What is bandwidth?

Bandwidth has several meanings depending on the context in which it is used.

Analog signal bandwidth :

In signal processing, bandwidth is a measure of the range of frequencies within a signal. It is often expressed in hertz (Hz) and indicates the range of frequencies over which a signal or system can operate effectively. For example, an audio system might have a specified bandwidth of 20Hz to 20,000Hz, indicating that it can reproduce audio frequencies within that range.

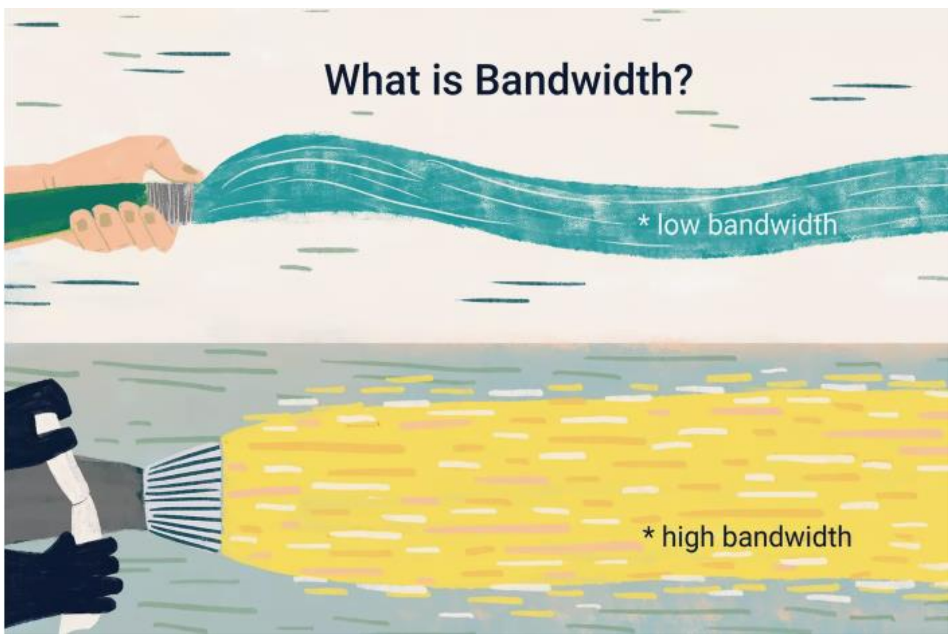
Also note that bandwidth of signal is different from bandwidth of the channel.

A channel is the medium through which the input signal passes. In terms of analog signal, bandwidth of the channel is the range of frequencies that the channel can carry.

Analog signal bandwidth is measured in terms of its frequency (Hz) but digital signal bandwidth is measured in terms of bit rate (bits per second, bps).

Digital signal bandwidth:

In the context of computer networks and telecommunications, bandwidth refers to the data transfer rate or capacity of a communication channel. It is typically measured in bits per second (bps) and represents how much data can be transmitted over a network connection in a given time period. Higher bandwidth allows for faster data transfer and is crucial for activities like streaming videos, downloading files, and online gaming. Different types of channels have different bandwidth. Ex. Twisted pair, coaxial cable, fiber optics, Microwave etc.



Type of the channel	Frequency range
Twisted pair	1MHz – 100 MHz)
Coaxial cable	0 – 750 MHz
Microwave	1 GHz-30 GHz
Satellite	1 GHz – 40 GHz
Fibre optics	180 THz – 330 THz

Bw= bandwidth (data transfer rate) (bit per second bps)
T = The time of sending or receiving data (second)
S= size of data (bit)

T = S/Bw

The time to send or receive data decreases as the bandwidth increases.

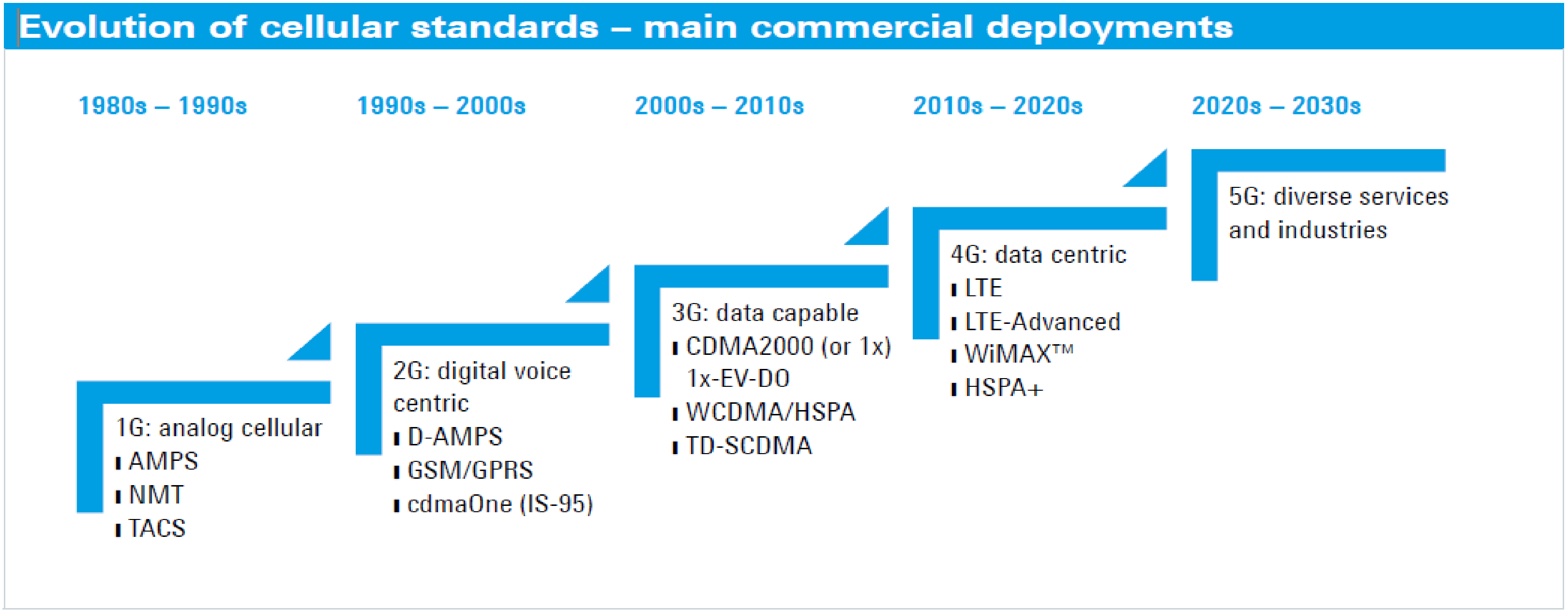
For example, What is the time required to download a file of 100 Mb through a transmission medium with a bandwidth of 50 Mbps?

T = S/Bw

T = 100 Mb/50 Mbps
T = 2 s

cellular networks

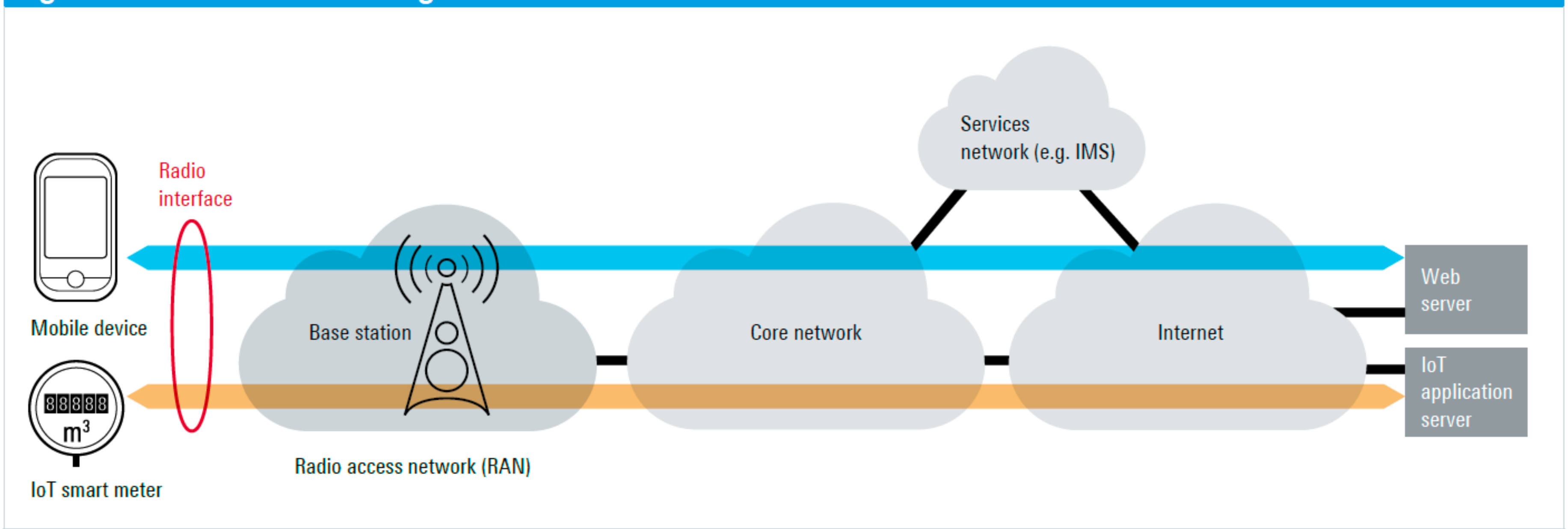
Cellular networks enable devices such as smartphones and internet of things (IoT) devices to communicate wirelessly. Cellular technologies have advanced from first generation(1G) analog technology to advanced high-performance fourth generation (4G) and fifth generation (5G) systems in just about four decades . While 1G cellular technologies have disappeared, 2G technologies are gradually being replaced by newer generations of technologies. 3G and 4G cellular technologies are widely deployed around the world. And 5G technologies have begun to appear in 2018.



1. cellular network architecture

Though the exact network architecture differs from one generation to another, a typical cellular network consists of a radio access network (RAN), a core network (CN) and a services network as shown in Fig. 1 . The RAN contains base stations (BS) that communicate with the wireless devices using radio frequency (RF) signals, and it is this interface between the base station and the devices that is the primary subject of this Lecture. The RAN allocates radio resources to the devices to make wireless communications a reality. The CN performs functions such as user authentication, service authorization, security activation, IP address allocation and setup of suitable links to facilitate the transfer of user traffic such as voice and video. The services network includes operator-specific servers and IP multimedia subsystem (IMS) to offer a variety of services to the wireless subscriber, including voice calls, text messages (SMS) and video calls.

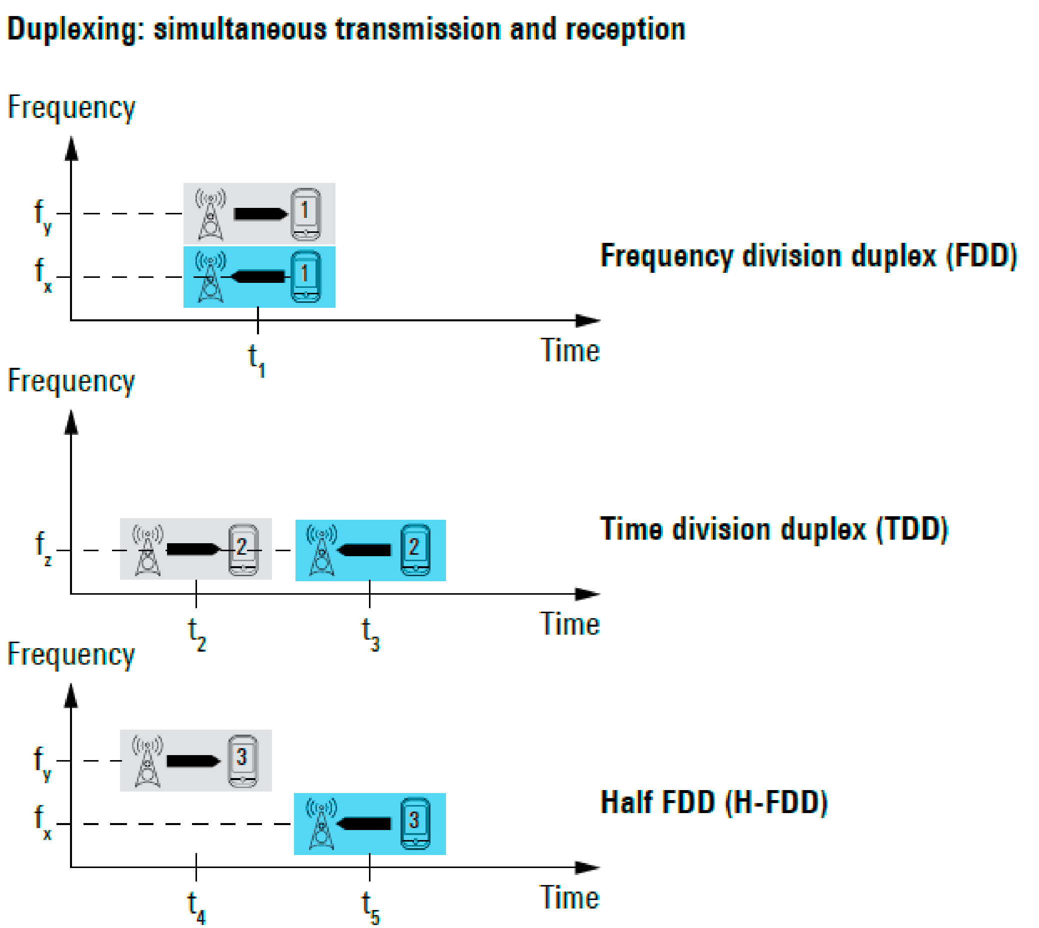
Fig. 1: Cellular network: a high-level view



2. Making communications wireless

Let us discuss communications between the device and the radio access network. A technique called duplexing allows the device or the base station to simultaneously transmit and receive information. Fig. 3 illustrates duplexing techniques.

Fig. 3: Duplexing in a cellular network



The communications link from the device to the base station is called the uplink or the reverse link, and the communications link from the base station to the device is called the downlink or the forward link. Duplexing allows the device and the base station to simultaneously send information on the one link while receiving information on the other link. Duplexing facilitates bidirectional and realtime transfer of information. **Two basic duplexing methods are frequency division duplex (FDD) and time division duplex (TDD). A special case of FDD is half-duplex FDD (H-FDD).**

In FDD, one part of the frequency spectrum is used for the uplink and a different part of the frequency spectrum for the downlink. From the device perspective, uplink transmission and downlink reception can occur at exactly the same time. From the base station perspective, downlink transmission and uplink reception can occur at exactly the same time.

In TDD, the same unpaired frequency spectrum is used for the uplink and the downlink.
The uplink exists at one instant, and the downlink exists at a different instant. Since the switching between the uplink and the downlink is carried out rapidly (e.g. on the order of milliseconds before 5G or even tens of microseconds in 5G), the uplink and the downlink are considered "simultaneous" for all practical purposes.

TDD is simpler and less expensive than FDD from the device design perspective. However, interference is easier to manage with FDD due to the separation of the uplink and the downlink in the frequency domain.

Half-duplex FDD (H-FDD) can be viewed as a special case of FDD. Like FDD, H-FDD uses different chunks of spectrum for the uplink and downlink. However, at the device, only one link is active at an instant in time. Therefore, with H-FDD, the device either transmits in the uplink using the uplink spectrum or receives in the downlink using the downlink spectrum at a given instant.

multiple access techniques

multiple access techniques allows multiple devices to access and use the network at the same time through suitable sharing of radio resources. Fig. 4 depicts a simplified view of multiple access techniques commonly used in cellular networks.

Fig. 4: Traditional multiple access in a cellular network