such as health and wellness, behaviors and other useful data that are important for improving the daily life of users.

5.8.2.1 Block Diagram-Wearable IoT

Architecture of all IoT applications have the similar architecture framework as of basic IoT as described in previous chapters.

Wearable body area sensors (wBAS), internet connected gateways and cloud & dig data support are the components of WIoT architecture.

****Internet-Connected Gateways and Cloud and big data support have the similar functionality that has been described in section 5.7*

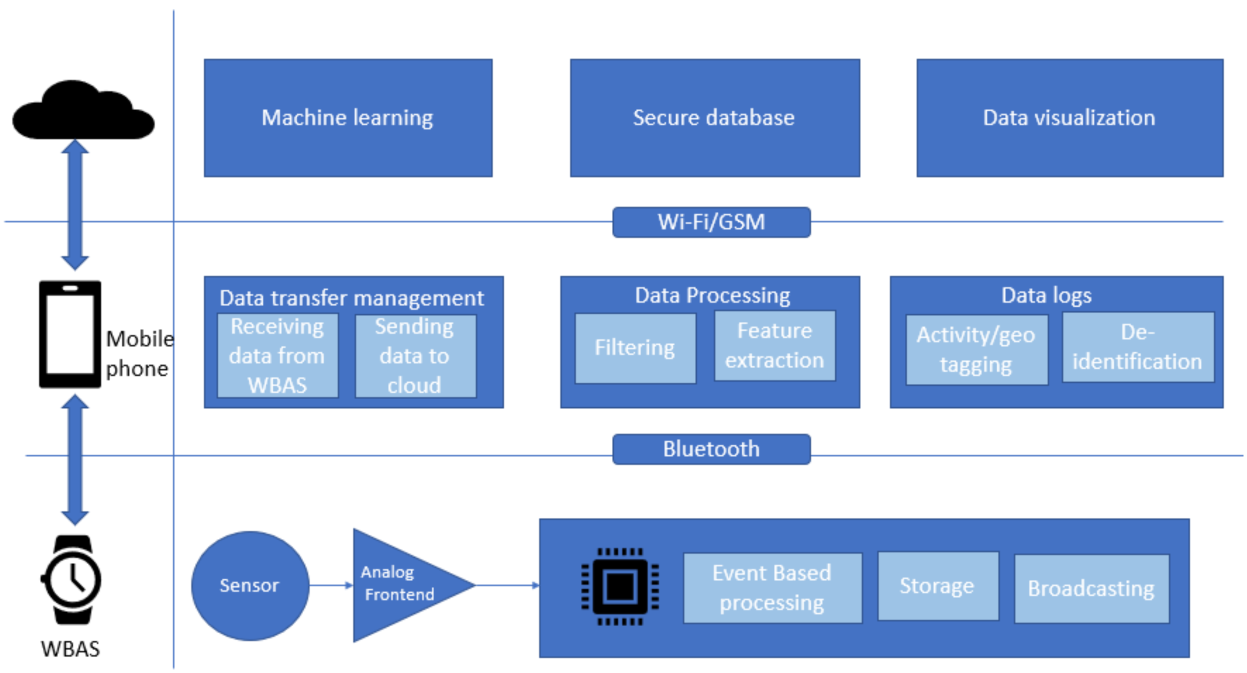


Figure 36: Functional block diagram of cloud-assisted BAS

Wearable Body Area Sensors: Wearable body area sensors (WBAS) are frontend components of WIoT that captures health-centric data. Main functions of wBAS are

- Data collection either directly from the body via contact sensors or from peripheral sensors that provide indirect information about the body and its behaviors.
- Preparing the data for onboard analysis or remote transmission for further analysis.

Internet Connected gateways: WBAS have limited computing power and communication bandwidth this is why they need to transmit the data to computing resources such as smartphones, tablets, and laptop PCs, or remotely-located cloud computing servers. These devices are used as gateways that enables information flow from sensors to the cloud or server centers for storage and further analysis. They have sort range communication enabled such as Bluetooth used to exchange data with wearable sensors, and of heterogeneous networks, such as WIFI and GSM, used to send the data to the cloud.

Gateways also store data for pre-processing, evaluation (whether data is relevant) and then send the data to remote servers. To improve the performance and the battery life of smartphones, Mobile Cloud Computing (MCC) is used that optimizes mobile computing and networking protocol to minimize the burden of computing for smartphones. WIoT can greatly benefit from MCC, as it allows data storage and data analysis on the cloud platform.

Cloud and big data support: A cloud computing infrastructure manages wearable data and support advanced functionalities of data mining, machine learning, and medical big data analytics. Cloud-assisted BAS (CaBAS) is a new technology that provides integration of MCC and WBAS to facilitate the growth of scalable, data-driven healthcare.

As shown in above diagram below are the main benefits of cloud-assisted BAS.

- Event-based Processing: Reduce unwanted data processing on resource constraint wearable sensors.
- Annotated data logs: It can add activity level information on top of clinical data to enhance the accuracy of machine learning algorithms on cloud.
- Person-centered databases: This stores the personalized data of patients securely for longitudinal analysis.
- Data visualization: it channelizes the data to end users such as physicians and patients to provide decision support and patient-physician interactions.

5.8.2.2 Advantages

- **More accurate data analytics:** Healthcare organizations use data analysis in a variety of ways to improve patient outcomes (such as predicting post-surgical complications, determining the most effective treatment for patients and reducing readmission) because wearable data is transmitted directly to providers, it is often more accurate than patient data.
- **Improved patient health:** Wearables focus on prevention, patients often see better health as the acute event does not occur. For example, if remote monitoring catches early

warning signs of complications for a cardiac patient, it is better for providers to take preventive measures to reduce the risk of a heart attack.

- **Increased quality of care:** The more information providers have about patients, the better they can provide quality care. In short, providers reduce the option for providers and provide better, more targeted patient care.
- **More timely interventions:** With Wearables, the information is sent to the provider in real-time, which means the provider can intervene more rapidly.
- **Reduction in healthcare costs:** Earlier, routine monitoring took place in the clinic and required a visit. However, Wearables allow for remote monitoring so the need for routine office visits is eliminated in some cases. This decreases the costs to both patients and insurance companies.

5.8.3 Connected Cars

A connected car is a car that has Internet access and usually also a local wireless network. This allows the car to share Internet access and therefore data both inside and outside the vehicle with other devices.

Connected cars can talk to other cars, exchange data and alert drivers to potential collisions. They can also communicate with sensors on signs on stoplights, bus stops, and even ones embedded in the roads to get traffic updates and rerouting alerts. Moreover, they can communicate with your house, office, and smart devices, acting as a digital assistant, gathering the information you need to go about your day. In short it is driven by Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure which is generally referred to as Vehicle-to-Everything (V2X).

In general, a connected car is a vehicle which is able to optimize its own operation, maintenance as well as comfort of passengers using onboard sensors and internet connectivity.

5.8.3.1 Connections of Connected Car

The car can be connected in several ways. It depends with which node it is connected, and every scenario uses a different form of technology. Below list shows several different nodes that the car is typically connected to:

Car-to-Car: In this type of communication, cars communicate wirelessly among each other over short-range communication with safety-related alerts.

Car-to-Network: In this form of connection, the car is connected to the cellular network (2G, 3G or 4G), and is the medium to where SMS, Data and Voice Calls are transmitted.

Car-to-Cloud: In this type of connection the car is connected to cloud which can store data and can be accessed by the car via the network.

Car-to-Infrastructure: the car is connected to the surrounding environment in this form of communication and exchanges data, such as traffic lights, stop signs or speed limits.

Car-to-TSP: In this connection car utilizes the network but is connected to a backend vehicle service provider. The Telematics Service Provider (TSP) can share data with the car.

5.8.3.2 Connected car Architecture

Car connected is a car with internet access. It allows the car to be shared data on the Internet. The Internet connection is typically made by an integrated modem on board the car called a Telematics Control Module (TCU) and a Wi-Fi connection available inside the car module. (Elliott & Amy-Mae, 25 February 2011)

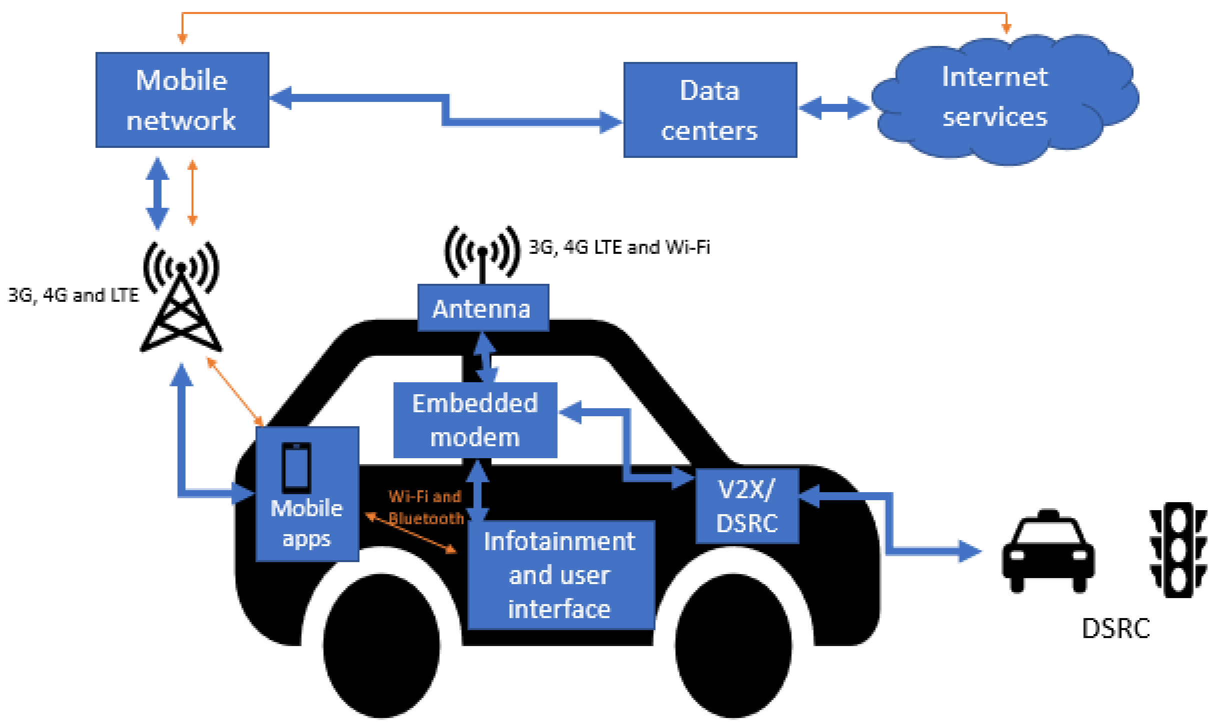


Figure 37: Connected Car architecture

Hardware modules that enable connectivity to anything outside the vehicle are as follows:

- *V2X/DSRC:* Vehicle-to-X (V2X) is a term used to describe the connection of a vehicle to anything such as a vehicle or infrastructure. V2X standards are currently being defined and are expected to operate with DSRC technology.
- *TCU/Embedded Modem*: The Telematics control unit typically houses the embedded modem which provides an Internet connection to the car based on a Cellular connection using 2G, 3G or 4G.

- *Infotainment:* Infotainment provides the car with user interface (UI) and radio / entertainment / media functionality, enabling the driver to connect via Wi-Fi or Bluetooth.

Vehicle Module	Technology	External to the vehicle
V2X	DSRC	Vehicle/Infrastructure
TCU	2G/3G/4G	Telematics services
Infotainment	Bluetooth/Wi-Fi	Smartphone/Home

Figure 38: Technology Chart

Below is the wireless technology that enables the connectivity between the modules inside and outside the vehicle as shown in above figure:

- *Dedicated Short Range Communication (DSRC):* a short-range wireless channel for automotive use. It uses the 5.9 GHz band.
- *Cellular networks (3G, 4G):* mobile telecommunications technologies are 3G and 4G. They are based on a set of standards that you must comply with to use services and networks for mobile communication.
- *Wi-Fi:* wireless local area communicating technology using the 2.4GHz and 5GHz bands. It is defined by the Wi-Fi Alliance and is based on the standards IEEE 802.11.
- *Bluetooth:* Short ranged, low powered radio waves. It communicates on the 2.4-2.48 GHz band.
- *NFC:* Near Field Communication (NFC), operates at 13.56 MHz and transfers wireless data with a range of 4- 10 cm up to 424 Kbit / s.

5.8.3.3 Functions/Advantages of Connected Car

- Automatic roadside assistance.
- Information calls to Telematics Service Providers (TSP)
- Stolen Vehicle Tracking (SVT)
- Remote Service (Vehicle on/off, vehicle lock/unlock)
- Vehicle Updates
- Video streaming / Web browsing

5.8.4 Smart Cities

Another powerful IoT application is Smart Town. Smart surveillance, automated transport, smarter energy management systems, water distribution, urban security and environmental monitoring are all examples of internet applications for smart cities. IoT will solve major problems faced by people living in cities such as pollution, congestion, energy shortages and so on. Products such as Smart Belly trash enabled cellular communication send alerts to municipal services when a bin needs to be emptied.

By installing sensors and using web applications, the public can find free parking spaces throughout the city. The sensors can also detect problems with meter manipulation, general malfunctions and any installation problems in the electricity system.

5.8.5 Industrial Internet

Industrial internet nowadays also known as Industrial Internet of Things (IIoT). IIoT is encouraging industrial engineering with sensors, software and big data analytics to create brilliant machines. The main sectors that are benefitted from IIoT are manufacturing, healthcare, energy and power production, logistics and transportation, oil and gas, and agriculture.

5.8.5.1 Benefits of IIoT

Industrial IoT solutions make it possible to maintain processes more efficiently, affordably and easily. Currently, almost all companies work in a simple way, they solve the problems / equipment if something breaks. However, IIoT correctly predicts future failures. The equipment can be replaced and maintained in a much more efficient manner, reducing the risk of industrial breakdowns and processes.

Below are some benefits of IIoT:

- **Facility Management**: In IIoT sensors are used to increase the effectiveness of facility management. They can monitor temperature, vibrations and other factors that could be leading to less than optimal operational conditions.
- **Inventory Management**: IIoT reduces the risk of inventory management errors. It helps to monitor across the supply chain and give companies a comprehensive view of inventory. Provides better and accurate estimate of available materials and supplies, which prevents slowdowns.
- **Enhanced industrial safety**: The Internet of Things effectively combines with Big Data analysis. Key health and safety performance indicators can therefore be monitored constantly to ensure better working conditions.
- **Optimization of logistics and the supply chain:** Real-time supply chain information is also made available by relying on IoT. Products and supplies will be easier to track and slowdowns and inefficiencies will be identified.
- **Smart metering:** Smart meters can monitor resource consumption, such as power, water, fuel, etc. By using IoT sensors, producers will know how much and for what is consumed. Operational expenditure can be significantly reduced through effective management. See section 6 for more information

5.8.6 IoT in agriculture

The demand for food is also increasing with the growing population. Governments help farmers use advanced techniques and research to improve the production of food products. Intelligent agriculture is one of IoT 's fastest growing fields. Farmers use meaningful data insights to achieve better returns on investment. Some simple uses of IoT are the sensing of soil moisture and nutrients, the control of water use for plant growth and the determination of custom fertilizer.

5.8.7 Smart Retail

The IoT potential in the retail sector is immense. It provides retailers with an opportunity to connect with customers to improve their experience in the store. Smartphones will be the way for retailers to stay out of store with their consumers. Interacting via smartphones and using Beacon can help retailers better serve their consumers. They can track consumers too.

Beacon Technology - Beacons are small, battery-operated wireless devices that transmit Bluetooth signals to nearby smartphones. In the context of retail, beacons can reach customers who have Bluetooth enabled and the right retail apps downloaded onto their phones.

5.8.8 Energy engagement/Smart Grid

The power grids of the future are not only intelligent but also extremely reliable. The concept of smart grids is becoming popular throughout the world. The basic idea behind the smart grids is to automatically collect data and analyze the behavior or electricity consumers and suppliers to improve efficiency and the economy of electricity use. Smart grids can also detect power outages faster and at individual household levels, such as the nearby solar panel, enabling a distributed energy system.

6. Designing IoT based Smart Water Metering System

6.1 Introduction

More than 70% of the surface of our Earth is covered with water. While water appears to be abundant, 97.5% of all water on earth is salt water, leaving only 2.5% fresh. Almost 70 percent of that fresh water is frozen in the icecaps; most of the rest is present as soil moisture or is found in deep underground aquifers as groundwater that is not accessible for human use. Only about 1 percent of the fresh water in the world is available for direct human use.

For this reason, water conservation is becoming hot potato worldwide and the first step in water conservation is to understand water consumption. Smart metering plays an important role in this context.

The water industry, like other industries, is currently undergoing a process of transformation through ICT (Information and communication technology) and near real time data generation. The main goal of smart water metering is to increase the efficiency for operations and management of water and reducing the expenditure and carbon footprint through the smart IoT technology.

Smart meters are the core of the global IoT, it records and track details of energy usage in homes and industries and send this information to utilities frequently in order to increase the overall efficiency and reliability of currently outdated and overburdened utilities.

As discussed in previous chapters, IoT can bring many advantages to businesses of all shapes and sizes. And as the IoT enters our everyday world, it brings with it more opportunities for change and innovation. Smart meters are a classic IoT advancement. It is predicted IoT will have an economic impact of more than $11 trillion per year by 2025

6.1.1 The need for smart metering

As the demand of water increases, the smart water metering technologies seems to be central to reducing the demand of water and facilitating more effective management. From a broader perspective, numerous studies have identified that the metering of the domestic users can have the positive impact on reducing water usage (Memon & Butler, 2006).

By gaining the information with regards to usage, consumers can become more aware about their water usage behavior. This encourages more efficient and sustainable management of water resources.

Traditional Metering	Smart Metering
1. Accumulation based measurement of	1. Accumulation, Pulse or time-based

consumption 2. Meters are read manually 3. A single consumption value is given to the user based on the meter reading	measurement of consumption 2. Data logger and transponder 3. Remote meter reading 4. Multiple consumption value based on different time variables 5. Consumption data available through network consumption

Figure 39: Comparison of traditional and smart metering

6.2 Smart water meter and its benefits?

A smart water meter is an electronic device that records consumption of water and communicates the information to the water supplier for monitoring and billing. Smart meters typically record water consumption at short intervals of time and remotely sends this information to energy distributors and retailers.

Smart water meters not only give residents an accurate and up to date information on their water consumption, they also help utilities to detect thousands of potential leaks in their infrastructure and at properties potentially saving water and money.

Smart water meters have very low electromagnetic levels, using just 25mW power emission. Mobile phones use 80 times more (2,000mW) and Wi-Fi four times higher (100mW).

Smart meters enable two-way communication between the meter and the central system using Advanced Metering Infrastructure (AMI).

6.2.1 Benefits of Smart Metering

- ***Smart meters are cheaper to read***
  There is a lot of cost saving, because we don't have to visit every home for reading purposes, instead meters communicate directly with the utility home office without any meter readers.

- ***Smart meters encourage customers to save energy***
  In fact, customers can see how their electricity consumption changes by one hour or even in one minute. By doing so, you can be more aware that it could save you money if you postpone some of the activities such as washing clothes to off-time. This can lead to less electricity being used during peak hours, when utilities use expensive power plants to cover peak electricity usage.

- ***The utility gets better information***
  Smart meters monitor the voltage of the line and report it to the utility. This information can be used to decide where to upgrade or reconfigure their distribution lines, thus

providing their customers with more reliable and better service. It also detects power shortages or line problems as they occur.

- ***The utility can better manage consumption***
  Utilities can manage consumption by means of time-to-use billing, dynamic pricing and load shedding (owner of a house or company has the choice to prioritize appliances) instead of causing total blackout.

- ***Faster leak detection***
  Utilities often receive reports from every smart meter, sometimes every 15 seconds. Sometimes they are called "beacons. " If a meter has not been reported for some time, an alarm will be generated. When a customer reports an outage, the utility can send signals (pings) to all meters in the area and easily detect leak detection.

- ***Easy connect/disconnect of service:*** Smart meters have an electronic disconnect inside, which can be controlled from the utility company's office, without a crew going to the site.

- ***The new meters can be more accurate:*** The traditional meters were totally mechanical. The magnetic field created by the water going through the meter turned a wheel inside the meter. The revolutions of this wheel were counted via a gear and displayed as water consumed. This method was very simple and reliable but not quite accurate. The new digital meters are more accurate and shows the real consumption.

6.3 Types of Smart Water Meter

Meters are classified into two basic types namely positive displacement water meters and velocity water meters.

6.3.1 Positive displacement meters

A known volume of liquid moves in a small compartment in positive displacement meters. It works by filling and emptying these compartments repeatedly. The flow rate is calculated according to the number of times these boxes are filled and emptied. The movement of a disk or piston drives an arrangement of gears that records the volume of liquid leaving the meter and records it. There are two types of positive displacement meters, namely disks and piston water meters, that can be used to measure water consumption.

Positive displacements are sensitive to low flow rates and have highly precise flow rates across a wide range. They are used in residences, in small businesses, in hotels and in apartments. These meters vary in size from 5/8 "to 2 ".

6.3.1.1 Nutating disc water meters

These meters contain a round disk in a cylindrical chamber. The disk in spindle mounted. The disk nutates as it passes a known volume of liquid through the cylindrical chamber. The rotating movement of the disk is then transferred to the register, which records the water volume that passed through the meter.

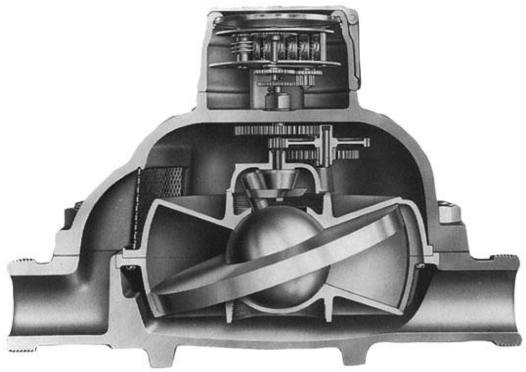


Figure 40: Nutating disc water meter
(Ref: http://www.semrad.com.au/products/flow-meters/niagara-meters-nutating-disc-flow)

6.3.1.2 Piston water meters

This water meter has a piston moving back and forth to record the water volume. For each rotation, a known volume of water is measured, and the motion is transmitted to the register by arranging the magnetic drive and gear assembly.

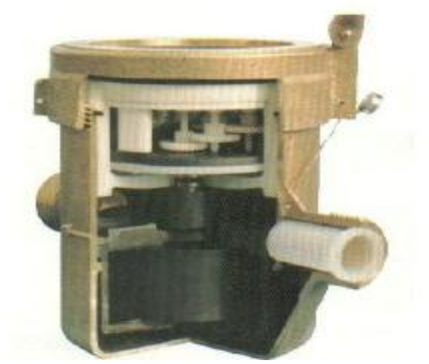


Figure 41: Piston water meter

6.3.2 Velocity meters

The speed meters as the name suggests measure the speed of the flow through the known capacity meter. The flow speed is then converted to the flow volume to determine the use. These meters are available in two inch and larger sizes, with the exception of multi-jet meters between 5/8 "and 2 inch. These meters contain five types as follows:

6.3.2.1 Fluidic Oscillator water meter

In these types of meters, water enters into the oscillator through a nozzle that creates jet. When the jet enters the flow chamber it travels along one of the diffuser walls through the principle of the Coanda effect and then exit from the flow chamber. Due to local pressure from the adjacent wall the jet starts to oscillate between the one wall or the other. This oscillation between the diffuser walls continues during flow, where each oscillation represents a specific volume through the meter.

These oscillations are then monitored by electrodes located next to each diffuser wall in which a pair of powerful permanent magnets induce an electric current in the jet. Sensing electronics capture when oscillations occur and total the volume transmitted to a liquid crystal display showing the registered volume.

Figure 42: Fluidic Oscillator water meter
(Ref - http://sdonga.co.kr/product/electronic-water-meter-fluidic-oscillation/)

6.3.2.2 Ultrasonic transit time water meters

This meter measures the difference of the transit time of ultrasonic pulses propagating in and against the direction of flow. The measure of the average velocity of the water along the path of the ultrasonic beam is transit time difference. Changes in the water velocity are electronically converted into changes in the flow rate.

Figure 43: Ultrasonic Transit Time water meter
(Ref: http://www.heremeter.com/battery-clampon-sonic-water-meter.html)

6.3.2.3 Electromagnetic or "Mag" water meters

Mag meters are based on Faraday's law. The velocity of the fluid is directly proportional to an induced voltage (electromotive force) as the fluid flows through a constant magnetic field. As the velocity of the water increases, the induced voltage increases and in turn the volume of water measured is greater.

Figure 44: Mag water meter

6.3.2.4 Multi Jet water meters

As the name suggests, this meter creates several water jets against an impeller using several ports around an internal chamber. The speed of rotation of the jets depends on the speed of flow of water. Multi-jets are very precise at low flow rates, but these meters are not intended for high flow because they do not have the direct flow path required for high flow or large meters. In general, multi-jet meters have an internal strainer that can protect the jet ports from clogging.

Figure 45: Multi-Jet water meter

6.3.2.5 Single jet water meter

The waterjet is channeled through an injector before the turbine hits. The single jet injector adjusts the flow profile. Its large bore area avoids clogging the meter over speed.

Figure 46: Single-Jet water meter

6.4 System/Network Monitoring method

6.4.1 Advanced Metering Infrastructure (AMI)

SWM uses advanced metering infrastructure. AMI is an architecture for automated two-way communication between a smart meter (which uses IP address) and a utility company. The goal of an AMI is to provides utility companies with real-time data about water consumption and allow customers to make informed choices about water usage based on the price at the time of use. AMI is important part of smart grid technology. The objectives of AMI can be remote meter reading for error-free data, network problem identification, load profiling, energy audit and partial load curtailment in place of load shedding.

6.4.1.1 Building blocks of AMI

AMI consist of various hardware and software components, that play important role in measuring energy consumption and transmitting information about water usage to utility companies and customers. Main building blocks of AMI are:

- **Smart Meters**
- **Communication Network:** Communication Network: advanced two-way communication networks enable information from smart meters to utilities and vice versa. For more details, see section 6.7.
- **Meter data acquisition system:** Software applications used to acquire data from meters via communication network and send it to the MDMS.

- **Meter data management system (MDMS):** MDMS is a host system which receives, stores and analyzes the metering information.

6.5 Building Blocks of Smart Water Meter

Most traditional water meters are mechanical meters which converts the water flow to the movement of a rotating disc. Each rotation measures given volume of water. The mechanical water meter functions include the measurement of water flow with mechanical pointers.

With the development of technology, mechanical water meters are gradually being replaced by smart meters. In smart water meters, a sensor converts the water flow to an electrical signal, which can be accepted and processed by the microcontroller unit.

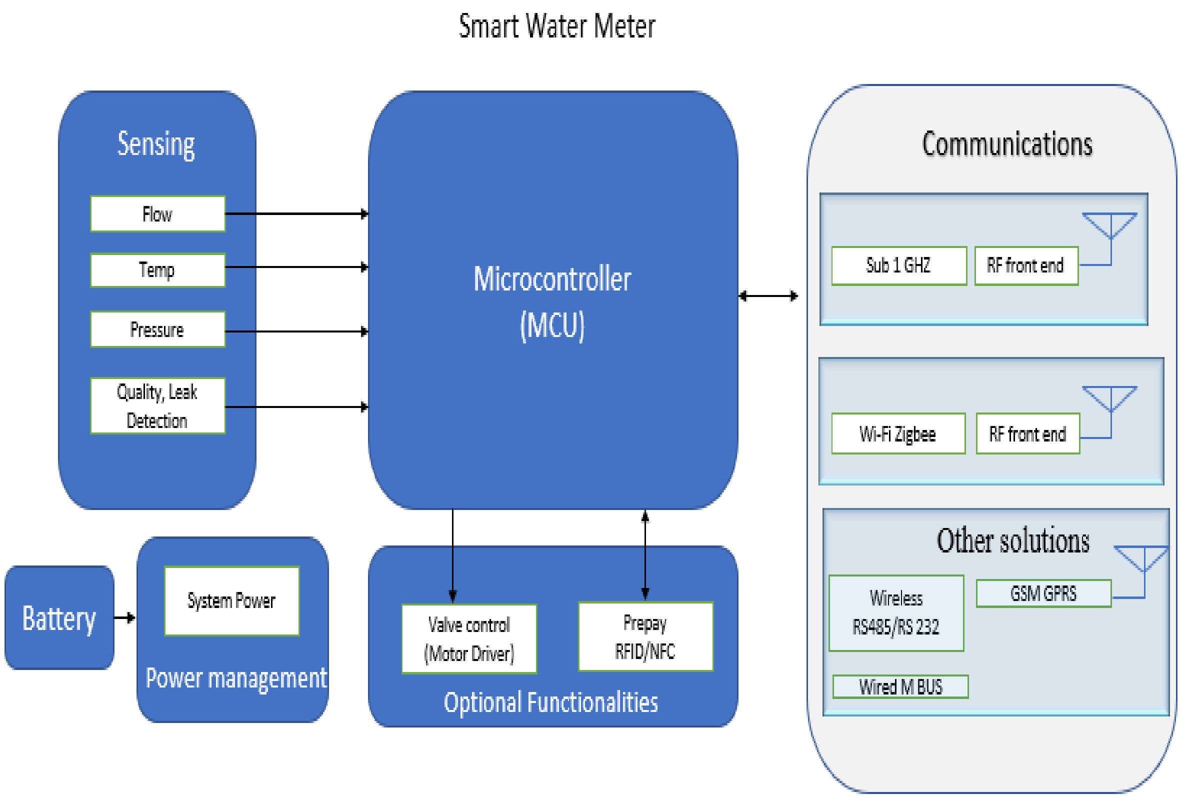


Figure 47: Smart water meter structure

Most smart mechanical water meters use hall-effect sensors to measure water usage. These meters are equipped with a magnet which is mounted on one rotating disc of the mechanical meter. The reed/hall-effect sensor is conveniently mounted on a printed circuit board to sense the magnet each time it completes a revolution and send out a pulse signal to the microcontroller unit (MCU). The water flow data is transferred to an information management system after processing by the MCU in the electronic module.

Low power RF radios are typically used to communicate between the battery-powered water meter and either another meter in a mesh network or a or in a wired MBUS. Meter based on near field communication (NFC) system receive tariff information, firmware upgrades or shut-off valve activation in combination with prepayment as shown in a diagram above.

The battery life expectation ranges 10 to 15 years which is a point of concern for water meter manufactures so to address this problem it is required to combine the right power supply design and radio performance without draining the battery.

For example, we can combine the TPS62730 step-down converter with the MSP430 microcontroller to provide the lowest battery consumption to ensure that the meter remains in the field for many years without having to change the battery.

6.5.1 Components of Smart Water Metering.

Smart water meter essentially performs three basic functions: capturing, collecting and communicating up-to-date information in real time. The information is available as an electronic signal that can be captured at an smart water meter, logged in the data logger and processed using the analysis software. When interrogated, the data logger downloads the water consumption data to a server, giving the value of water consumption for the required period.

In this way smart meters can send the captured data to a broad audience, such as utility managers, consumers and facility. Below figure shows the components of a typical smart meter set-up for a residential household.

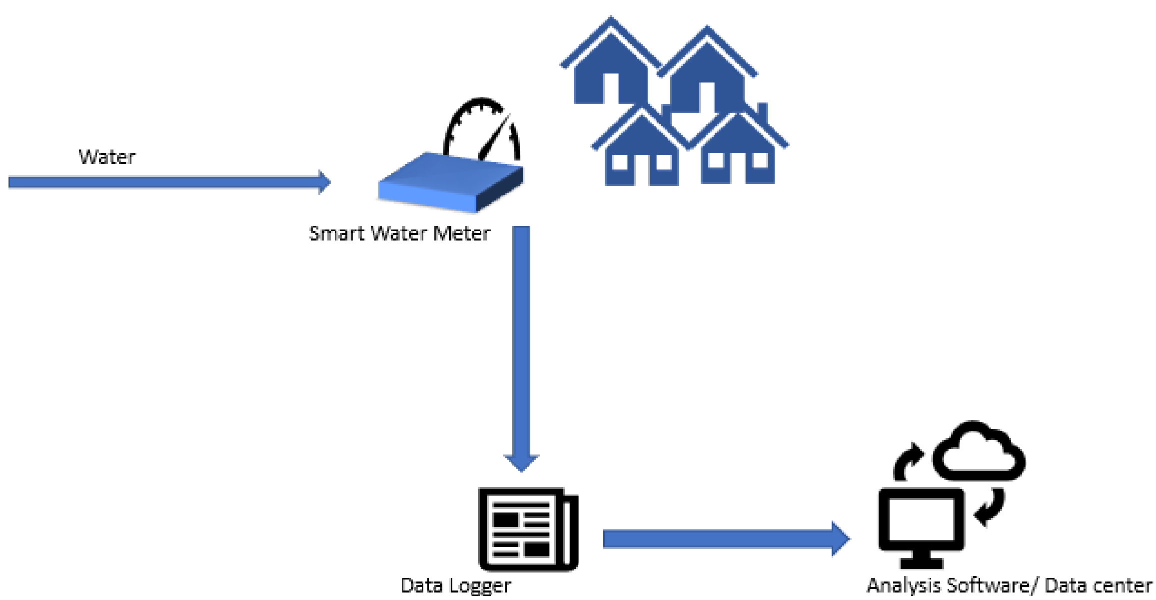


Figure 48: Components of a typical smart water meter set-up for a residential household

A smart water meter replaces the traditional accumulation meter and thus providing more accurate water readings through efficient methods of water flow detection. SWM can occur without the use of an actual smart water meter.

The components that make up a smart water meter include flow detection hardware, a transmitter and memory to store data.

6.5.1.1 Transmitters

A transmitter is the most basic component of the smart water meter (SWM). A transmitter can be attached to an accumulation meter to enable wireless data transmission. Transmitters are used to transmit water meter readings to a remote location (typical range 1KM) in the form of radio waves. However, transmitting data over large distance requires the use of GSM transmitter. Most applications of smart metering use radio transmitters because they are cheaper than the GSM transmitters.

6.5.1.2 Data loggers

Transmitters can further be improved by joining data loggers with data storage capabilities. This device can both store and send interval data. The transmitter and a data logger are attached to an accumulation meter shown below: (Amanda Blom)

Figure 49: Smart Water meter with data logger

Data logger is adjustable in time scale, it can range from one recording per second to one recording per month. The main immediate advantage of interval data logger is, it simplifies leak detection. Leaks are identified by the constant flow of water over time. There are many Software available that can calculate the precise amount of water lost in an interval of time.

6.5.1.3 Gateway

Gateway is a device that receives signals from one or more data transmitting devices or SWM and sends the information to a distant location. Smart water meters and data loggers typically use radio transmitters to send information to a gateway, which then relays all end-user data via telecom networking.

6.5.2 What they Transmit and Receive

Smart meters work under one of two concepts. Those that only transmit data of household usage patterns and those that not only transmit this data but can also receive data from the network.

The information sent to the utility may include

- detailed usage
- voltage monitoring data
- various alarms

The information sent to the meter may include

- pricing information
- pre-pay information
- disconnect/reconnect instruction
- alarm/load-shed instruction
- programming of meter
- upgrade of meter software
- date and time

A smart meter can communicate with appliances at home via a network in the home area. It could communicate with:

- a display screens
- a gas or water meter
- various appliances (room thermostat, water heater, etc.)

6.6 Sensing in IoT

6.6.1 Flow and Pressure Monitoring

Water Flow monitoring: The sensors stores information regarding several key factors, from the site settings to serial numbers that are usually required during installation, maintenance or replacement.

Measuring the volume of water used in commercial and residential buildings is important. The water is supplied through a public water supply system to homes and offices. Water meters can also be used for calculating the flow rate of a part of the system in water sources or throughout the water system.

The water flow rate is measured on the electronic or mechanical register in cubic meters (m3) or liters. Two common methods for measuring water flow meters are used: speed and flow meters for displacement. Each type uses a variety of technologies. For more information, see section 6.7.

Water Pressure monitoring: Water pressure is the measure of force to get water into the mains and into the household pipework. Pressure is measured in bars. One bar is the equivalent of the force required to push water up to 10 meters in height. For water utilities, therefore, understanding the water pressure in the distribution system is a critical component of managing the water supply of their community.

Pressure loss can cause contamination of the groundwater system. Pressure fluctuations can affect the physical integrity of the pipes. Pressure increases can lead to leaks, major breaks and further reduce the life of the infrastructure. Pressure management can save money as well. Exact pressure data enables system operators to reduce leakage volumes, energy costs, system maintenance costs, customer complaints and problems with water quality.

6.6.2 Water Quality Monitoring

Many water utilities have developed systems for the collection of data on water quality in real time. Various sensors and remote monitoring systems for the measurement of pH water, turbidity, chlorine and other parameters have been used. These sensors monitor and detect water quality variations by continuously measuring these parameters that are essential for the calibration of the water quality model.

6.6.2.1 Chlorine

Adequate chlorine residuals to provide a first defense against microorganism contamination, yet excess chlorine is harmful to health. Sensor provides either a free or total chlorine reading in every few minutes to monitor chlorine level in real time.

6.6.2.2 Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles, which are generally invisible to the naked eye, similar to smoke in the air. Turbidity measurement is a key test of water quality. Turbidity may not exceed 1,0 units of nephelometric turbidity (NTU). (Turbidity , n.d.)

6.6.2.3 pH

The pH of a solution is the measurement of its acidity or alkalinity. The pH scale is a logarithmic scale with a neutral point of 7 in the range from 0 to 14. Values above 7 show a basic or alkaline solution and values below 7 show an acid solution. Extreme pH values also improve the solubility of the toxic elements and compounds. Temperature also has an inverse relationship with pH, which means that the temperature increases the pH and vice versa.

pH measuring sensor provides information on the acid/base nature of the water.

6.6.2.4 Conductivity

Conductivity means the solution's ionic strength. In other words, a solution's ability to conduct electricity is micro-Siemens per centimeter (uS / cm) with the typical measuring unit. Tap water conductivity is perceptibly low at around 100 uS / cm. Any further increase in the conductivity value may be indicative of polluted waters flooding into the water, such as sewer leaks or chemical waste.

6.6.2.5 Temperature

Temperature is measured to ensure the probes are measuring correctly and for other generic water
quality information. It is important to record temperature alongside the other parameters as this will be useful in behavioral analysis of the parameters being measured. With regard to the theories of temperature relations, pH and conductivity have an unwanted effect with large changes in temperature. (A.N.Prasad, Mamun, Islam, & Haqva, 2009)

6.6.3 Leakage Monitoring sensors

The monitor communicates wirelessly with data loggers to collect leak data and then transmits this information directly to an office computer. This removes the requirement for expensive site visits. Instead, leakage data can be delivered automatically to the monitoring station.

The unit consists of built-in radio receiver and SMS transmitter. When it is not receiving or transmitting data it remains in a low power "sleep" mode to conserve battery life. Data is sent from data loggers in range via radio and the unit then transmits this information via SMS to the monitoring station running the relevant software. The online monitor can be configured to send an immediate leak alert whenever one of the loggers reports a potential leak.

The unit is waterproof and can operate at temperatures between -40C and+ 85C at a depth of 4 meters (IP68 rated). (Shihu.Shu, 2011)

6.7 Communication Technologies for SWM

In general, smart meters transmit data more frequently than other simple meters. Some models can transmit every few seconds as frequently. Sending that can often help the utility to detect problems (such as low voltage) quickly enough to solve them. A central controller is also likely to broadcast date / time more frequently in order to keep the meters synchronized for precise time signals.

You can communicate from the meter to the network using below communication technologies:

- Fixed wired connections - power line carrier (PLC), Fiber optic cable.
- Wireless – Telephone dialup, Cellular (Expensive), Radio Communication, Fixed wireless network, Wi-Fi, low power long range wireless (LoRa), NB-IoT (narrowband

IoT), ZigBee (low power, low data rate wireless), and Wi-SUN (Smart Utility Networks).

6.7.1 Fixed Communication Technologies

6.7.1.1 Fiber Optic Cable

The intelligent meter communicates by sending a short light pulse on a fiberglass cable. The advantage of fiber optic technology is the fast, secure and reliable communication that does not radiate the fiber cable. This is one of the safest methods as well. The main drawback of this technology is its installation costs. Smart fiber optic cable meters are currently rarely used. Probably they are only available in densely populated areas.

6.7.1.2 Power Line Communication (PLC)

Power line communication is the technology that uses the existing electrical wires. It can be over the wiring inside the house or via the utility wire from the outside to the house. This technology is also known as the Power Line Carrier and Telecommunication Power Line (PLT). This technology is mainly used for information purposes in rural areas. It is not used in densely populated areas, however, as this method can not handle such a great deal of traffic.

There are three general technologies:

- **Low-frequency power line communication (TWACS/Turtle):** This method works by changing the normal 60-cycle sinewave on the electrical wires of the alternating current. One system is called TWACS, another is the Hunt Technologies Turtle System. When a voltage passes zero on an AC, TWACS communicates by adding a pulse (400-650hz range) 60 times a second. The Turtle system has a particular frequency for each meter. All meters communicate constantly with the electrical lines by adding their individual frequency.

  Advantages: Long distance communication; signals can travel for many miles on the wires and pass unhindered through transformers. The utility will only need one controller for a large area, which is typically located at the base. The low frequencies make this method safe.

  Disadvantages: Suitable only for sparsely populated areas and extremely slow.

- **Medium-frequency power line communication:** This technology adds a signal similar to the "dirty power "generated on the wires by electronic equipment (computers, televisions, etc.) to the electrical lines. It is only a much more powerful signal, so that it does not drown in the static. Some meters use this method to transfer data to the utility (50 kHz to 100 kHz range). This method is mainly used in areas where a transformer is shared by several households because these signals do not travel far and can be blocked.

The receiver should not be far from every house, which is often mounted on the same pole as the transformer. This device then transmits the data it has received, possibly using a telephone modem or some wireless technology (cell phone, Wi-Fi, WiMax).

- **Broadband over power line (BPL):** This method is used in some areas to provide households with fast Internet (broadband) services and can also be used for networking intelligent meters. It transmits waves across the power line with high frequency (1-30 MHZ range). This means that the transmission capacity is much higher than the low and medium frequency methods.

6.7.2 Wireless Communication technologies

6.7.2.1 Telephone dialup

This method uses a household dialup modem or a new line modem to communicate. This method is the safest of all automated systems for communication. This is not, however, appropriate because the utility often sends and receives the information several times a day.

6.7.2.2 Radio Communication

This is the simplest wireless communication. It uses one-way communication; the utility cannot remotely program the meters or communicate with them. These meters can typically just transmit their readings.

- Wake-up Meters: The wake-up meters listen for a signal prompting them to start transmitting their data. Otherwise, they do not transmit.
- Bubble-up Meters: The bubble-up meters simply transmit frequently, typically every 15 or 30 seconds.

The utility truck drives through the neighborhood once a month with an onboard receiver and reads from those meters. It simply picks up the signals sent out within the range of the bubble-up meters as it passes without stopping. The meters are transmitted all the time (every 30 seconds), whether or not there is a utility vehicle.

If we use wake-up meters, the truck sends a signal that prompts all meters within the range to be transmitted. The wake-up and bubble-up meters can also be collected in the neighborhood by a fixed receiver (collector mounted on a utility pole). This collector is then transmitted to a central computer. These radio systems usually transmit at 450 MHz or 900 MHz and can reach approximately 3 km (2 miles).

6.7.2.3 Cellular communication (GPRS)

That's the easiest setup. The meter has a built-in modem for the cell phone, so that it dials the computer of the utility company and downloads the information or the computer can dial into the meter. In smart metering, GPRS can be used to connect data concentrators to servers.

Concentrators exchanged data collected from managed meters with server using the TCP / IP protocol. However, some manufacturers also offer meters directly supported by GPRS, where the wireless sensor network is realized via GSM. These meters must be slotted to insert a SIM card or they have a SIM built-in and are usually more costly.

6.7.2.4 Wi-Fi

Wireless Fidelity or Wi-Fi is one of the most popular communication protocols, that enables exchange of data wirelessly over a network. The Wi-Fi use 2.4GHz or 5GHz frequency. The Wi-Fi network consist of LAN (Local Area Network). It can be generally seen at home, almost every family has Wi-Fi router to spread wireless internet connection over a house. This mass deployment makes this technology available and practically tested. (Xiaoguang, Jian, & Ketai, 2009)

Some advantage of Wi-Fi includes: unlicensed radio spectrum, reduced cost, availability, roaming support, global standards

Disadvantages: High power consumption, interference due to unlicensed spectrum, hacking (Free access points can be used by hacker), interoperability issues.

6.7.2.5 Fixed Wireless network

In a wireless network, each meter does two-way communication with a central control station (Collector/Access-point), which then communicates directly with the utility. This control station is usually mounted on a utility pole or a light pole. In rare cases, the collector is mounted on a building smart meter.

In small and simple networks, each meter usually turns on its transmitter once a day, listen for a pause in the other meter’s transmissions, and then passes its information to the collector. The collector then passes back new rate information, the current time, etc. Then the meter’s transmitter is turned off again

A central collector can communicate with an area of 500-5000 intelligent meters. It can have a stronger transmitter than smart meter. In a LAN network, the meters communicate with the collector throughout the day.

The meters can send much more often than needed, generating a lot of wireless traffic. The additional information can be what the current voltage of the line is and each meter is all right to detect line failures quickly. The networks can communicate with Wi-Fi (2.4GHz) or a proprietary system (900 MHz).

The collector communicates with a central computer by dialup phone, cell phone (GPRS), DSL / ADSL, satellite connection. A wireless network will probably require the installation of a separate set of transmitters mounted throughout the area on lamp posts or utility poles. These can be continuously transmitted.

6.7.2.6 ZigBee (low power, low data rate wireless)

Zigbee is a reliable, cost-effective, low-power and secure wireless communications standard that is built upon the release of the IEEE 802.15.4 specification. This standard which ZigBee uses is built upon two physical layers: 868/915 MHz and 2.4GHz frequency band and provides higher network and application layers.

ZigBee supports mesh network which is fixed wireless network, shown in figure below. It is used when end meters are far away from the collector and routers are used that acts as a relay/repeater which receive messages from the more remote meters and re-transmit the messages onwards to the collector. These relay meters will also send the collector's messages. ZigBee nodes can be either a ZigBee Endpoint (ZED), a ZigBee router (ZR), or a ZigBee Coordinator (ZC). A network can contain only one coordinator but can contain several routers and endpoints.

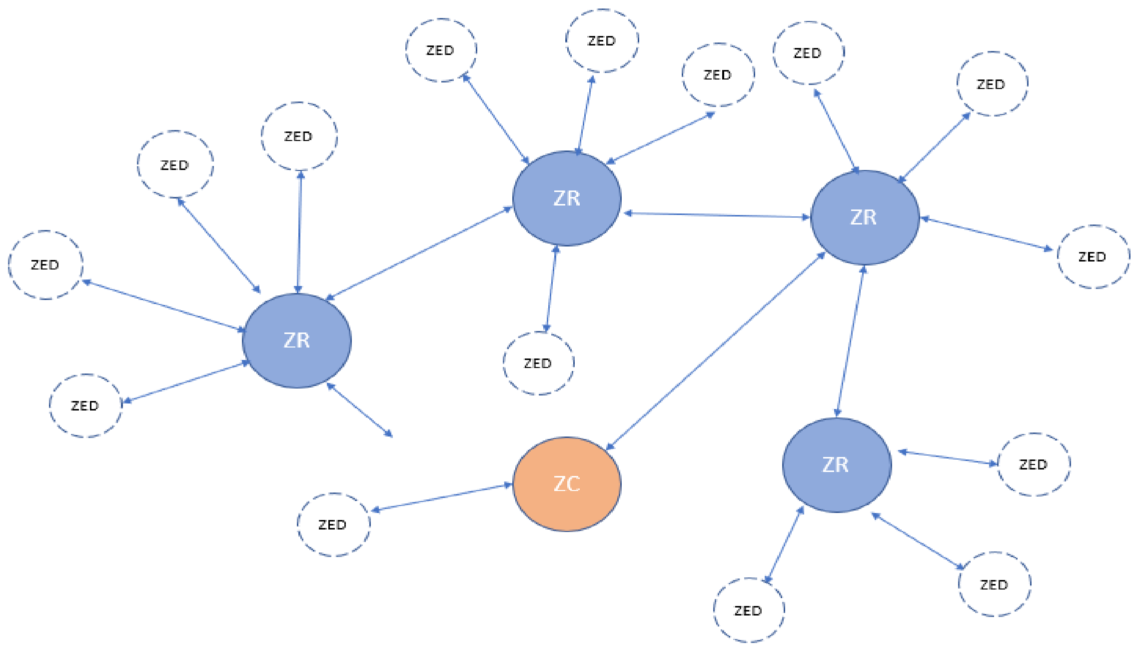


Figure 50: ZigBee mesh network with ZR, ZED and ZC

Coordinators are responsible for forming the network and setting up routing tables. A router's main function is simply to route traffic between nodes. Coordinators and routers need to be awake most of the time. Because of this they need to be mains powered often. Endpoints cannot route traffic and only communicate with a router or coordinator. They are generally low-power, since they sleep most of the time, and often battery powered. The maximum range is about 100 m line-of-sight.

6.7.2.7 Wi-SUN (Smart Utility Networks).

The term Wi-Sun is the short form of the Wireless Smart Utilities Network. It's a secure network optimized by the Wi-Sun Alliance. It interoperates without problems with products from multiple vendors. The Wi-Sun network is developed in accordance with IEEE 802.15.4g defining the specifications of the PHY and MAC layer.

6.7.2.8 LoRa (Low Range)

LoRa is a digital wireless data communication technology that uses license-free sub-gigahertz radio frequency bands like 169 MHz, 433 MHz, 868 MHz (Europe) and 915 MHz (North America).

LoRa enables very-long-range transmissions with low power consumption. This technology has two parts LoRa the Physical layer and LoRa WAN.

This technology is inexpensive and provides long range up to 10 Km connectivity for IoT.

LoRa Architecture:

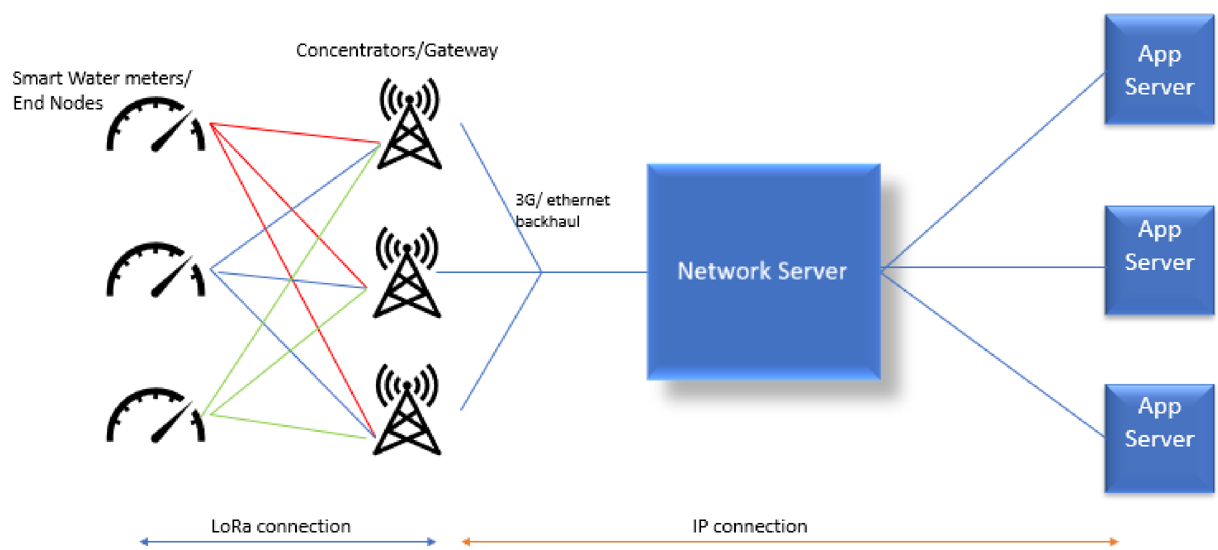


Figure 51: LoRa architecture

End devices such as smart water meters communicate with gateways using the LoRa connection, as shown in the above diagram. Gateways then forward raw LoRaWAN frames from end devices to a network server via a higher throughput backhaul interface, usually Ethernet or 3G. Gateways are therefore only bidirectional relays or protocol converters, the network server being responsible for decoding the packets sent by the devices and generating the packets to be returned to the devices.

Function of Nodes:

LoRa Nodes / End Points: LoRa endpoints are sensors or applications in which sensing and control are carried out. These nodes are often remotely placed. Examples, sensors, device trackers, etc.

LoRa Gateways: LoRaWAN nodes are associated with a specific gateway. Any data transmitted by the node is sent to all gateways and each gateway receiving a signal transmits it to a network server based on the cloud. However, mobile devices are connected to the serving base stations in cellular communication and no gateway data is sent directly to the cloud server. Gateways and network servers are typically connected via a backhaul system (cell phone, Wi-Fi, Ethernet or satellite).

The gateway is only a relay which means packets sent by the devices have no destination address (which saves a few bytes) and that there is no association between a device and a gateway. Consequently, several gateways can receive the same message from a device, only one of them should reply to it. It is network server task to choose the best gateway.

The only task that should be handled by the gateways is the timing of the downlink messages. This timing should be accurate so that the device receives the message in its receiver window.

Network Servers: The server of networks has all intelligence. It filters the duplicate packets from various gateways, checks security, sends ACKs to the gateway. Ultimately, if a packet is for an application server, the network server sends the packet to the application server in question. This type of network communication, in which all gateways can send the same packet to the network server, removes the need for hand-off or handover.

Advantages:

- LoRa is perfect for single-building applications.
- Customer can set up and manage their own network.
- LoRa devices work well when they are in motion, which makes them useful for tracking assets on the move, such as shipments.
- LoRa devices have longer battery life than NB-IoT devices.

Disadvantages:

- It has lower data rates than NB-IoT.
- It has a longer latency time than NB-IoT.
- It requires a gateway to work.

6.7.2.9 NB-IoT (Narrow Band – IoT)

NB-IoT or NarrowBand-IoT is a LPWAN (Low power wide area network) radio communications protocol designed for small data to be sent at regular intervals. It’s part of the 3GPP standardized protocols, competing with LoraWan, Sigfox etc. Please see Section 6.8 for more details.

6.8 NB-IoT (Narrow Band IoT)

NB-IoT (also known as Cat-M2) has a goal similar to Cat-M*. But instead of LTE radios, it uses DSSS* modulation. NB-IoT does not therefore operate in the LTE band, which means that providers have a higher cost of deploying NB-IoT in advance. NB-IoT is a costly option because it removes a gateway need. Other infrastructures usually have gateways that add sensor data to the primary server. The sensor data is sent directly to the primary server using NB-IoT. Huawei, Ericsson, Qualcomm and Vodafone are therefore investing actively in NB-IoT 's commercial applications.

*CAT-M / LTE-M is usually considered to be the second generation of IoT built LTE chips. This technology's main advantage is that it is compatible with the existing LTE network.

*DSSS Direct Sequence Spectrum (DSSS) is a transmission technology used for wireless network transmissions in the local area. In this technology, a data signal is combined with a high data rate bit sequence at the sending station, which divides user data based on a spreading ratio.

6.8.1 Features of NB-IoT

- Uplink and downlink rates of approximately 200 kbps
- Gaining 20dB over conventional GSM networks
- Compatible with over 100,000 connections per cell.
- Works with licensed frequency bands in comparison to other LPWAN protocols that uses unlicensed spectrum such as LoRa and Sigfox and because of this NB-IoT can guarantee SLA (Service Level Agreements) where others cannot
- Can work in remote locations where the normal coverage of the Internet is not an option because of its increased budget.
- offers wide coverage, 3 kilometers in urban areas and 7 kilometers in suburbs.
- Provide high interference resistance to encryption algorithms to ensure data security.

These are the main reasons why telecom carriers are implementing NB-IoT nowadays.

6.8.2 NB-IoT deployment options

NB- IoT has provided key features, including non-realtime voice support, that enable 3GPP networks to offer a low- cost, expanded IoT coverage market. NB-IoT offers three deployment options:

- In-band: use resource blocks in the normal LTE band
- Guard band: use unused resource blocks in the LTE guard band
- Stand-alone: use the reframed GERAN spectrum.

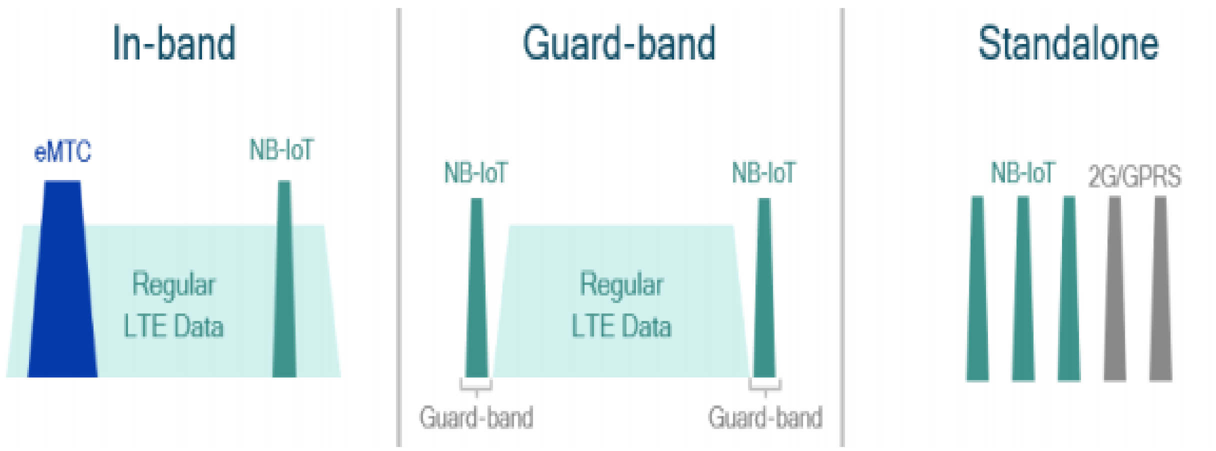


Figure 52: LTE IoT flexible deployment options *(Source: https://www.qualcomm.com/media/documents/files/whitepaper-leading-the-lte-iot-evolution-to-connect-the-massive-internet-of-things.pdf)*

6.8.3 NB-IoT network architecture

Following image shows NB-IoT network structure overview, in this example a smart water meter was installed at home. It periodically sends water consumption information to the application server. On the other hand, the homeowner can check information on the use of water, statistics on the smartphone.

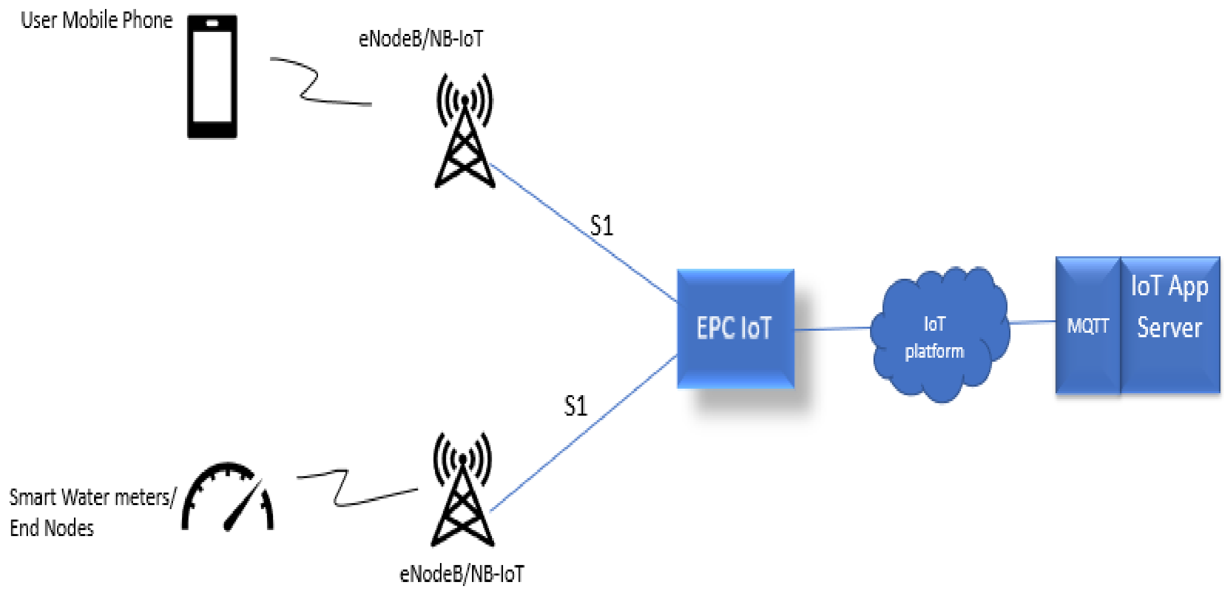


Figure 53: NB-IoT architecture

NB-IoT smart water meter:

- Acquires signals from the primary transducer
- Preprocess raw data (linearization, filtration, thermal correction, analytics)
- Manages and reports useful data for example total and immediate flow rate, metering time on minimum, optimal and overload conditions, battery level and temperature
- Water consumption modes along with separate counters for each mode.
- Secured connection to a cloud using NB-IoT technology and MQTT* protocol
- Extraordinary events information is sent via SMS and E-mail
- Three levels of access to calibrate, configure and service check
- Self-diagnostics including a device e-passport
- 10+ years battery life

**MQTT (Message Queuing Telemetry Transport): MQTT is a lightweight messaging protocol for small sensors and mobile devices, optimized for high-latency or unreliable networks. It works on top of the TCP/IP protocol.*

6.9 Traditional network technologies (LoRa) vs NB-IoT. Which one to use for SWM?

There are many factors that should be considered while selecting suitable technology for an IoT application, including quality of service, latency, battery life, coverage, range, deployment model, and cost. (Sinha, Wei, & Hwang, March 2017)

6.9.1 Network Construction

The development of smart water meter were restricted by two hop traditional network technologies such as LoRa and RF networks. With these, one of the major issues was network construction. For example, Concentrators/ Gateways can only be deployed after site selection, electricity connection, and network planning. On the other side, NB-IoT runs on public networks upgraded from the existing 2G, 3G, and 4G networks provided by operators. Water meter vendors and water utilities save significant amounts of time and money needed to build a network.

Network Construction takes long time and Concentrators are usually unable to withstand extreme weather conditions. Consequently, require frequent maintenance.

6.9.2 Quality of Service

LoRa is an asynchronous protocol and uses unlicensed spectrum. LoRa can handle interference, multipath, and fading but it cannot offer the same QoS as NB-IoT can provide. Because NB-IoT uses a licensed spectrum and its synchronous time-slotted protocol is ideal for QoS. NB-IoT suffers from low interference and can achieve a meter reading success rate of over 99%.

Therefore, applications that need QoS prefer the NB-IoT, while the applications that do not need high QoS should choose LoRa.

6.9.3 Battery life and latency

LoRaWAN is an asynchronous, ALOHA-based protocol. So, devices can sit idle as little or as the application desires. In NB-IoT, because of infrequent but regular synchronization, the device consumes additional battery energy and OFDM or FDMA require more peak current for the linear transmitter as shown in table below. This shows that device battery life of NB-IoT is shorter than devices based on LoRa because of high energy demand. On the flip side, these demands offer NB-IoT the advantage of low latency and high data rate.

	Peak Current	Sleep Current	Latency
LoRa	32 mA	1 μA	Insensitive
NB-IoT	120/130 mA	5 μA	<10s

Figure 54: Peak & sleep currents and latency

Therefore, LoRa is the best choice for applications which are latency-insensitive and do not have large amounts of data to send. NB-IoT is the best choice for applications that require low latency and high data rate.

6.9.4 Reliability

LoRa and RF networks operate on unlicensed spectrum. The NB-IoT network uses licensed spectrum and thus, highly reliable.

6.9.5 Network Coverage and Range

NB-IoT has a better range of < 35 km than LoRa < 15 km. NB-IoT is, however, lagging behind network coverage, as the deployment of NB-IoT is limited to base stations 4G / LTE. It is not therefore suitable for rural or suburban areas with no 4G coverage. Lora, on the other hand, has a broader network coverage than the NB-IoT network and can only cover the entire city with one gateway.

6.9.6 Cost

Spectrum costs, network costs, equipment costs and deployment costs should be taken into account when selecting the best network technology for the application case. The table below shows the costs of NB-IoT and LoRa. It can be seen that LoRa has a huge cost advantage.

	Spectrum Cost	**Network & Deployment cost**
LoRa	Free	\$100–\$1000/gateway
NB-IoT	>\$500 million/MHz	\$15000/base station

Figure 55: Cost – LoRa and NB-IoT

6.9.7 Deployment Model

NB-IoT can be deployed by reusing and upgrading the existing cellular network but its deployments are restricted to the area supported by cellular network.

*** The NB-IoT network can be easily upgraded to 5G and maintained by operator industry specialists.*

In Summary, LoRa and NB-IoT have their respective advantages in terms of different factors of IoT as shown in table below:

Best Choice	Use case	Major IoT Categories	Parameters
LoRa	Asset tracking Smart agriculture Intelligent building Facility management Healthcare Industries Manufacturing	IoT Industries	Device cost, Battery life Coverage
NB-IoT	Wearables Smart Bicycle Pet tracking POS terminal Kids tracking	IoT personal	Range, Diversity, Latency, QoS
	Smart Metering Smart Parking Alarms and Event Detectors Smart Garbage bins	IoT Public	Range, Diversity, Latency, QoS
Depends on specific requirements	Refrigerators Air conditioners Microwave Printers Water Coolers	IoT appliance	Range, Coverage, Diversity, Latency, QoS

Figure 56: IoT use case with parameters

NB-IoT for Smart Water Meter:

NB-IoT offers more coverage and massive connections with low power consumption. It is an ideal communications network technology for the smart water solution.

Though Network and tower handoffs may create problem, but NB-IoT is best suited for primarily static assets, like meters and sensors in a fixed location (Such as smart water meters) rather than roaming assets.

6.10 NB-IoT- a solid foundation for Massive IoT (MIoT-5G)

NB-IoT is a 4G technology, but they also play a vital role in a 5G system to support 5G LPWA use cases and for the foundation of Massive IoT. NB-IoT also provides seamless migration path for legacy 2G/GPRS deployments, as its narrowband carrier can directly fit into the reframed GSM spectrum bandwidth.

Figure 57: NB-IoT- foundation for Massive IoT *(Source: https://www.qualcomm.com/media/documents/files/whitepaper-leading-the-lte-iot-evolution-to-connect-the-massive-internet-of-things.pdf)*

Narrowband IoT (NB-IoT) defined in 3GPP Release 13 and beyond extends LTE to even narrower bandwidth that is optimized for low data rate, latency-tolerant IoT applications. It reduces device complexity, enables multiyear battery life and provides deeper coverage to reach sensors and meters in challenging locations such as remote rural areas or inside buildings.

When 5G becomes commercially available, IoT connectivity will be further enhanced (refer to next section). The 3rd Generation Partnership Project (3GPP), the standards group specifying 5G and other wireless networking standards, has indicated NB-IoT and LTE-M will be part of 5G and are the only 5G technology in the foreseeable future to support 5G LPWA usage cases. 3GPP also agreed that no 5G New Radio (5G NR) solutions based on LPWA will be studied or specified in the foreseeable future. (Sierra Wireless , n.d.)

It should be noted that NB-IoT devices deployed today are firmware upgradable to support the 5G NB-IoT features, so we can say that NB-IoT is the foundation for 5G IoT or MIoT. (Sierra Wireless , n.d.)

The main requirements of IoT are:

- Cheap Device
- Long Battery Life
- Low Data Requirements
- Extended Coverage
- Massive no. of Device Support in a Cell

In the following section we will discuss how NB-IoT as a technology can provide solution for the same.

6.10.1 Reducing Complexity to enable lower cost devices

	LTE Cat-1 (Rel-8)	eMTC Cat-M1 (Rel-13)	NB-IoT Cat-NB1 (Rel-13)
Peak data rate	Up to 10 Mbps	Up to 1 Mbps	<100 kbps
Bandwidth	Up to 20 MHz	1.4 MHz	200 kHz
Rx antenna	Dual Rx	Single Rx	Single Rx
Duplex mode	Full duplex FDD/TDD	Full or Half duplex FDD/TDD	Half duplex FDD
Mobility	Full mobility	Limited-to-full mobility	Cell reselection only
Voice	VoLTE	VoLTE	No voice support
Transmit power	23 dBm	23, 20 dBm	23, 20 dBm

Figure 58: Reducing complexity for LTE IoT devices *(Source: https://www.qualcomm.com/media/documents/files/whitepaper-leading-the-lte-iot-evolution-to-connect-the-massive-internet-of-things.pdf)*

Peak Data Rate: NB-IoT further reduces peak data rate down to 10's of kbps. The reduced peak data rates can save both processing and memory in the hardware of the device.

Bandwidth: NB-IoT further reduces device bandwidth to 200 kHz (180 kHz plus guard-band for a single RB). Reduction in BW allows NB-IoT to replace legacy old channels (PCFICH, PHICH, PDCCH) which no longer fit into NB-IoT with new channel M-PDCCH.

Rx Antenna: For both Cat-M1 and Cat-NB1, the receive RF is reduced to a single antenna, which simplifies the RF frontend. Though there will be RF degradation but that will be taken care by other advanced coverage enhancing techniques.

Duplex Modes: Cat-NB1 devices only support half-duplex FDD. This allows the device to implement a simpler RF switch instead of a full duplexer which is more complex and costlier.

Mobility: Only Cat-M1 devices support limited-to-full mobility. However, Cat-NB1 devices support cell reselection only, which is optimized for static or nomadic IoT use cases.

Voice: Another key feature of Cat-M1 is its ability to support VoLTE in IoT applications like Wearables. Because of its simplified hardware and limited bandwidth, Cat-NB1 does not support voice.

Transmit Power: The maximum uplink transmission power from LTE 23 dBm (200mW) is reduced to 20 dBm (100mW) for both new LTE IoT UE categories, allowing the power amplifier (PA) to be integrated at lower device costs.

6.10.2 Multi-year Battery Life

Many IoT devices are battery operated and it is highly desirable that they last on a single charge as long as possible. In addition to the power savings realized through reduced device complexity, two new low-power enhancements have been introduced: power save mode (PSM) and extended discontinuous receive (eDRx) to extend the battery life to 10 years.

Power Save Mode (PSM): PSM is a new low-power mode that allows the device to skip the periodic page monitoring cycles between active data transmissions, allowing the device to sleep for longer. It is best utilized by device-originated applications, where the device initiates communication with the network. It also enables more efficient low- power mode entry/exit, as the device remains registered with the network during PSM, without the need for additional cycles to set up registration after each PSM exit event.

Smart Water Meters, Sensors, and any IoT devices that periodically push data up to the network takes advantage of this PSM mode.

PSM Procedure:

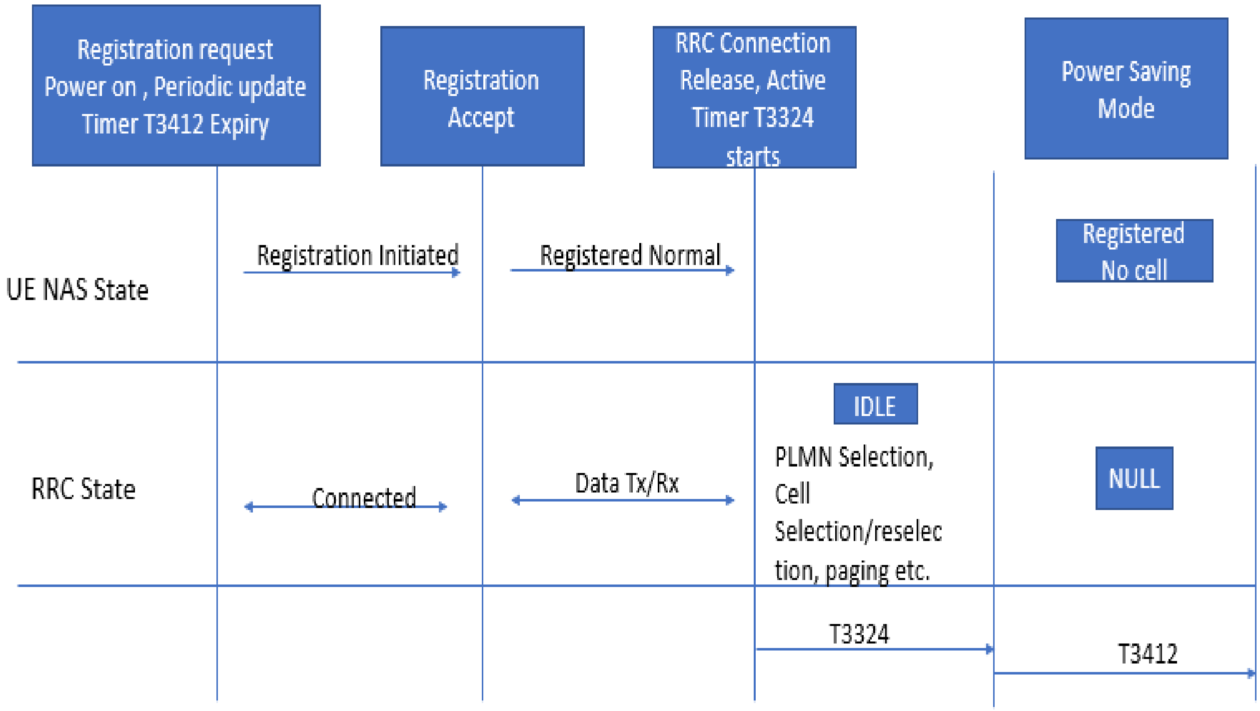


Figure 59: Power Saver Mode Procedure

Registered UE goes into the idle mode, it releases RRC connection, it then starts an active timer T3324 and perform all the idle mode functions such as PLMN selection, Cell selection/reselection, paging etc. When active timer T3324 expires UE enters into PSM and starts Periodic Update Timer and expiry of this time indicates the end of PSM.

PSM State: In PSM state UE stops reading paging and or performing any NAS related functions. Network should not send any paging as UE is unreachable at this time but still registered in the network. The Device will remain in the PSM mode until it is required to initiate any procedure toward network such as periodic tracking area update or uplink data from device.

When UE wants to use PSM it will request an active timer in attach or TAU (Tracking Area Update) request. If eNB supports PSM it will accept the request. The maximum value of PSM is about 12 days (Timer T3412 can be configured with 12.1 days value)

Extended Discontinuous Reception (eDRx): It allows the network and device to synchronize sleep periods, so that the device can check for network messages less frequently. However, this increases latency, so eDRx is optimized for device-terminated applications.

Use cases such as asset tracking and intelligent grid can benefit from the reduced power consumption through the longer eDRx cycles.

eDRx optimizes battery life by extending the maximum time between network data reception to 10.24s in connected mode and page monitoring and tracking area update to 40 + minutes in idle mode.

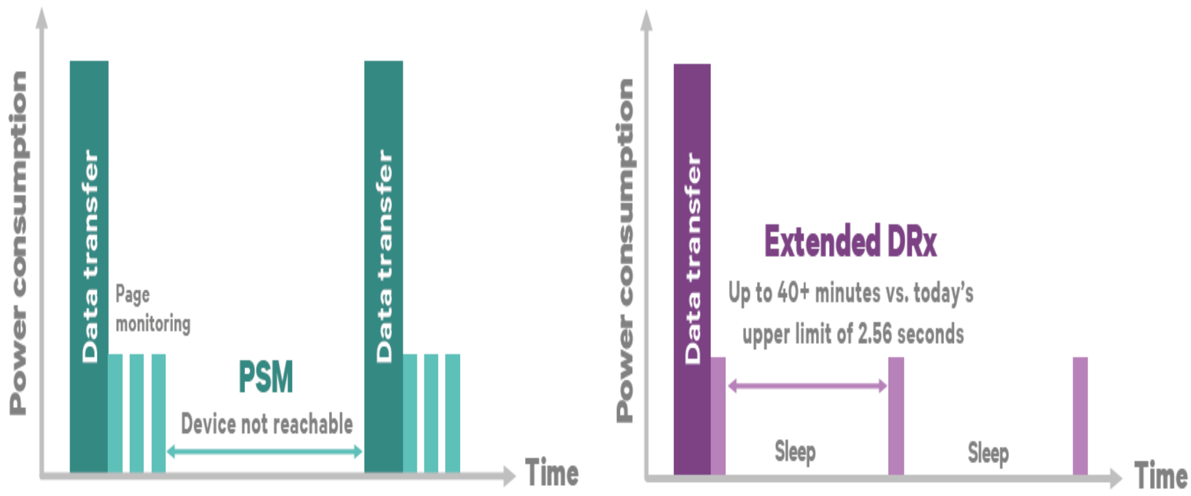


Figure 60: Power Saver Mode and eDRx

(Source: http://blogs.univ-poitiers.fr/f-launay/2016/11/04/paging-et-mecanisme-psmdrx/)

6.10.3 Low Data requirements

Device data rates depend on bandwidth, MIMO support, and coding modulation (MCS). NB-IoT UE is expected to support downlink 200Kbps and uplink 144Kbps. 3GPP has provided following recommendation for these low data requirements.

- Reduce bandwidth
- Reduce support of MIMO
- Reduce MCS to 16 QAM or QPSK

The BW of IoT devices is reduced to 200KHz i.e. 1 RB. Also, IoT devices are not designed to support MIMO, these devices are recommended have to be single antenna, and 64-QAM is not supported in NB-IoT. Maximum Transport block size is defined as 680bits and minimum TBS is 16 bits.

Data Rate Calculation:

NB-IOT consist of 1 RB. One subframe contains 168 REs (Resource elements). Due to the QPSK modulation each RE can carry 2 Bits information. With Peak QPSK it can achieve:

- No. of Bits per milli-second 168*2=316 Bits/mSec.
- No. of Bps = 316000 Bits/Sec = 300 Kbps

6.10.4 Extended coverage for challenging locations

Many IoT use cases can benefit from deeper network coverage, such as utility meters. IoT devices are expected to be deployed in indoor environment or in some application basements such as Automated Parking system having multiple level of basements. LTE-M should provide a strong indoor coverage of 15 dB and NB-LTE should provide an additional 20 dB link budget compared to the conventional LTE system. This extra link budget can be achieved using a range of techniques such as:

Repetitive Transmissions: Transmitting the same transport block multiple times in consecutive sub-frames (TTI- transmission time interval bundling) or repeatedly sending the same data over a period of time can significantly increase the probability for the receiver to correctly decode the transmitted messages

Power Spectral Density (PSD) boosting: Although the serving cell can simply increase the transmitting power in the downlink to extend the coverage, the device can also combine all the power with some reduced bandwidth.

Single-tone uplink: NB-IoT device can utilize single-tone uplink (3.75 kHz or 15 kHz subcarrier spacing) to further extend coverage, trading off-peak data rate (limiting to 10's of kbps).

Lower-order modulation: By utilizing QPSK instead of 16-QAM, the SINR (Signal to interference plus noise ratio) decreases significantly.

With these new coverage enhancements, the link budget of a NB-IoT is increased to 164dB. And 3GPP recommended to use low bandwidth such as 200KHz to get the extended coverage. By reducing the BW, 20dB improvement can be seen in the Maximum coupling loss (MCL) or Maximum Allowable Path loss (MAPL) as compared to 20 MHz LTE system.

6.10.5 Massive number of device support

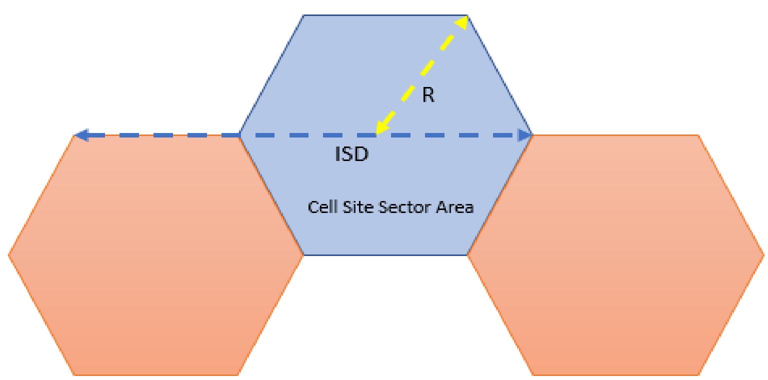


Figure 61: Cell site Sector Area Definition

According to IOT requirements, a large number of connected devices will support various applications. NB-IoT need to support this massive IoT capacity by using only one PRB in both uplink and downlink.

NB-LTE supports more than 52500 UEs per cell with one PRB. This count calculation is described below:

- Inter-site Distance (ISD) = 1732m (macro cell standard)
- Cell site sector radius, a = ISD/3 = 577.3m
- Area of cell site sector (assuming a regular hexagon) = $\frac{3\sqrt{3}}{2}\,a^2$ = 0.866 Sq Km
- Number of devices per cell site sector = Area of cell site sector*Household density per Sq km*number of devices per household (Assumed)
  = 0.866*1517*40= 52549 user/cell site

6.10.6 Optimizing LTE network

Most IoT devices sporadically transfer small amounts of data instead of large data packets. The LTE core network must therefore also evolve to better support IoT traffic profiles by providing more efficient signaling and management of resources.

More efficient signaling: New access control mechanisms, such as EAB, prevent devices from generating access requests when the network is congested, thereby eliminating unnecessary signaling. The network can also use group-based paging and messaging to communicate more efficiently with multiple downlink devices.

Enhanced resource management: The network can allow a large number of devices to share the same subscription so that resources and device management can be consolidated. In our use case, for example, a group of water meters (SWMs) can be collectively supplied, controlled and billed in a smart city.

Simplified core network (EPC-lite): The LTE core network can be optimized for IoT traffic, allowing more efficient use of resources and consolidation of the MME, S-GW, and P-GW into a single EPC-lite. Using this, operators have the option to optimize for lower OPEX, or to minimize CAPEX spend by leveraging existing LTE core network to support LTE IoT.

6.10.7 eSIM (eUICC)

One of the barriers to adapting cell connectivity to IoT device makers is the physical SIM card that locks the devices to a single mobile carrier. To make NB-IoT successful the entire ecosystem needs to be involved to simplify the overall deployment and management of LTE IoT services.

eUICC is Embedded Universal Integrated Circuit Card, it makes mobile carrier switching easy, eSIM carrier profiles can be managed remotely over the air (OTA), meaning that the

SIM never needs to be removed or replaced. The EUICC SIM will be built into phones and other devices and follows GSMA specifications.

EUICC will enable:

- Global machine to machine rollouts remote management
- Less worry about difficult machine environment.
- EUICC cards only need cellular tech
- Cheaper
- More secure
- Shared data plans
- SIM cards can’t be stolen

6.11 What will 5G bring to NB-IoT?

5G is designed from the beginning for a broader scope than previous generations. From initial phase of 5G standard development, 3GPP focused on three principal areas: eMBB, mMTC and URLLC. With mMTC as a key focus area, 3GPP maintains a massive IoT momentum for very low- cost UE with strong coverage and high connectivity.

To ensure the next generation of networks can support a wide range of services, devices and seamless interoperability a 5G New Radio (NR), a new, flexible 5G air interface is designed and standardized that will scale efficiently for all kinds of IoT applications, from high-end surveillance cameras down to ultra-low-cost sensors.

With today's wireless networks 5G NR will provide new capabilities and efficiencies not possible. In addition, 5G NR is designed to be future proof and to provide forward-looking compatibility with services and devices not yet known.

3GPP Release 15 delivers the first set of 5G standards and is expected to provide:

- Latency and power consumption reduction
- Deep coverage for challenging locations
- Ultra-low energy usage in order to provide 10+ years battery life
- Ultra-high density per square kilometer for 1 million devices.
- Release 15 also adds TDD support in-band, guard-band and standalone operation modes of NB-IoT.
- NB-IoT small cell support in 3GPP release 15.
- The new 5G NR (New Radio) air interface will further enhance OFDM to deliver an improved degree of flexibility and scalability.

In this section, we summarize some key enhancements in 3GPP release 15.

6.11.1 TDD Support

In Rel-13 and Rel-14, NB-IoT only supports frequency division duplex (FDD) mode. Since a subset of the LTE spectrum is reserved for TDD mode, TDD support in Rel-15 will allow operators having been allocated TDD bands to optimize the use of their available spectrum for NB-IoT deployments.

6.11.2 Lower Latency

Faster system acquisition and early data transmission, both enhancements in 3GPP Release 15 contributed towards lower latency in addition to more HARQ (Hybrid Automatic Repeat Request) processes that we have used in 3GPP release 14.

It has been observed in the previous releases that the combined time for the UE to acquire the Narrowband Master Information Block (MIB-NB) followed by the Narrowband System Information Block SIB1 (SIB1-NB) could cross the SIB1-NB modification period (40.96 seconds), leading to the UE having to re-acquire the MIB-NB.

In release 15 the main enhancements for improving system acquisition times is achieved by:

- Additional repetitions of NPSS (Narrow Band Primary Synchronization Signal) /NSSS (Narrow Band Secondary Synchronization Signal) /NPBCH (Narrow Physical Broadcast Channel) enhanced in such a way to minimize false detection and/or improve correlation properties.
- Additional repetitions of SIB1-NB on other subframes or carriers.
- New mechanisms (e.g., new wake-up signal) to allow UE to skip reading of MIB-NB, SIB1-NB and/or SI messages

6.11.3 Power Consumption reduction

For typical IoT applications, the UE is not expected to be scheduled very often by the eNB. However, it is expected to be reachable by the network within a reasonable period. Hence, the UE consume a lot of power by continuously monitoring the NPDCCH (Narrowband Physical Downlink Control Channel) even when it is rarely scheduled.

In Rel-15, for both idle mode paging and connected mode discontinuous reception (DRX), a new physical channel or signal can be efficiently decoded prior to decoding NPDCCH or NPDSCH, to avoid unnecessarily decoding.

In order to increase the battery life further, 3GPP Release 15 introduces a new low-power wake-up radio design, relaxed cell reselection monitoring, semi-persistent scheduling, faster RRC release and lower power transmission.

6.11.4 Cell Size extension

Additional cyclic prefixes (CP) are supported in 3GPP Release 15 to extend the cell radius to at least 100 km.

6.11.5 High-Density Support

Additional improvements are also being made to load control with level-based access class barring in 3GPP Release 15

6.12 New 5G capabilities to enable massive IoT

In order to further improve the device density, future advanced massive IoT design techniques such as RSMA (resources speared multiple access) will enable

- Grant-free asynchronous transmissions to lower signaling overhead

RSMA is a multi-access asynchronous, non-orthogonal and contention-based uplink design that further reduces device complexity and overhead signaling, allowing IoT devices to transmit without prior network schedule.

To further extend the network coverage massive IoT will provide

- Multi-hop mesh to expand network coverage more cheaply

Multi-hop mesh enables out-of-coverage devices to connect directly with devices that can transfer data back to the access network. This creates an edgeless network that extends coverage beyond the typical cellular access. The core network also takes into account the WAN management for devices in coverage and those supported by the peer-connected mesh network.

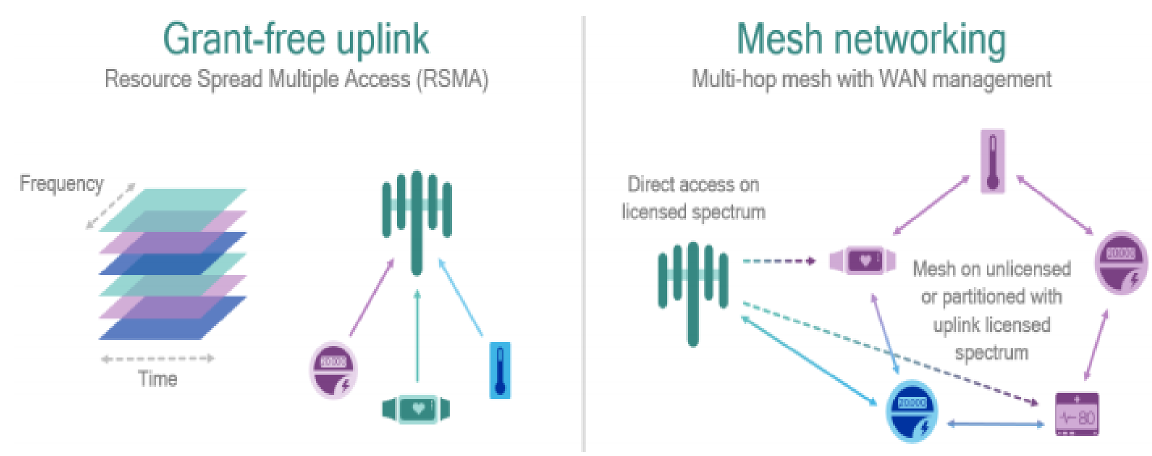


Figure 62: New 5G capabilities to enable massive IoT *(Source: https://www.qualcomm.com/media/documents/files/whitepaper-leading-the-lte-iot-evolution-to-connect-the-massive-internet-of-things.pdf)*

6.13 What is required to upgrade to 5G LPWA?

For MIoT, it is expected that both NB-IoT and LTE-M deployments will be able to seamlessly transition from existing 4G to 5G LTE networks with a simple over-the-air firmware (which both technologies support). Many features on the device side and infrastructure on the network side of things will be upgradeable to 5G by software means only.

7. Conclusion

The Internet of Things is bringing a huge surge of smart, connected devices that will enable new services across different industries. The IoT will transform businesses and change the way people live. And cellular technologies such as 5G will play an important role providing connectivity for a wide range of things.

In this project we studied 5G and its enables technologies which are being used in IoT nowadays. We have done this project in three parts.

In the first part we have studied basic design fundamentals of 5G. we have studied the architecture (RAN – radio access network & Core Network) of 5G thoroughly and major 5G challenges: High Data Rate, Reduced Latency, Low Power Consumption and scalability etc. We did research on its enabling technologies such as WSDN, NFV, Millimeter Wave, D2D, MIMO, Ultra-densification and IoT.

In the second part we have studied IoT in depth including IoT challenges, architecture, IoT technologies: RFID, NFC, M2M & V2V, Other IoT applications and use cases.

In third and the final part of the project we did research on designing Smart water Meter use case for IoT enabled application. We discussed in depth about the need for smart metering and designed a smart water meter system using AMI (Advanced Metering Infrastructure). We have studied all the fixed (PLC, Fiber) and wireless communication technologies (GPRS, Wi-Fi, Zigbee, Wi-Sun, LoRa, NB-IoT) in SWM and after research we concluded that NB-IoT will be the best option for SWM which will act as foundation for Massive IoT (5G) in future.

NB-IoT not only provides ubiquitous coverage through established global networks, but also brings reliability, security, and performance which is needed by the almost all of the IoT applications. We have discussed how we will be moving from NB-IoT to massive IoT which will be further delivering lower complexity, increase battery life, extended coverage, and high device density deployments.

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9. Glossary

Term	Explanation
3GPP	3rd Generation Partnership Project (www.3gpp.org)
5GC	5G Core Network (24.301)
AMPS	Advanced Mobile Phone System
NMT	Nordic Mobile Telephone
TACS	Total Access Communication System
GSM	Global System for Mobile Communication
SMS	Short Message Service
CDMA	Code Division Multiple Access
ME	Mobile Equipment
BSS	Base Station Subsystem
NSS	Network and Switching Subsystem
BTS	Base Transceiver System
BSC	Base Station Controller
MSC	Mobile Switching Center
SIM	Subscriber Identity Module
PSTN	Public switched Telecommunication Network
ISDN	Integrated Services Digital Networks
PLMN	Public Land Mobile Networks
VLR	Visitors Location Register
HLR	Home Location Register
AUC	Authentication Center
EIR	Equipment Identity Register
IMEI	International Mobile Equipment Identity
GPRS	General Packet Radio Services
EDGE	Enhanced Data Rates for GSM Evolution
IP	Internet Protocol
WCDMA	Wideband Code Division Multiple Access
UMTS	Universal Mobile Telecommunications Systems

HSUPA	High Speed Uplink Packet Access
HSDPA	High Speed downlink Packet Access
EVDO	Evolution Data Optimized
RAN	Radio Access Network
CN	Core Network
SGSN	Serving GPRS Supporting Node
GGSN	Gateway GPRS Supporting Node
IMS	IP Multimedia Subsystem
LTE	Long Term Evolution Technology
WIMAX	Worldwide Interoperability for microwave access
OFDMA	Orthogonal Frequency Division Multiple Access
FDE	Frequency Division Equalization
MIMO	Multiple Input Multiple Output
MBMS	Multiple Broadcast Multicast Services
UE	User Equipment
E-UTRAN	Evolved UMTC Terrestrial Radio Access Network
EPC	Evolved Package Control
HSS	Home Subscriber Server
MME	Mobility Management Entity
S-GW	Signaling Gateway
P-GW	Packet Data Network Gateway
PCRF	Policy and Charging Rule Function
BDMA	Beam Division Multiple Access
FBMC	Filter Bank Multiple Carrier
TTI	Transmission Time Interval
eMBB	Enhanced mobile Broadband
mMTC	Massive Machine Type Communication
uRLLC	Ultra-Reliable and Low-Latency communication
NE	Network Elements
DC	Data Center
SDN	Software Defined Network
NFV	Network Function Virtualization
IOT	Internet of Things
D2D	Device to Device

NFC	Near Field Communication
AAA	Authentication Authorization and Accounts
WSDN	Wireless Software Defined Networking
API	Application Programming Interfaces
CAPEX	Capital Expenses
OPEX	Operating Expenses
NFVI	NFV Infrastructure
VNF	Virtual Network Functions
NFV MANO	NFV Management and Network Orchestration
SNR	Signal to Noise Ratio
BS	Base Station
MTC	Machine Type Communication
V2V	Vehicle to Vehicle
TDD	Time Division Duplexing
HetNet	Heterogenous Network
AUSF	Authentication Server function
AMF	Access and Mobility Function
DN	Data Network
UDSF	Unstructured Data Storage Function
NEF	Network Exposure Function
NRF	Network Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
SMF	Session Management Function
UDM	Unified Data Management
UPF	User Plane Function
AF	Application Function
UE	User Equipment
5G-EIR	5G-Equipment Identity Register
SEPP	Security Edge Protection Proxy
NWDAF	Network Data Analytics function
AKA	Authorization and Key Agreement
SA	Stand Alone
NSA	Non Stand Alone

5GC	5G Core Network
DC	Dual Connectivity
MN	Master Node
SN	Secondary Node
CU	Central Units
HLS	Higher Layer Split
RNL	Radio Network Layer
TNL	Transport Network Layer
DRB	Data Radio Bearers
SRB	Signaling Radio Bearers
SDAP	Service Data Adaptation Layer
PDCP	Packet Data Convergence Layer
URLLC	Ultra Reliable Low Latency
RLC	Radio Link Control Protocol
MAC	Medium Access Control
NAS	Non Access Stratum
RRC	Radio Resource Control
cIot	Consumer IoT
iIoT	Industrial IoT
OT	Operational Technology
IT	Information Technology
MTC	Machine Type Communication
SDN	Software Defined Networking
RFID	Radio Frequency Identification
NFC	Near field Communications
RS	Relay Station
DAS	Data Acquisition System
WIoT	Wearable IoT
wBAS	Wearable Body Area Sensors
MCC	Mobile Cloud Computing
CaBAS	Cloud Assisted body area sensor
ICT	Information and Communication Technology
AMI	Advance Metering Infrastructure
MDMS	Meter Data Management System

MCU	Microcontroller Unit
SWM	Smart Water Meter
PLC	Power Line Carrier
SUN	Smart Utility Networks
LAN	Local Area Network
LORA	Low Range
PLC	Power Line Communication
BPL	Broadband Over Powerline
MIB1/NB	Mater Information Block Type 1/ Narrow Band
SIB1/NB	System Information Block Type 1/ Narrow Band
NPSS	Narrowband Primary Synchronization Signal
NSSS	Narrowband Secondary Synchronization Signal
NPBCH	Narrowband Physical Broadcast Channel
NPDCCH	Narrowband Physical Downlink Control Channel
HARQ	Hybrid Automatic Repeat Request
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PHICH	Physical HARQ Indicator Channel
M-PDCCH	MTC- Physical Downlink Control Channel
PSM	Power saving Mode
RRC	Radio resource control
NAS	Non Access Stratum
PLMN	Public Land Mobile Network
TAU	Tracking Area Update
eDRx	Extended Discontinuous Reception
TTI	Transmission Time Interval
SINR	Signalling to Interference plus Noise Ratio
MCS	Modulation coding scheme
RB	Resource Block
TBS	Transport block Size
RE	Resource Elements
MCL	Maximum coupling loss
MAPL	Maximum Allowable Path loss

ISD	Inter-site Distance
EAB	Extended Access Barring
OPEX	Operational Expenditure
CAPEX	Capital Expenditure
eUICC	Embedded Universal Integrated Circuit Card
eSIM	Embedded Subscriber Identity Module