The air interface defined by 3GPP for 5G is known as New Radio (NR), and the specification is subdivided into two frequency bands, FR1 (below 6 GHz) and FR2 (24–54 GHz)

Frequency range 1 (< 6 GHz)

Otherwise known as sub-6, the maximum channel bandwidth defined for FR1 is 100 MHz, due to the scarcity of continuous spectrum in this crowded frequency range. The band most widely being used for 5G in this range is 3.3–4.2 GHz. The Korean carriers use the n78 band at 3.5 GHz.

Some parties used the term "mid-band" frequency to refer to higher part of this frequency range that was not used in previous generations of mobile communication.

Frequency range 2 (24–54 GHz)

The minimum channel bandwidth defined for FR2 is 50 MHz and the maximum is 400 MHz, with two-channel aggregation supported in 3GPP Release 15. The higher the frequency, the greater the ability to support high data-transfer speeds. Signals in this frequency have been described as mmWave.

Advantages of using small cells in 5G instead of traditional cell towers

It strengthens coverage and data transfer speeds where devices might otherwise compete for bandwidth. And small cells have been shown to extend handset battery life by reducing power draw, so devices can go longer between charges.

Small cells are low-powered radio access points that connect mobile devices to mobile networks over a small area. They typically reuse frequencies on an extremely dense basis to take full advantage of available spectrum. For 5G, network operators are planning to use not just the low- and midband spectrum that existing cellular networks mostly rely on. They will also need high-band spectrum, which carries over shorter distances than the lower frequencies that currently dominate wireless networks. Carriers will therefore need a much larger number of access points, which cover smaller areas, to roll out 5G.

A fact to share

One FCC (Federal Communications Commission) commissioner recently estimated that the US needs 800,000 small cells to make 5G a reality. International Data Corporation (IDC) expects over two million—by 2021. By comparison, the existing 2G/3G/4G network, built over many years, has just over 200,000 cell towers.

Picocells and femtocells are **small cells belonging to the family of Low-Power Nodes (LPNs)**. Depending on the environment, the quality and type of communication service, one may be a better candidate than the other.

In telecommunications, a **femtocell** is a small, low-power cellular base station, typically designed for use in a home or small business. A femtocell allows service providers to extend service coverage indoors or at the cell edge, especially where access would otherwise be limited or unavailable.

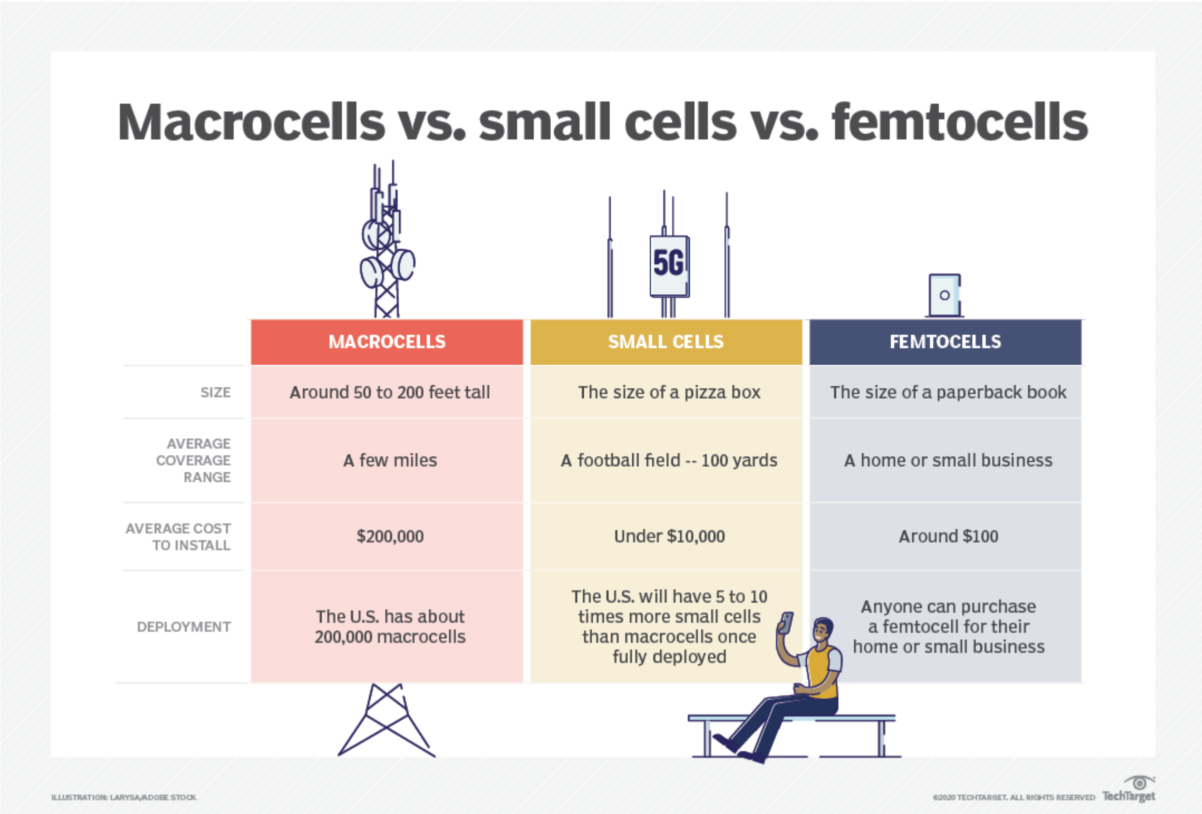
A broader term which is more widespread in the industry is small cell, with **femtocell** as a subset.

A **picocell** is a small cellular base station typically covering a small area, such as in-building (offices, shopping malls, train stations, stock exchanges, etc.), or more recently in-aircraft. In cellular networks, picocells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations or stadiums. Picocells provide coverage and capacity in areas difficult or expensive to reach using the more traditional macrocell approach.

Femtocell is generally a better candidate for high-capacity in-building solutions, while the picocell is a better candidate for serving outdoor hotspots.

Cell Type	Typical Cell Radius	PA Power: Range & (Typical Value)
Macro	>1 km	20 W~ 160 W (40 W)
Micro	250 m ~ 1 km	2 W ~ 20 W (5 W)
Pico	100 m ~ 300 m	250 mW ~ >2 W
Femto	10 m ~ 50 m	10 mW~200 mW

Table 1: Different cell radii and Tx power levels



5G System Architecture (Perspective 1)

As illustrated in Figure 1, 5G will be a truly converged system supporting a wide range of applications from mobile voice and multi-Giga-bit-per-second mobile Internet to D2D and V2X (Vehicle-to-X; X stands for either Vehicle (V2V) or Infrastructure (V2I)) communications, as well as native support for MTC and public safety applications. 3D-MIMO will be incorporated at BSs to further enhance the data rate and the capacity at the macro-cell level. System performance in terms of coverage, capacity and energy efficiency (EE) will be further enhanced in dead and hot spots using relay stations, hyperdense small-cell deployments or WiFi offloadin; directional mmWave links will be exploited for backhauling the relay and/or small-cell BSs. D2D communications will be assisted by the macro-BS, providing the control plane. Smart grid is an interesting application envisaged for 5G, enabling the electricity grid to operate in a more reliable and efficient way. Cloud computing can potentially be applied to the RAN,

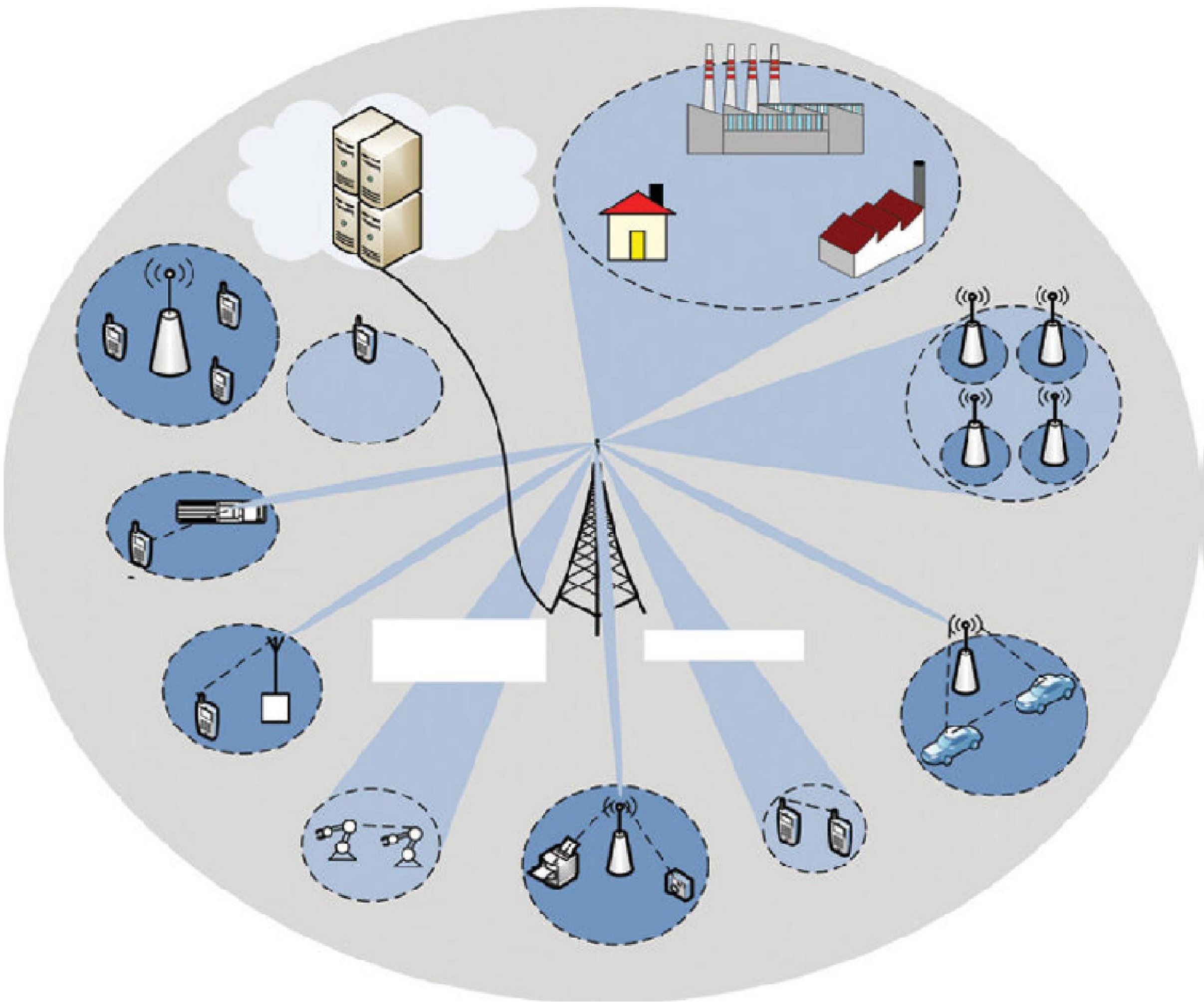


Figure 1: 5G system architecture

and beyond that, to mobile users that can form a virtual pool of resources to be managed by the network. Bringing the applications through the cloud closer to the end user reduces the communication latency to support delay-sensitive real-time control applications.

It is envisaged that 5G will seamlessly integrate the existing radio access technologies (RATs, e.g. GSM, HSPA, LTE and WiFi) with the complementary new ones invented in mmWave bands. MmWave technology will revolutionise the mobile industry not only because of plenty of available spectrum at this band (readily allowing Gbps wireless pipes), but also because of diminishing antenna sizes, enabling the fabrication of array antennas with hundreds or thousands of antenna elements, even at the UE. Smart antennas with beam forming and phased array capabilities will be employed to point out the antenna beam to a desired location with high precision, rotated electronically through phase shifting. The narrow pencil beams will enable the exploiting of the spatial DOF, without interfering with other users. The small antenna sizes will enable Massive/3D MIMO at BSs and eventually at UEs.

The mmWave technology will also provide ultra-broadband backhaul links to carry the traffic from/to either the small BSs or the relay stations, allowing further deployment flexibility for the operators, compared to the wired (copper or fibre) backhaul link. Hyperdense small-cell deployment is another promising solution for 5G to meet the 1000x capacity challenge. Small cells have the potential to provide massive capacity and to minimise the physical distance between the BS and the UEs to achieve the required EE enhancement for 5G. The traditional sub-3 GHz bands will be employed for macro-cell blanket coverage, while the higher frequency bands (e.g. cm- and mmWave bands) will be employed for small cells to provide a spectral- and energy-efficient data plane, assisted by a control plane served by the macro-BS [38].

N.B.

Control plane vs. User/data plane

Control plane refers to the all functions and processes that determine which path to use to send the packet or frame. Data plane refers to all the functions and processes that forward packets/frames from one interface to another based on control plane logic.

The data plane (sometimes known as the user plane, forwarding plane, carrier plane or bearer plane) carries the network user traffic. The control plane carries signaling traffic.

MTC -- ***Machine-Type Communication*** *(MTC) denotes the broad area of wireless communication with sensors, actuators, physical objects and other devices not directly operated by humans. Different types of radio access technologies are targeting MTC.*

MIMO -- *MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors, optimize data speed and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time.*

3D-MIMO is a promising technique in massive MIMO networks to enhance the cellular performance by deploying antenna elements in both horizontal and vertical dimensions.

Creating multiple versions of the same signal provides more opportunities for the data to reach the receiving antenna without being affected by fading, which increases the signal-to-noise ratio and error rate. By boosting the capacity of radio frequency (RF) systems, MIMO creates a more stable connection and less congestion.

WiFi offloading -- Wi-Fi offload transparently connects devices to fixed hot- spots or Wi-Fi access points (AP) when they are available. By using a Wi-Fi connection to the Internet, the carrier's mobile network is bypassed, thereby significantly reducing the demand on available spectrum.

Blanket coverage -- In Communication, blanket coverage is **that which is not targeted but is covered by all channels**.

Architecture of 5G (Perspective 2)

As shown in Figure 2, the cellular network consists of two main subsystems: the *Radio Access Network (RAN)* and the *Mobile Core*. The RAN manages the radio spectrum, making sure it is used efficiently and meets the quality-of-service requirements of every user. It corresponds to a distributed collection of base stations.

The Mobile Core is a bundle of functionality (as opposed to a device) that serves several purposes.

- Provides Internet (IP) connectivity for both data and voice services.
- Ensures this connectivity fulfils the promised QoS requirements.
- Tracks user mobility to ensure uninterrupted service.
- Tracks subscriber usage for billing and charging.

Even though the word "Core" is in its name, from an Internet perspective, the Mobile Core is still part of the access network, effectively providing a bridge between the RAN in some geographic area and the greater IP-based Internet. 3GPP provides significant flexibility in how the Mobile Core is geographically deployed, but for our purposes, assuming each instantiation of the Mobile Core serves a metropolitan area is a good working model. The corresponding RAN would then span several dozens (or even hundreds) of cell towers.

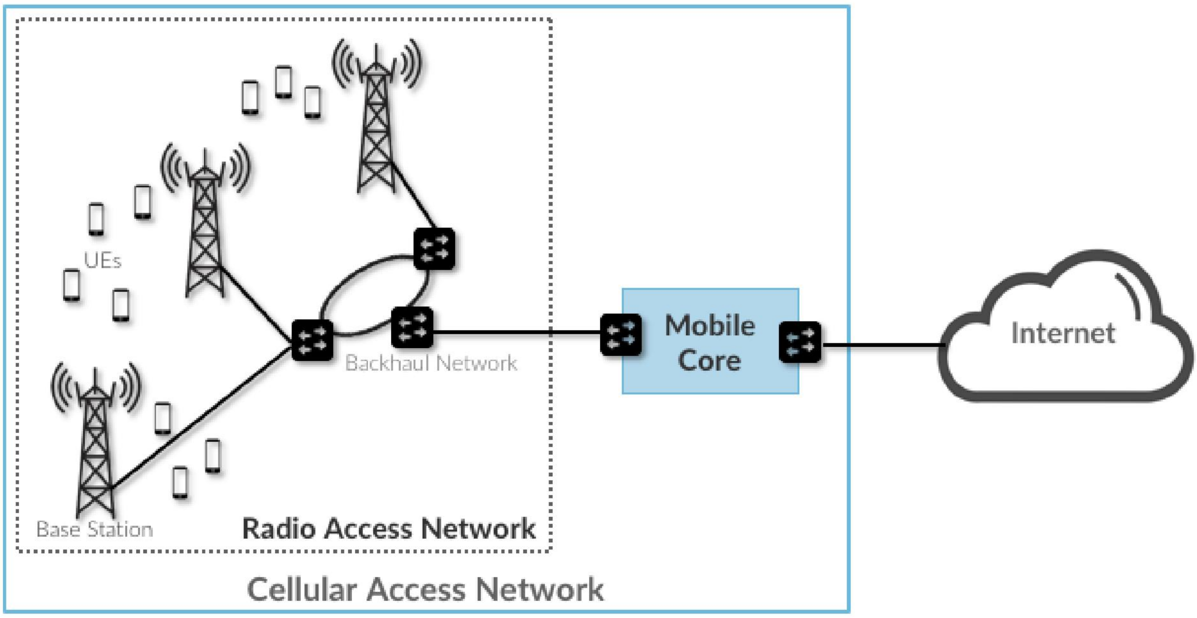


Figure 2: Cellular networks consists of a Radio Access Network (RAN) and a Mobile Core
https://5g.systemsapproach.org/arch.html

In the above Figure, a *Backhaul Network* interconnects the base stations that implement the RAN with the Mobile Core. This network is typically wired, may or may not have the ring topology shown in the Figure. For example, the *Passive Optical Network (PON)* that implements Fiber-to-the-Home is a prime candidate for implementing the RAN backhaul. The backhaul network is obviously a necessary part of the RAN, but it is an implementation choice and not prescribed by the 3GPP (3^{rd} generation partnership project) standard.

Architecture of 5G (Perspective 3)

Architecturally, 5G builds on LTE by adding a number of new components that are shown in Figure 3. The *5G core network* (5GC) contains new network functions that support NFV (Network Functions Virtualization), SDN (Software Defined Networking) and network slicing. The *next-generation radio access network* (NG-RAN) introduces new interfaces and signalling procedures for the backhaul and for communications between nearby base stations, and supports RAN centralization and virtualization, edge computing and network slicing. Together, the two networks form the *5G system* (5GS).

NFV, SDN -- *SDN separates the data and control planes, which enables operators to manage features from a centralized location. NFV, too, is a process involving separation. By virtualizing network infrastructure, NFV separates the functions that typically run in hardware and implements them as software.*

Network Slicing -- *Network slicing is a method of creating multiple unique logical and virtualized networks over a common multi-domain infrastructure.*

The 5G base station is known as a *next-generation Node B* (gNB). The gNB communicates the mobile over an air interface known as the *New Radio* (NR), which supports millimetre-wave and multiple antenna communications.

Generically, an individual eNB or gNB is known as a *node*. As shown in Figure 3, an individual node can lie in either the E-UTRAN, the NG-RAN or both. Specifically, a node lies in the E-UTRAN if it supports the legacy LTE backhaul and is connected to the evolved packet core (EPC), and in the NG-RAN if it supports the new 5G backhaul and is connected to the 5G core(5GC).

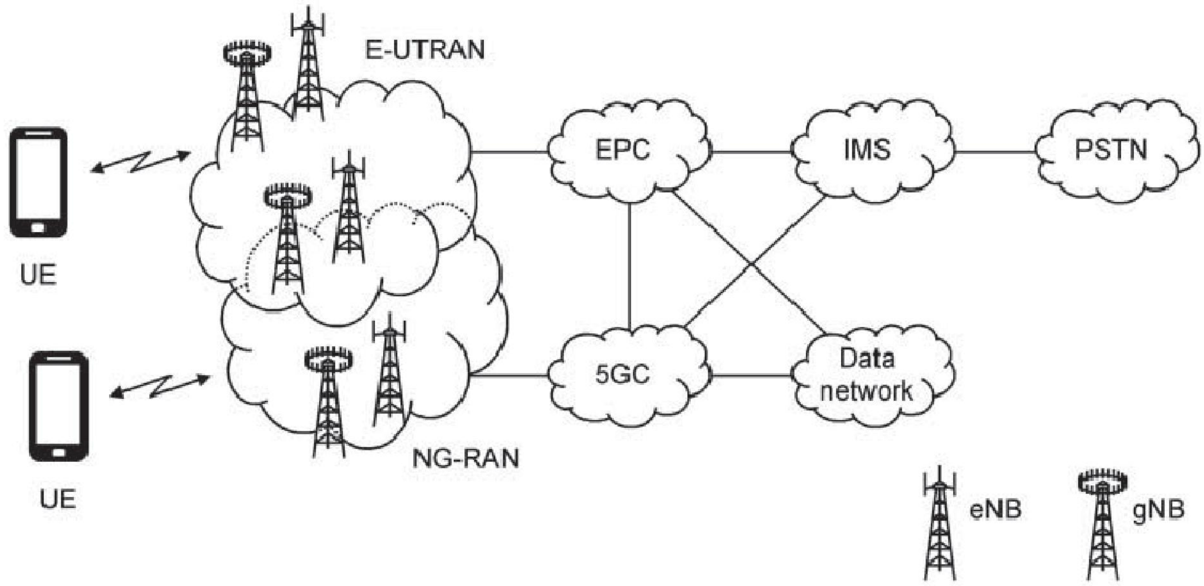


Figure 3: High-level architecture of 5G

In Release 15, the 5G core network handles voice calls using VoIP alone, with the calls controlled by either a third-party application or the IP multimedia subsystem. Release 16 introduces support for SRVCC, in which the network can convert an IMS voice call to a circuit-switched call, and can hand the mobile over to a 3G cell [59]. However, that is the only direct interaction between the 5G core network and the core networks of 2G and 3G. If, for example, an SRVCC handover takes place, then the mobile's communications with any external packet data networks are all torn down.

Single radio voice call continuity (SRVCC) is an LTE feature that allows a VoIP/IMS call in the LTE packet-switched domain to be transferred to a legacy circuit-switched domain (GSM/UMTS or CDMA2000).

The 5G Core Network

5G Core (5GC) is the heart of a 5G mobile network. It establishes reliable, secure connectivity to the network for end users and provides access to its services. The core domain handles a wide variety of essential functions in the mobile network, such as connectivity and mobility management, authentication and authorization, subscriber data management and policy management, among others. 5G Core network functions are completely software-based and designed as cloud-native, meaning that they're agnostic to the underlying cloud infrastructure, allowing higher deployment agility and flexibility.

Using the 5G core network, the mobile can connect to one or more packet data networks (abbreviated in 5G as DN), for example the Internet, the IMS, or a low-latency network for a private industrial client. Each connection is associated with a *session management function* (SMF). The SMF controls the mobile's interactions with the data network, communicates with the mobile by means of session management signalling and sends information about the mobile's data usage to a separate charging system. The SMF also controls one or more *user plane functions* (UPFs), which handle the user's traffic.

IMS -- IP Multimedia Subsystem or IMS is a standards-based architectural framework for delivering multimedia communications services such as voice, video and text messaging over IP networks.

Reference Point System Architecture vs Service Based Architecture

The Service Based architecture is applicable to the control plane, and Reference Point architecture is used for the user plane of the 5G Core Network. The interface naming for the Reference point is given as a number with the letter "N" like N2, N3 or N4.

Reference Point architecture consists of a set of Network Elements (NE) which uses point to point interfaces to inter-connect those Network Elements.

Service Based architecture replaces the set of Network Elements with a set of Network Functions (NF). Each Network Function is a service provider to other Network Function(s).

5G REFERENCE POINT SYSTEM ARCHITECTURE

5G System Reference point architecture is shown in Figure below. It lists a set of Network elements and set of point to point interfaces which interconnect those Network Elements.

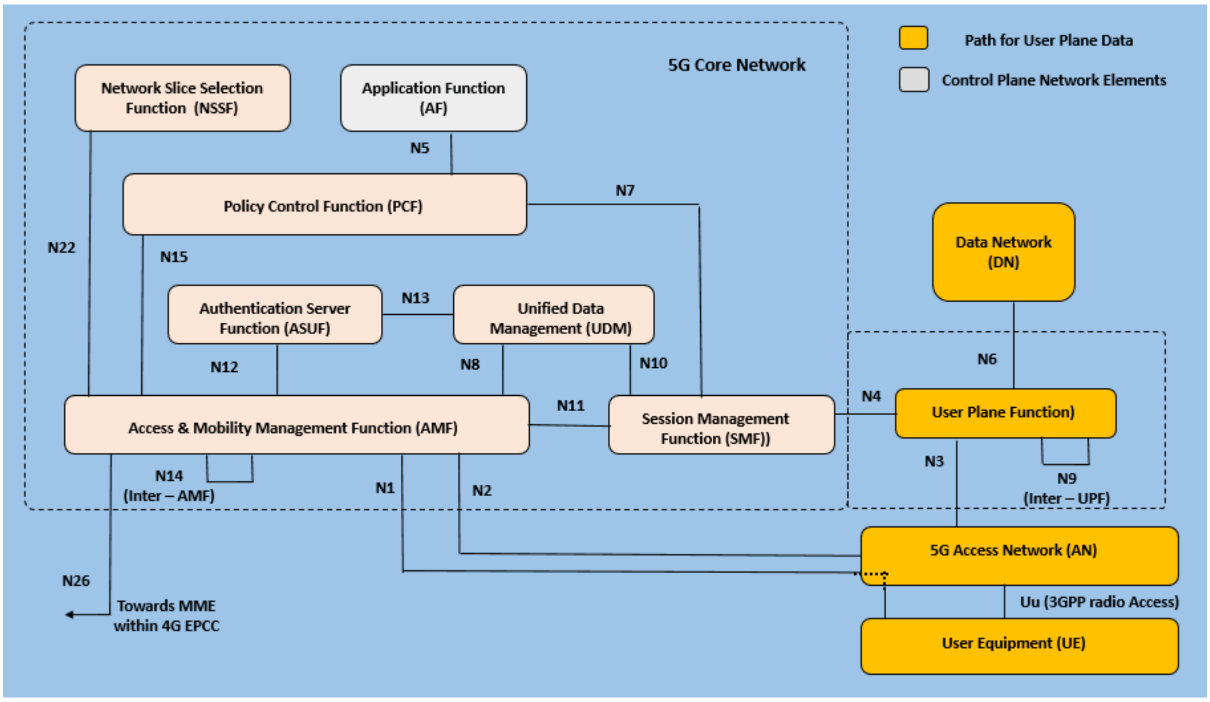


Figure 4: 5G System Reference Point Architecture
http://www.techtrained.com/reference-point-system-architecture-vs-service-based-architecture/

- 5GS Reference point architecture describes the separation of control plane and user plane functions.
- Uplink data is transferred from UE to 5G Access Network. It is transferred through user plane functions (UPF) before forwarded into an external network (internet etc.) Same is the case for down-link data but in opposite direction.
- Of-course there are exceptions to the separation of user plane and control plane functions. For example user plane data belonging to the Short Message Service (SMS) can be transferred using Non-Access Stratum (NAS) signalling between the UE and Access and Mobility Management Function (AMF).
- Point to Point interfaces connecting the Network Elements are labelled as N1, N2, N3, etc. known as Reference points according to 3GPP TS 23.501
- N3 is the Reference Point between the 5G Access Network and the User Plane Function (UPF)
- N1 is the Reference Point between UE and the Access and Mobility Management Function (AMF). It is usually shown as a direct logical connection between the UE and AMF.
- N9 Reference point is used to inter-connect User Plane Functions (UPF). First UPF can be used to provide connectivity to the 5G Access Network while a second UPF can be used to provide connectivity to external data network. N9 Reference Point defines the connection between two UPF.
- N26 Reference point can be used to connect an AMF within the 5G Core Network, with a Mobility Management Entity (MME) within 4G Evolved Packet Core (EPC). This reference point is used for inter-working between 4G and 5G handovers.

- 3GPP Next Generation Radio Access Network (NG RAN), user plane data and control plane signalling are transferred between the UE and NG RAN using the Uu air-interface.

5G SYSTEM SERVICE BASED SYSTEM ARCHITECTURE

5G System service based architecture is shown below. It specifies a set of Network Function (NF) and a common bus which connects these Network Functions.

Service based architecture is applicable to the control plane section of 5G Core Network only.

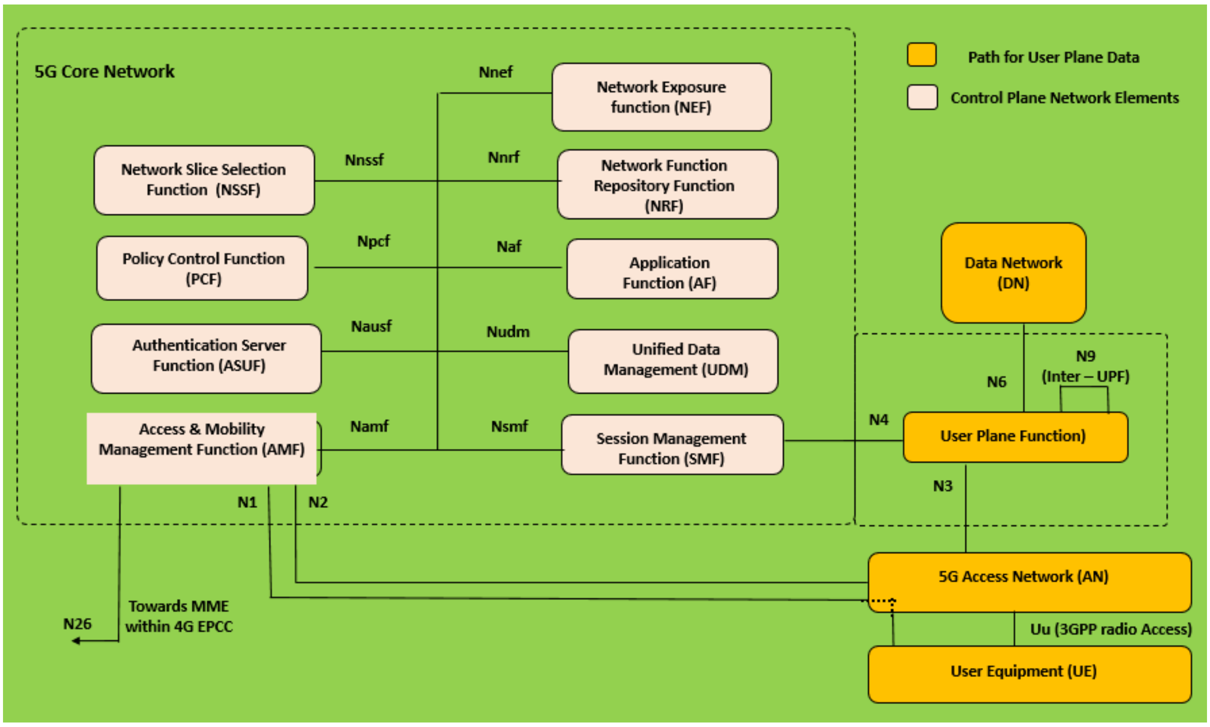


Figure 5: 5G Service based System Architecture

UPF -- The User Plane Function (UPF) represents the data plane evolution of a Control and User Plane Separation (CUPS) strategy, which is a fundamental component of the 3GPP 5G core network (5GC).

Figure 6: Representation of the 5G core network using reference points

Network Function Service Discovery

Once a network function has registered with the NRF, it can be discovered by another network function, for example by an AMF.

NRF -- Network Repository Function; it is a key element of the new 5G Service Based Architecture. The NRF is a centralized repository for all the 5G network functions (NFs) in the operator's network. The NRF allows 5G NFs to register and discover each other via a standards-based API.

AMF – Access & Mobility Management Function: It is a control plane function in 5G core network. The main functions and responsibilities of AMF are Registration Management and Reachability Management.

To ask for the details of any registered AUSFs, the AMF requests the NFDiscover operation from the NFDiscovery service in the NRF.

AUSF -- The Authentication Server Function (AUSF) provides authentication services and other security-related services to the 5G Core (5GC) network through the Nausf Service-Based Interface (SBI). Authentication server function (AUSF), which authenticates UEs and stores authentication keys.

NSSF -- Network Slice Selection Function (NSSF) selects the network slicing instance (NSI), determines the allowed network slice selection assistance information (NSSAI) and set AMF to serve the UE. AMF can retrieve NRF, NSI ID, and target AMFs as part of UE initial registration and PDU establishment procedure.

Oracle NSSF interaction with NRF allows retrieving specific NF services to be used for registration request. It also allows mechanism for registration and subsequent notification Function Instance Discovery.

PCF -- In the 5G network, Policy Control Function (PCF) has the following features and functions:

- Support 5G QoS policy and charging control functions and the related 5G signaling interfaces. The 3GPP standards, such as N7, N15, N28, N36, and Rx, define these interfaces for the 5G PCF.
- Provide policy rules for control plane functions, which include network slicing, roaming, and mobility management.
- Collect the subscriber metrics in context with their network, usage, applications, and more. The operators analyze this information to optimize resources and make informed decisions to segment users.
- Provide the real-time management of subscribers, applications, and network resources based on the business rules configured for a service provider.
- Accelerate and simplify deployment and upgrades using the ConfD CLI, increased speed and efficiency, and low latency by adopting the cloud-native implementation.
- Collaborate with other NFs through NRF, which provides a unified communication platform for the NFs to interact with each other.

NEF -- Network Exposure Function(NEF) of Alepo provides a simple, secure, and streamlined means to control network access for external applications, enabling developers and enterprises to swiftly create, launch, and manage new services. Its modern and advanced underlying architecture helps to:

- **Leverage Software Developer Kits (SDKs):** supports a developer environment with service exposure capabilities in sync with developer workflows and practices. Operators can extend advanced capabilities to activate multiple libraries, functions, and containers with just a few additional clicks through a wide range of plugins, simplifying service introduction.
- **Support partnerships:** provides secure access for partners to launch and manage advanced innovations.

AF -- Application Function (AF) is **a control plane function within 5G core network, provides application services to the subscriber**. Example it can be for video streaming service. If an AF is trusted it can interact directly with 5GC network functions or if it is 3rd party, then it should interact with an NEF.

UDM -- Alepo's 5G Unified Data Management helps operators looking to meet dynamic customer demands by supporting the segmentation of subscribers with personalized services and targeted offers. It performs service and access authorization for authenticated subscribers, ensuring that customers only have access to their subscribed services.

SMF -- The 5G Session Management Function (SMF) is a fundamental element of the 5G Service-Based Architecture (SBA). The SMF is primarily responsible for interacting with the decoupled data plane, creating updating and removing Protocol Data Unit (PDU) sessions and managing session context with the User Plane Function (UPF).

The NRF replies with the HTTP response 200 OK. In its JSON data, the NRF lists the profiles of AUSFs that match the request, and includes a validity period that states how long those profiles can be cached.

Assisted by the priority and capacity fields from their network function profiles, the AMF selects one of the matching AUSFs, sets up TCP and HTTP/2 connections with it, and requests the appropriate service operation.

To support roaming mobiles, the AMF may have to discover an instance of an AUSF in a different network. To do so, the AMF sends its request to an NRF in its own network, which forwards the request to a second NRF in the destination network. On receiving the response, the AMF can contact the selected AUSF directly.

Architecture of the Radio Access Network

We will introduce the next-generation Node B, and discuss its internal division into central and distributed units. We will then move on to the next-generation radio access network, introduce the concept of multi-radio dual connectivity. The most important specifications are the descriptions of the air interface and the radio access network.

oth types of node at the same time.

Network Areas and Identities

Tracking Areas

The NG-RAN is organized into *tracking areas* (TAs). Tracking area is a small geographical region containing perhaps 100 nodes. The NG-RAN's tracking areas do not overlap: a cell lies in just one tracking area, but a node can lie in multiple tracking areas by virtue of controlling multiple cells.

Each tracking area is identified by a 24-bit *tracking area code* (TAC), which is unique within the public land mobile network (PLMN). Adding the public land mobile network identity (PLMN-ID) gives the *tracking area identity* (TAI), which is globally unique.

Registration areas (RA) are implemented by means of geographical regions known as tracking areas. Each registration area is implemented as a mobile-specific *tracking area list* that contains a maximum of 16 tracking areas.

For instance, the UE is connected to cell 1 in TA1 as shown in the following Figure.

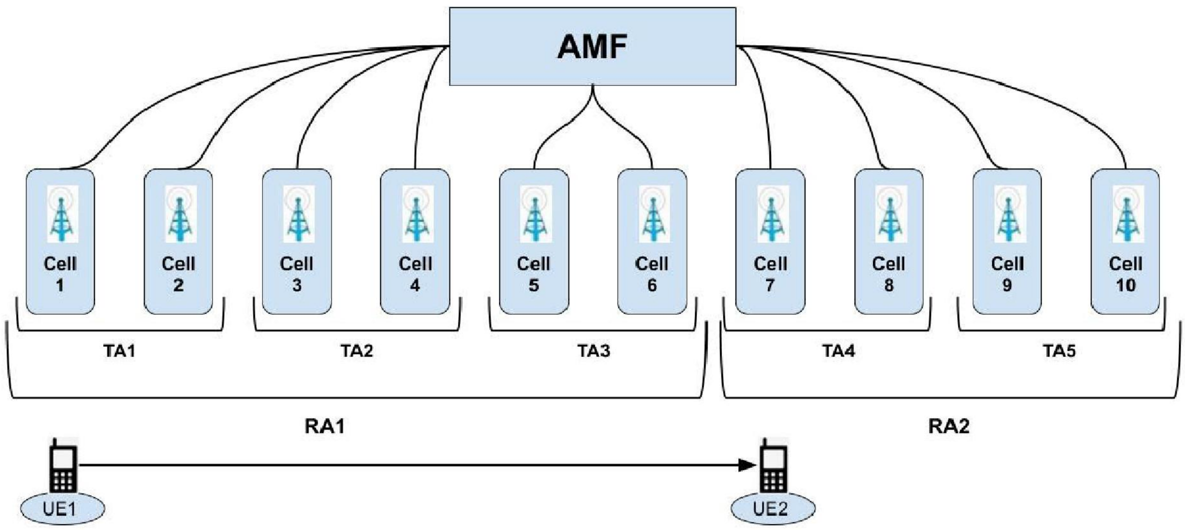


Figure 10: 5G Mobility Management Architecture

When the UE becomes active to take advantage of network services and capabilities, it needs to be registered on the network. There are several types of registration such as initial registration, periodic registration, mobility registration etc.

Initial registration: It is performed by the UE to connect to a network after the device is turned on.

Periodic registration: It is the process by which the network checks the UE periodically to perform a new registration so that the UE in the registration area (RA) can be sure whether its registration is deleted without notifying the network.

Mobility registration: It is the registration by the UE when the user changes the location and the TA of the cell to which it is linked is not in the RA list.

Paging is a system access function used by the network to locate the UE and is triggered when there is a downlink packet for the UE.

DRX cycle – Disconnection in reception

Spread spectrum

The advantage of spread spectrum technique is that — many users can simultaneously use the same bandwidth without interfering with each other. Therefore, spread spectrum is not economic when the number of users is less.

Spread Spectrum refers to a system originally developed for military applications, to provide secure communications by spreading the signal over a large frequency band. Figure 1 represents a narrow band signal in the frequency domain. These narrowband signals are easily jammed by any other signal in the same band.

In many instances it is necessary to keep transmissions as narrow as possible to conserve the frequency spectrum. However, under some circumstances it is advantageous to use what are known as 'spread spectrum techniques', where the transmission is spread over a wide bandwidth.

OFDM/ OFDMA

Orthogonal Frequency Division Multiplexing (OFDM) for single-user transmissions on an 802.11 frequency. 802.11ax radios can utilize Orthogonal frequency-division multiple access (OFDMA) which is a multi-user version of the OFDM digital-modulation technology.

Primarily, OFDM is more resilient to electromagnetic interference, and it enables more efficient use of total available bandwidth because the subchannels are closely spaced. It is also more resistant to interference because several channels are available.

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient modulation format used in modern wireless communication systems including 5G. OFDM combines the benefits of Quadrature Amplitude Modulation (QAM) and Frequency Division Multiplexing (FDM) to produce a high-data-rate communication system.

In OFDM, multiple closely spaced orthogonal subcarrier signals with overlapping spectra are transmitted to carry data in parallel. Demodulation is based on fast Fourier transform algorithms. OFDM was improved by Weinstein and Ebert in 1971 with the introduction of a guard interval, providing better orthogonality in transmission channels affected by multipath propagation. Each subcarrier (signal) is modulated with a conventional modulation scheme (such as QAM or QPSK) at a low symbol rate. This maintains total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

What is orthogonal?

Orthogonal frequency-division multiplexing is a method of data transmission where a single information stream is split among several closely spaced narrowband subchannel frequencies instead of a single Wideband channel frequency. It is mostly used in wireless data transmission but may be employed in wired and fiber optic communication as well.

In a traditional single-channel modulation scheme, each data bit is sent serially or sequentially one after another. In OFDM, several bits can be sent in parallel, or at the same time, in separate substream channels. This enables each substream's data rate to be lower than would be required by a single stream of similar bandwidth. This makes the system less susceptible to interference and enables more efficient data bandwidth.

The term "orthogonal" means **two things acting independently or in an uncorrelated manner**; in this case, any two signals of an OFDM-based product operating without dependence on, or interference with one another.

How orthogonal subcarriers help?

The spacing of the subcarriers is orthogonal, so they will not interfere with one another despite the lack of guard bands between them. This creates signal nulls in the adjacent subcarrier frequencies, thus preventing inter-carrier interference (ICI).

The main advantage of OFDM over single-carrier schemes is **its ability to cope with severe channel conditions** (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without the need for complex equalization filters.

It's important to have a fundamental understanding of Orthogonal Frequency Division Multiplexing (OFDM) because this technology is a basic building block for many of the current modulation schemes including; 802.11 WLAN, 802.16 WiMAX, and 3GPP LTE. This topic discusses the basic concepts of OFDM and how OFDM is implemented in 802.11a WLAN modulation. The basic OFDM principles will be introduced using a simple analog OFDM implementation and then those concepts will be extended to the digital domain with a simple digital OFDM implementation which utilizes the FFT transform and DSP technology. The discussion ends with an explanation of how

OFDM is implemented in 802.11a WLAN and how the OFDM symbol and burst is created.

Introduction to OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme that extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Rather than transmit a high-rate stream of data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at low symbol rate. However, the combination of many subcarriers enables data rates similar to conventional single-carrier modulation schemes within equivalent bandwidths.

OFDM is based on the well-known technique of Frequency Division Multiplexing (FDM). In FDM different streams of information are mapped onto separate parallel frequency channels. Each FDM channel is separated from the others by a frequency guard band to reduce interference between adjacent channels.

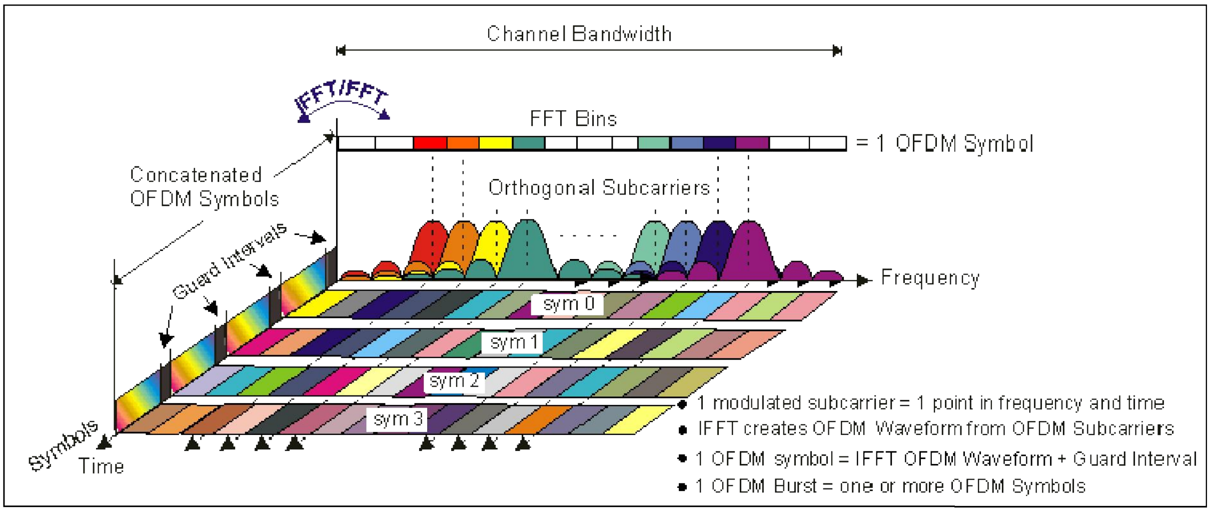
The OFDM scheme differs from traditional FDM in the following interrelated ways:

1. Multiple carriers (called subcarriers) carry the information stream,

2. The subcarriers are orthogonal to each other, and

3. A guard interval is added to each symbol to minimize the channel delay spread and inter symbol interference.

The following figure illustrates the main concepts of an OFDM signal and the inter-relationship between the frequency and time domains. In the frequency domain, multiple adjacent tones or subcarriers are each independently modulated with complex data. An Inverse FFT transform is performed on the frequency-domain subcarriers to produce the OFDM symbol in the time-domain. Then in the time domain, guard intervals are inserted between each of the symbols to prevent inter-symbol interference at the receiver caused by multi-path delay spread in the radio channel. Multiple symbols can be concatenated to create the final OFDM burst signal. At the receiver an FFT is performed on the OFDM symbols to recover the original data bits.



Frequency-Time Representative of an OFDM signal

A fast Fourier transform (FFT) is an algorithm that computes the discrete Fourier transform (DFT) of a sequence, or its inverse (IDFT). Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

Definition of QPSK

Quadrature Phase Shift Keying (QPSK) is a form of Phase Shift Keying in which two bits are modulated at once, selecting one of four possible carrier phase shifts (0, 90, 180, or 270 degrees)**. QPSK allows the signal to carry twice as much information as ordinary PSK using the same bandwidth.**

Definition of QAM

QAM (Quadrature Amplitude Modulation) is the combination of analog and digital modulation method. In order to transmit two analog message signals/two digital bit streams, it modulates the amplitude of the two carrier waves with the help of amplitude shift keying (ASK).

QPSK conveys 2-bit simultaneously while in case of QAM the number of bits depends on the type of QAM such as 16 QAM, 32 QAM, 64 QAM, 128 QAM, 256 QAM conveys 4, 5, 6, 7, 8 bits respectively. The performance of QPSK is superior to QAM. The bit error rate of QAM is high as compared to QPSK.

Differences between QAM and QPSK

- The spectral width of QPSK is wider than that of QAM.
- QPSK conveys 2-bit simultaneously while in case of QAM the number of bits depends on the type of QAM such as 16 QAM, 32 QAM, 64 QAM, 128 QAM, 256 QAM conveys 4, 5, 6, 7, 8 bits respectively.
- The performance of QPSK is superior to QAM.
- The bit error rate of QAM is high as compared to QPSK.