

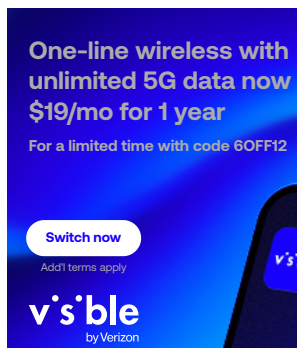
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How cellphones work



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by [Chris Woodford](#). Last updated: February 20, 2025.

Walking and talking, working on the train, always in contact, never out of touch—cellphones have dramatically changed the way we live and work. No one knows exactly how many little plastic handsets there are in the world, but the [current estimate](#) is that 80 percent of people over the age of 10 own one and there are over 9.1 billion subscriptions. That's more than the planet's population! In developing countries, where large-scale land line networks (ordinary [telephones](#) wired to the wall) are few and far between, over 93 percent of the phones in use are cellphones. [1] Cellphones (also known as cellular phones and, chiefly in Europe, as mobile phones or mobiles) are [radio](#) telephones that route their calls through a network of masts linked to the main public telephone network. Here's how they work.

Photo: Most people now use smartphones as their cellphones, which are actually small computers with cellphone circuitry built in. Back in the 1990s, cellphones were simpler and could only be used for making voice calls. Now 92 percent of the world's people can access 4G networks, which are far faster and capable of handling greater volumes of traffic, smartphones are used as portable communication centers, capable of doing all the things you can do with a telephone, digital camera, MP3 player, GPS "sat nav," and laptop computer. Landlines (like the ones in the background) are now becoming obsolete: only 10 percent of the world's people have one in 2025—a fall of about 50 percent over the last decade. [2]

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Cellphones use wireless technology

Although they do the same job, land lines and cellphones work in a completely different way. Land lines carry calls along [electrical](#) cables. Cut out all the [satellites](#), [fiber-optic](#) cables, switching offices, and other razzmatazz, and land lines are not that much different to the toy phones you might have made out of a piece of string and a couple of baked bean cans. The words you speak ultimately travel down a direct, wired connection between two handsets. What's different about a cellphone is that it can send and receive calls without wire connections of any kind. How does it do this? By using [electromagnetic](#) radio waves to send and receive the sounds that would normally travel down wires.

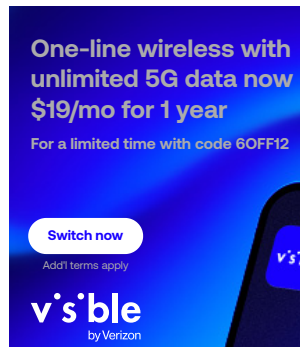
Whether you're sitting at home, walking down the street, driving a [car](#), or riding in a train, you're bathing in a sea of electromagnetic waves. [TV](#) and [radio](#) programs, signals from [radio-controlled](#) cars, cordless phone calls, and even wireless doorbells—all these things work using electromagnetic [energy](#): undulating patterns of [electricity](#) and [magnetism](#) that zip and zap invisibly through space at the speed of light (300,000 km or 186,000 miles per second). Cellphone networks are by far the fastest growing source of electromagnetic energy in the world around us.



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Photo: Cellphones as they used to be. This Nokia dates from the early 2000s and has a slide-out keypad. Although it has a camera and a few other basic functions, it doesn't have anything like the computing power of a modern smartphone. Phones like this are sometimes called "handhelds" or "feature phones" to distinguish them from iPhones and other smartphones.

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How cellphone calls travel

When you speak into a cellphone, a tiny [microphone](#) in the handset converts the up-and-down sounds of your voice into a corresponding up-and-down pattern of electrical signals. A [microchip](#) inside the phone turns these signals into strings of numbers. The numbers are packed up into a radio wave and beamed out from the phone's [antenna](#) (in some countries, the antenna is called an aerial). The radio wave races through the air at the speed of light until it reaches the nearest cellphone mast.

The mast receives the signals and passes them on to its **base station**, which effectively coordinates what happens inside each local part of the cellphone network, which is called a **cell**. From the base station, the calls are routed onward to their destination. Calls made from a cellphone to another cellphone on the same network travel to their destination by being routed to the base station nearest to the destination phone, and finally to that phone itself. Calls made to a cellphone on a different network or a land line follow a more lengthy path. They may have to be routed into the main telephone network before they can reach their ultimate destination.

How cellphone masts help



Photo: A typical modern 4G cellphone mast in urban Leicester, England. In closeup (pullout, left), you can see that there are multiple antennas on a mast like this, forming what's called an array. The mast is controlled and powered by the cabinets at the base.

At first glance, cellphones seem a lot like two-way radios and [walkie talkies](#), where each person has a radio (containing both a sender and a receiver) that bounces messages back and forth directly, like tennis players returning a ball. The problem with radios like this is that you can only use so many of them in a certain area before the signals from one pair of callers start interfering with those from other pairs of callers. That's why cellphones are much more sophisticated—and work in a completely different way.

A cellphone handset contains a radio transmitter, for sending radio signals onward from the phone, and a radio receiver, for receiving incoming signals from other phones. The radio transmitter and receiver are not very high-powered, which means cellphones cannot send signals very far. That's not a flaw—it's a deliberate feature of their design! All a cellphone has to do is communicate with its local mast and base station; what

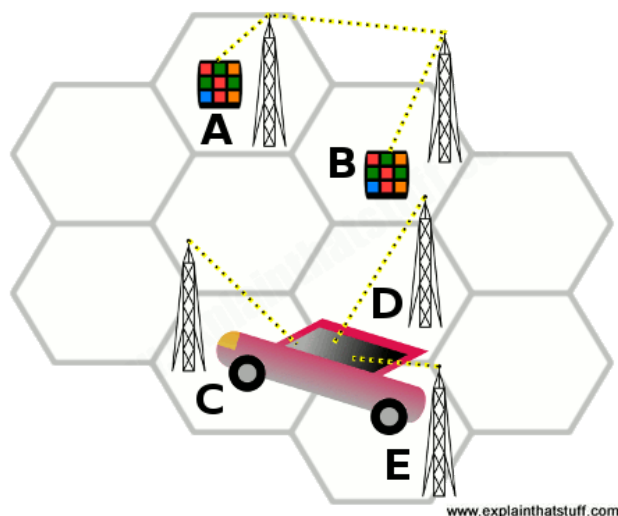
the base station has to do is pick up faint signals from many cellphones and route them onward to their destination, which is why the masts are huge, high-powered antennas (often mounted on a hill or tall building). If we didn't have masts, we'd need cellphones with enormous antennas and giant power supplies—and they'd be too cumbersome to be mobile. A cellphone automatically communicates with the nearest cell (the one with the strongest signal) and uses as little power to do so as it possibly can (which makes its battery last as long as possible and reduces the likelihood of it interfering with other phones nearby).

What cells do

So why bother with cells? Why don't cellphones simply talk to one another directly? Suppose several people in your area all want to use their cellphones at the same time. If their phones all send and receive calls in the same way, using the same kind of radio waves, the signals would interfere and scramble together and it would be impossible to tell one call from another. One way to get around this is to use different radio waves for different calls. If each phone call uses a slightly different **frequency** (the number of up-and-down undulations in a radio wave in one second), the calls are easy to keep separate. They can travel through the air like different radio stations that use different wavebands.

That's fine if there are only a few people calling at once. But suppose you're in the middle of a big city and millions of people are all calling at once. Then you'd need just as many millions of separate frequencies—more than are usually available. The solution is to divide the city up into smaller areas, with each one served by its own masts and base station. These areas are what we call **cells** and they look like a patchwork of invisible hexagons. Each cell has its base station and masts and all the calls made or received inside that cell are routed through them. Cells enable the system to handle many more calls at once, because each cell uses the same set of frequencies as its neighboring cells. The more cells, the greater the number of calls that can be made at once. This is why urban areas have many more cells than rural areas and why the cells in urban areas are much smaller.

How cellphone cells handle calls



This picture shows two ways in which cells work.

Simple call

If a phone in cell A calls a phone in cell B, the call doesn't pass directly between the phones, but from the first phone to mast A and its base station, then to mast B and its base station, and then to the second phone.

Roaming call

Cellphones that are moving between cells (when people are walking along or driving) are regularly sending signals to and from nearby masts so that, at any given time, the cellphone network always knows which mast is closest to which phone.

If a car passenger is making a call and the car drives between cells C, D, and E, the phone call is automatically "handed off" (passed from cell to cell) so the call is not interrupted.

The key to understanding cells is to realize that cellphones and the masts they communicate with are designed to send radio waves only over a limited range; that effectively defines the size of the cells. It's also worth pointing out that this picture is a simplification; it's more accurate to say that the masts sit at the intersections of the cells, but it's a little easier to understand things as I've shown them.

Types of cellphones

The first mobile phones used [analog](#) technology. This is pretty much how baked-bean can telephones work too. When you talk on a baked-bean can phone, your voice makes the string vibrate up and down (so fast that you can't see it). The vibrations go up and down like your voice. In other

words, they are an *analogy* of your voice—and that's why we call this analog technology. Some land lines still work in this way today.

Most cellphones work using **digital technology**: they turn the sounds of your voice into a pattern of numbers (digits) and then beam them through the air. Using digital technology has many advantages. It means cellphones can be used to send and receive computerized data. That's why most cellphones can now send and receive text (SMS) messages, [Web](#) pages, [MP3 music files](#), and digital photos. Digital technology means cellphone calls can be [encrypted](#) (scrambled using a mathematical code) before they leave the sender's phone, so eavesdroppers cannot intercept them. (This was a big problem with earlier analog phones, which anyone could intercept with a miniature radio receiver called a scanner.) That makes digital cellphones much more secure.

The world of cellphones

Cellphones have dramatically changed the way the world connects. In the early 1990s, only one per cent of the world's population owned a cellphone; today, in a growing number of countries [people spend more time on their mobiles](#) than on their landlines. According to the ITU-T, in 2001, only 58 percent of the world's population had access to a (2G) cellphone network; by 2019, that had risen to 98.8 percent. By the end of 2024, there were 9.1 billion cellphone subscriptions—more than the number of people on the planet. Cellphones have also powered a big leap in Internet access. At the end of 2016, [mobile \(smartphone and tablet\) Internet traffic passed desktop traffic](#) for the first time ever. By the end of 2024, 94.6 percent of the world's people had active, cellphone-based, mobile broadband subscriptions, which is about five times as many as have traditional wired broadband (just 19.6 percent). [3]

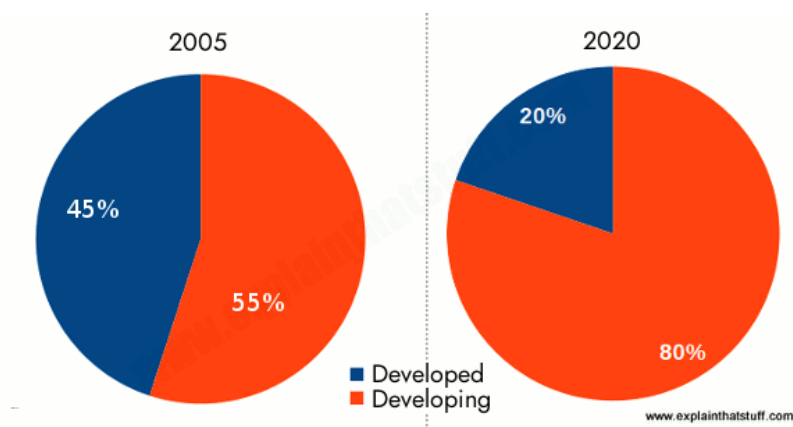


Chart: Cellphone subscriptions: The most dramatic cellphone growth has happened in developing countries, which now represent around 80 percent of subscriptions. Source: Drawn in 2021 using November 2020 data from [International Telecommunications Union \(ITU\)](#).

Cellphones are also used in different ways by different people. Back in the early 2000s, cellphones were used entirely for voice conversations and sending short "texts" (text messages, also known as SMS messages). A lot of people owned a mobile phone purely for occasional emergency use; and that still remains a popular reason for owning a phone (according to [NENA: The 9-1-1 Association](#), over 80 percent of all 911 emergency calls in many parts of the United States are made from cellphones). Today, smartphones are everywhere and people use them for emailing, browsing the web, downloading music, social media, and running all kinds of apps. Where old-fashioned cellphones relied entirely on a decent signal from a cellphone network, smartphones hop back and forth, as necessary, between ordinary networks and [Wi-Fi](#). Where old cellphones were literally "mobile phones" (wireless landlines), modern smartphones are essentially pocket computers that just happen to make phone calls. You can see just how much phones have changed internally in the photos in the box below.

Cellphones and mobile broadband

If you want to find out how cellphone networks have evolved from purely voice networks to form an important part of the Internet, please see our separate article on [broadband and mobile broadband](#). It also covers all those confusing acronyms like FDMA, TDMA, CDMA, WCDMA, and HSDPA/HSPA.

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What's inside your phone?



Photo: Cellphones past and present. Left: A Motorola V66 from about 2000, a Nokia 106 from about 2010, and an LG G series smartphone from about 2016. I will be taking apart the Motorola and the LG.

A broken phone is a wonderful thing if, like me, you enjoy figuring out how things work. Not surprisingly, there's much more going on inside a modern smartphone than inside the kind of basic cellphone people used to carry about 20 years ago. Old phones were just phones; smartphones are computers packed with all kinds of gadgetry, from [fingerprint readers](#) to electronic payment chips. But though phones have changed dramatically, the problems of designing a new handset are, in many ways, just the same as they always were: How do you pack all these components into a small enough space, keep their total weight down, and avoid them overheating? How do you ensure critical components like microphones, loudspeakers, and antennas continue to work effectively even when they're miniaturized?

Inside a classic phone

The biggest difference between old phones and new ones is that older ones have [keyboards](#) and small [LCD](#) screens, while smartphones have [touchscreens](#) that do away with the need for a keyboard altogether (they do still need a few buttons for switching the power on and off and controlling speaker volume). In an old phone, the keyboard's typically one of the "membrane" kind: instead of moving keys, it has squashy rubber buttons that push down on electrical contacts on a printed-circuit board (PCB) below.

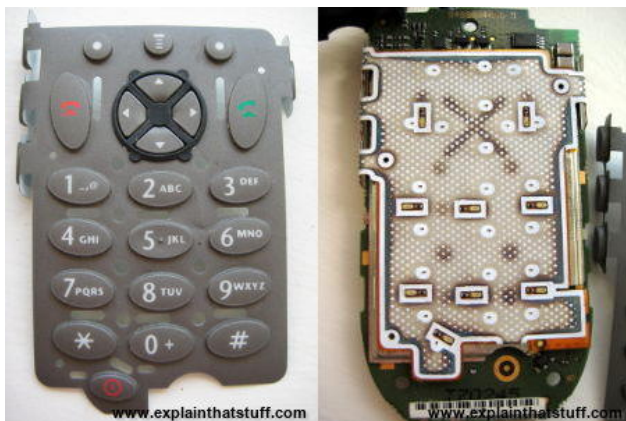


Photo: Left: The top side of an old Motorola phone keyboard is what's called a rubber membrane, a thin sheet of rubbery plastic with "keys" that press down to make electrical contact with the circuit board below. Right: Each key pushes a little round peg against the corresponding part of

the circuit board (the small dots). The keyboard is also packed with LEDs (the eight rectangles with white outlines) that make it light up when you make or take a call.

Unfortunately, digital gadgets aren't anything like as interesting (or as easy to figure out) as mechanical things: most of the good stuff happens inside chips, out of sight, and you can't figure out how a chip works just by looking at it. Taking the keyboard off, there's very little of interest in the board beneath, but do notice the gold antenna running all the way around it. That's why a cellphone like this does not need a long, telescopic (pull-out) antenna.

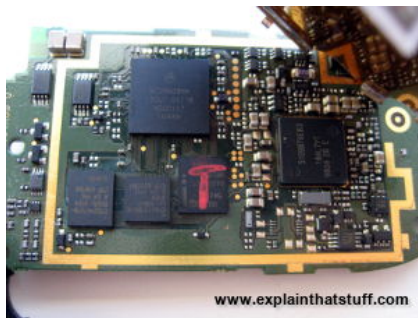


Photo: The main circuit board from a Motorola V66 phone is directly underneath the keyboard and above the battery compartment.

The other side of the circuit board is a little bit more interesting:

1. LCD screen, connected to the keyboard unit by a ribbon cable.
2. Earphone socket.
3. Battery connector
4. Battery charger and cable connector for hooking up to a computer.
5. Heatsinks/screening for chips on the circuit board.
6. Piezoelectric buzzer.
7. Buzzer control chip
8. Antenna connector—links a small external antenna to the gold antenna running round the circuit board.

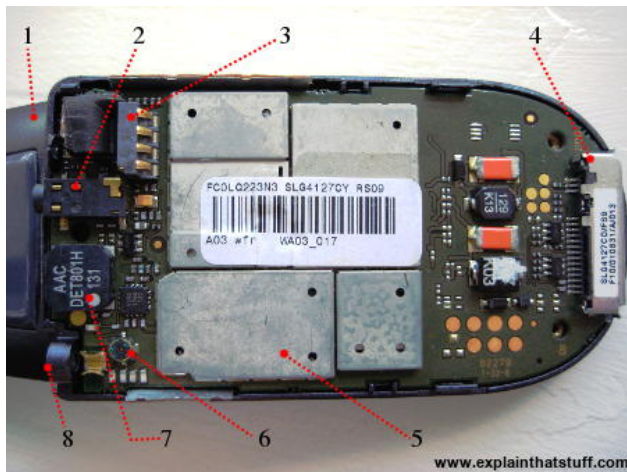


Photo: The back of the main circuit board from a Motorola V66 phone.

Inside a smartphone

There's quite a lot more going on inside a smartphone, as you'd expect. I've not taken the screen apart (it's directly below the circuit board on the right-hand side), but here are some of the other things you'll find:



Photo: The main circuit board from a more modern LG G-series smartphone.

1. Contact connections between upper (left photo) and lower (right photo) parts of the circuit board.
2. Heatsink/screening for processor chips. (The gray stuff you can see here is thermal paste—a kind of heat-conducting goo—that helps to improve cooling.) The power on/off button is under here.
3. NFC antenna connectors (for contactless payments).
4. Infrared focusing beam for camera.
5. 13-megapixel rear [digital camera](#).
6. Flashlight/camera flash.
7. Quad-core Qualcomm Snapdragon processor chip.
8. Micro SD card slot (allows storage to be extended to 32GB).
9. Micro-SIM card slot
10. [Lithium-ion battery](#). (3000 mAh capacity).
11. Entirely plastic case with a "brushed metal" finish gives the appearance of a metal case with the fingerprint smudges.
12. Headphone connector.
13. [Microphone](#).
14. USB and charging connector.
15. [Loudspeaker](#).
16. Screwed-down plastic shim protects the circuit board and components when you open up the case to change the battery.
17. Screws!
18. More contact connections between upper and lower boards.

Who invented cellphones?

How did we get from land lines to cellphones? Here's a quick history:

- 1873: British physicist **James Clerk Maxwell** (1831–1879) published the theory of electromagnetism, explaining how electricity can make magnetism and vice-versa. Read more about his work in our main article on [magnetism](#).
- 1876: Scottish-born inventor **Alexander Graham Bell** (1847–1922) developed the first telephone while living in the United States (though there is some dispute about whether he was actually the original inventor). Later, Bell developed something called a [photophone](#) that would send and receive phone calls using light beams. Since it was conceived as a wireless phone, it was really a distant ancestor of the modern mobile phone.
- 1888: German physicist **Heinrich Hertz** (1857–1894) made the first electromagnetic radio waves in his lab.
- 1894: British physicist **Sir Oliver Lodge** (1851–1940) sent the first message using radio waves in Oxford, England.
- 1899: Italian inventor **Guglielmo Marconi** (1874–1937) sent radio waves across the English Channel. By 1901, Marconi had sent radio waves across the Atlantic, from Cornwall in England to Newfoundland. Marconi is remembered as the father of radio, but pioneers such as Hertz and Lodge were no less important.

- 1906: American engineer **Reginald Fessenden** (1866–1932) became the first person to transmit the human voice using radio waves. He sent a message 11 miles from a transmitter at Brant Rock, Massachusetts to ships with radio receivers in the Atlantic Ocean.
- 1920s: Emergency services began to experiment with cumbersome radio telephones.
- 1940s: Mobile radio telephones started to become popular with emergency services and taxis.
- 1946: AT&T and Southwestern Bell introduced their Mobile Telephone System (MTS) for sending radio calls between vehicles.
- 1960s: Bell Laboratories (Bell Labs) developed Metroliner mobile cellphones on trains.
- 1973: **Martin Cooper** (1928–) of Motorola made the first cellphone call using his 28-lb prototype DynaTAC phone.
- 1975: Cooper and his colleagues were granted a patent for their radio telephone system. Their original design is shown in the artwork you can see here.

Cellular (mobile) phone

Martin Cooper, Motorola, 1973

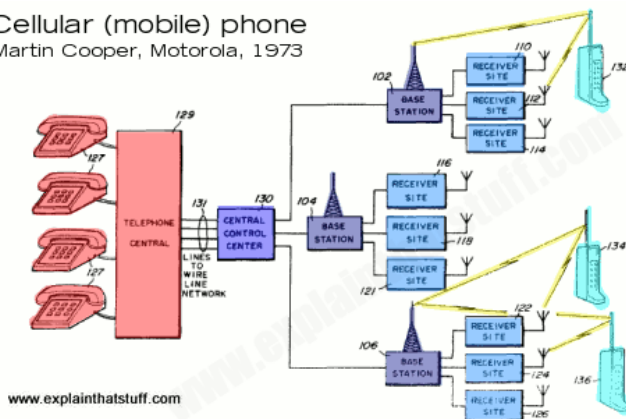


Photo: Martin Cooper's original radio telephone system (cellphone) design, submitted as a patent application in 1973. Note how the mobile part forms an entirely separate system (shown in blue, on the right) that communicates with the existing public network (shown on the left in red). Individual cellphones (turquoise on the extreme right) communicate with their nearest masts and base stations using radio waves (yellow zig-zags). Patent drawing from [US Patent 3,906,166: Radio telephone system](#) by Martin Cooper et al, Motorola Solutions Ltd., courtesy of US Patent and Trademark Office.

- 1978: Analog Mobile Phone System (AMPS) was introduced in Chicago by Illinois Bell and AT&T.
- 1982: European telephone companies agreed a worldwide standard for how cellphones will operate, which was named Groupe Speciale Mobile and later Global System for Mobile (GSM) telecommunications.
- 1984: Motorola DynaTAC became the world's first commercial handheld cellphone. Take a look at a [picture of Martin Cooper and his DynaTAC](#).
- 1995: GSM and a similar system called PCS (Personal Communications Services) were adopted in the United States.
- 2001: GSM had captured over 70 percent of the world cellphone market.
- 2000s: Third-generation (3G and 3.5G) cellphones were launched, featuring faster networks, Internet access, music downloads, and many more advanced features based on digital technology.
- 2007: Apple's iPhone revolutionized the world of cellphones, packing what is effectively a touch-controlled miniature computer into a gadget the same size as a conventional cellular phone.
- 2013: Cellphones celebrate their 40th anniversary.
- 2024: Cellphone subscriptions reach 9.1 billion. About 80 percent of them are in developing countries.



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ABOUT THE AUTHOR

Chris Woodford is the author and editor of dozens of science and technology books for adults and children, including DK's worldwide bestselling *Cool Stuff* series and *Atoms Under the Floorboards*, which won the American Institute of Physics Science Writing award in 2016. You can hire him to write books, articles, scripts, corporate copy, and more via his website chriswoodford.com.

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History of cellphones

- [New take-along telephones give you pushbutton calling to any number](#): Read how Motorola announced portable cellphones to the world in this fascinating July 1973 issue of the ever-excellent Popular Science magazine.
- [US Patent #3,906,166: Radio Telephone System](#) by Martin Cooper et al. This is Motorola's groundbreaking, original cellphone patent, filed October 17, 1973 and granted September 16, 1975. It includes lots of technical details about how early cellphone systems work, including the artwork up above, but it's relatively easy to follow.

References

1. ↑ Cellphone subscription statistics come from [UN International Telecommunication Union \(ITU\) statistics](#). The latest, estimated figure (for November 2024) is 9.144 billion where for 2013 it was 6.662 billion.
2. ↑ The 2024 figures are 10.3 percent landlines and 91.8 percent 4G coverage according to [UN International Telecommunication Union \(ITU\) statistics](#).
3. ↑ Except where noted, all statistics in this paragraph are from [UN International Telecommunication Union \(ITU\) statistics](#) and the most up-to-date available at the time of last updating (February 2025).

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