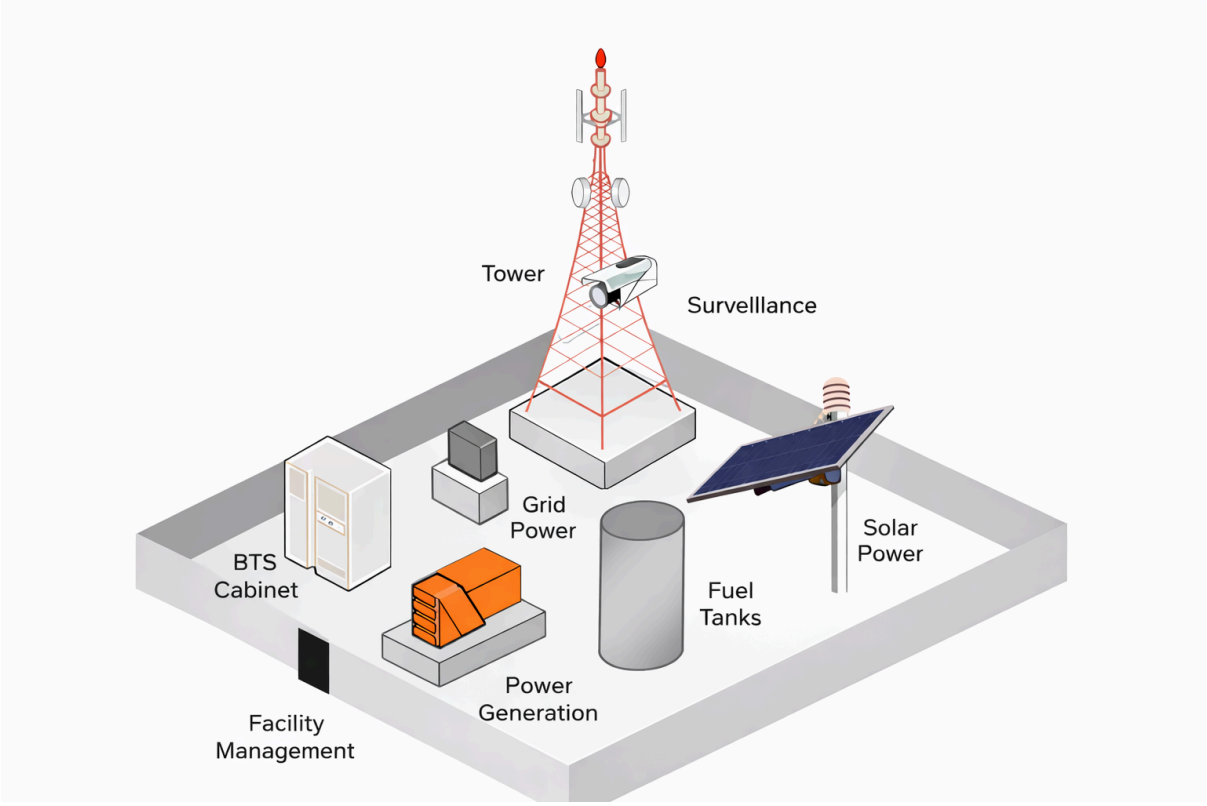
Mobile network

Written by [Febogamedev]

A mobile network is a wireless communication system that allows users of devices such as mobile phones, smartphones, tablets, and other mobile devices to connect with one another and with the rest of the world through radio signals (Kurose & Ross, 2026).
Mobile networks are built using a combination of communication infrastructures.

A key component of a mobile network is **the base station (*BS*)**.
The *BS* includes the equipment that transmits and receives radio signals (3rd Generation Partnership Project [3GPP], 2022; Kurose & Ross, 2026).
Antennas can be installed on towers, masts, building rooftops, or other physical structures.



The following steps take place when a packet is sent from a device (3GPP, 2022; Kurose & Ross, 2026):

- The device converts digital data into radio signals, which are transmitted through its built-in antenna.
- These waves allow data—such as voice, text, or images—to be transmitted through the air without cables.
- The data is received by an antenna on a cell tower, which converts the radio waves into electrical signals.
- These electrical signals are carried into the network through underground fiber-optic cables.

- The data then enters the mobile operator’s network, which routes it toward its destination:
    - For a phone call, the audio data is sent to the tower antenna nearest to the person we are speaking with and is then transmitted by radio waves to the correct smartphone.
    - When accessing a website, the request travels through the Internet using the network types discussed earlier, and the response returns to the device through the operator’s network and the base station to which it is connected.

This infrastructure enables mobile users to make calls, send messages, browse the Internet, and use a variety of online services wherever mobile network coverage is available (Kurose & Ross, 2026).

But how does mobile coverage work?
The area covered by a mobile network is divided into regions called **cells**.
A cell is the geographical area served by a base station, which consists of equipment and antennas that communicate by radio with mobile devices in that area (3GPP, n.d.; Kurose & Ross, 2026).

It is important to distinguish between the tower and the network of an individual operator.
A tower is the physical structure on which the antennas and equipment of one or more mobile operators may be installed. However, not every operator is necessarily present on the same tower (Kurose & Ross, 2026).

For example, a tower may contain WindTre antennas and equipment but no Vodafone equipment. In the same area, a WindTre user might therefore have coverage, while a Vodafone user might have no coverage or a weaker signal because the device must connect to a more distant Vodafone cell (Kurose & Ross, 2026).

As a smartphone moves, it can gradually switch from one cell to another. This handover allows communication to continue while the user is moving, for example while walking, travelling by car, or riding on a train (3GPP, n.d.).

If no usable cell belonging to the user’s operator is available in a certain area, the smartphone searches for another cell from the same operator, even if it is farther away. If no usable cell can be found, the phone may show no service, although emergency calls may still be possible through available networks (European Commission, 2026).

In general, a device tends to connect to the cell from which it receives the best signal, which is often also one of the nearest cells.
However, the choice does not depend on distance alone: signal quality, physical obstacles, the frequencies used, network congestion, and the operator’s configuration also matter (3GPP, n.d., 2022).

The signal bars shown on a smartphone provide a simplified indication of the quality or strength of the radio connection to the mobile network. Mobile coverage therefore depends

on the presence of towers in the area, the operators using those sites, the frequencies employed, physical obstacles, and the network configuration (3GPP, n.d.).



Each antenna operated by a service provider uses one or more radio-frequency bands, meaning specific ranges of frequencies, to transmit and receive signals (3GPP, 2022).
Radio-frequency bands are allocated and regulated by the relevant public authorities to prevent interference between services and operators.
Users' devices must also support the specific frequency bands used by their operator; otherwise, they cannot connect to the network (3GPP, 2022).

Under normal conditions, a phone with a SIM from a particular operator connects to that operator's network.
However, it can also connect to other networks when roaming agreements exist—that is, commercial and technical agreements between mobile operators—for example when the user is abroad or in certain special circumstances European Commission, 2026).
As a result, in the same geographical area, a Vodafone user might have better coverage than a TIM user if there are more Vodafone cells or if they are configured more effectively.

Internationally standardized rules and protocols are used so that mobile phones made by different manufacturers and transmitters operated by different providers can communicate reliably with one another (3GPP, 2022).
Mobile networks have evolved through several generations of standards, including **2G**, **3G**, **4G**, and **5G**.
At present, 5G is one of the most recent and advanced generations (3GPP, 2022).

The main characteristics of 5G include (3GPP, 2022; International Telecommunication Union, 2015):

- High speeds: 5G offers much faster download and upload speeds than 4G. This enables rapid downloads of large files, high-resolution video streaming, and other activities that require substantial bandwidth (International Telecommunication Union, 2015).
- Low latency: latency is the delay between sending and receiving data. 5G is designed to reduce latency to extremely low levels, enabling almost instantaneous communication. This is essential for real-time applications such as online gaming, virtual reality (VR), augmented reality (AR), and communication between IoT (Internet of Things) devices (International Telecommunication Union, 2015).
- Greater capacity: through advanced modulation techniques and the use of wider frequency ranges, 5G can support a much larger number of simultaneously connected devices (International Telecommunication Union, 2015).
- Stable connections while moving: 5G is designed to maintain a stable connection even when users are travelling at high speeds, such as in cars or on high-speed trains (International Telecommunication Union, 2015).
- Support for advanced applications: 5G is considered an enabling technology for new applications and advanced services, including autonomous vehicles, telemedicine, industrial automation, smart cities, and many others (3GPP, 2022; International Telecommunication Union, 2015).

5G can use different frequency bands: some are low or mid-band frequencies that provide wider coverage, while others are higher frequencies, such as millimeter waves, which can deliver high performance but over a more limited area (3GPP, 2022).
To compensate for these limitations, 5G requires a higher density of base stations, resulting in a larger number of more closely spaced cells to provide adequate coverage and high performance, including in urban areas (3GPP, n.d., 2022).

Supplementary materials

Exercises

From a Smartphone to the Internet
Luca is outdoors and uses the mobile network to open a website on his smartphone.

Reconstruct the path followed by the data.

- Explain how the smartphone's digital data is transmitted through the air.
- Identify which network component receives the radio signal sent by the phone.
- Explain what happens to the signal when it reaches the base station.
- Indicate which types of connections can be used to transfer the data from the base station to the operator's network.
- Explain what the operator's network does when it receives the request intended for the website.
- Describe the reverse path followed by the server's response back to the smartphone.
- Explain why communication between the smartphone and the antenna is wireless, while other parts of the path may use fiber-optic cables or other physical connections.

Two Phones, Two Different Coverage Levels
Anna and Marco are standing in the same place in the city.

Anna uses Operator A and her smartphone shows a very strong signal. Marco uses Operator B, but his phone shows only one signal bar.
A few hundred meters away, there is a tower with several antennas.

Analyze the situation.

- Explain why the presence of a nearby tower does not automatically guarantee the same coverage for both users.
- Explain the difference between a tower, a base station, and a cell.
- Suggest a possible explanation for why Anna receives a better signal than Marco.
- Identify at least four factors, covered in the learning material, that can affect the quality of a mobile connection besides simple distance from the antenna.
- Marco travels by car and his phone gradually moves from one cell to another. Explain why this transition is necessary to maintain communication while moving.
- Imagine that Marco can no longer find any usable cell belonging to his operator. Explain what might happen.
- Marco later travels abroad and his phone connects to another operator's network. Explain which mechanism makes this possible.

Designing a Mobile Network for a City
A mobile operator wants to improve its network in a large city.
In the city center, many users are connected at the same time, using streaming services, online video games, IoT devices, and mobile devices while traveling by car or public transport.

The operator wants to make greater use of 5G and must decide how to organize the network.

Answer the following questions:

- Explain why greater network capacity can be important in an area with many devices connected at the same time.
- Explain why low latency can be particularly important for online video games, augmented reality, and other interactive applications.
- Explain what advantage high transmission speeds provide to users who watch videos or download large files.
- The operator decides to also use very high-frequency bands. Explain what advantage they can provide and what problem they introduce in terms of coverage.
- Explain why the use of higher frequencies may require a larger number of base stations and more closely spaced cells.
- A new smartphone supports 5G but not some of the frequency bands used by the operator. Explain why it may not be able to use all parts of the network.
- Propose a general solution for covering a city by combining frequency bands with different characteristics, and justify your choice using the concepts of coverage, performance, capacity, and cell density.

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Kurose, J. F., & Ross, K. W. (2026). *Computer networking: A top-down approach* (9th ed.). Pearson. https://www.pearson.com/en-us/subject-catalog/p/computer-networking-a-top-down-approach/P200000013385/9780135415603

Further reading

- James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach, 9th ed., Pearson, 2026 — Provides an accessible introduction to wireless and mobile networking, connecting cellular access networks, mobility, 5G, radio communication, and the mobile network infrastructure to the broader architecture of the Internet. The 9th edition includes updated coverage of 5G cellular networks. .
- Theodore S. Rappaport, Wireless Communications: Principles and Practice, 2nd ed., Cambridge University Press, 2024 — Explores the foundations of wireless and cellular communication, including the cellular concept, radio propagation, path loss, fading, modulation, multiple-access techniques, wireless networks, and mobile communication standards.
- Christopher Cox, An Introduction to 5G: The New Radio, 5G Network, 5G Advanced and Beyond, 2nd ed., Wiley, 2025 — Offers an approachable system-level introduction to 5G and 5G-Advanced, covering the radio access network, 5G core, spectrum, antennas, millimeter waves, radio transmission, mobility, and the architecture that connects user devices to the operator's network.
- Erik Dahlman, Stefan Parkvall, and Johan Sköld, 5G/5G-Advanced: The New Generation Wireless Access Technology, 3rd ed., Academic Press/Elsevier, 2023 — Provides a more technical treatment of 5G radio access, including spectrum, cells, radio-interface architecture, cell search, mobility, scheduling, multi-antenna transmission, millimeter-wave frequencies, IoT, and the evolution toward 5G-Advanced.
- Rajib Taid, Mobile Communications Systems Development: A Practical Introduction to System Understanding, Implementation, and Deployment, Wiley, 2021 — Examines mobile communication systems from an implementation and deployment perspective, helping deepen the understanding of radio access technologies, mobile network architecture, signaling, core networks, and the transition between different generations of cellular systems.

Editorial notes

In producing these materials, I have used generative artificial intelligence tools to support the writing process, particularly to improve the form of the text, reorganize content, refine wording, and speed up certain editorial tasks.

As I work independently on the production of these materials, I try to automate any activities that can reasonably be automated, so that I can devote more time to research, design, and content development.

However, artificial intelligence does not determine the content of this work: the choice of topics, structure, ideas, interpretations, examples, and teaching approach are developed by me. AI is therefore used primarily as a tool to support production and formal revision, while authorship and responsibility for the design and content remain mine.

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