Evolution of mobile data

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1. Introduction

Nowadays everyone carries a mobile phone, which used to be called a mobile phone, which they use very often and almost all the time connected to the Internet, in data applications: WhatsApp, navigation, downloads, etc. Young people hardly use it for telephone calls, which, however, was the only use thirty years ago. On the other hand, when you look at a current model of mobile phone, now Smartphone, with its ability to connect to the internet and download data at speeds of hundreds of megabits per second, you cannot help but be amazed and recognize an almost miraculous evolution of data transmission on these devices during the last twenty years.

In this time we have seen many network symbols on the screen of the mobile phone '3G', 'H', 'H+', '4G', 'G' or 'E' that indicated that we were in coverage of networks of different technology, most of them developed to facilitate the transmission of data. Thus, downloading a video via WhatsApp, limited to 100 MB (Mbytes), with a UMTS/3G mobile phone from 2005 at an average speed of 200 kbit/s would have taken an hour, with a 2010 HSPA+/3G mobile phone at 14 Mbit/s it would have taken a minute, with a 2015 LTE-A/4G mobile phone at 150 Mbit/s it would have taken only 6 seconds and with a current 5G mobile phone the download would have been practically instantaneous.

If we compare contracts from the beginning of 2000 and today, we can see that, for example, the data rate per MB was in the order of €1/MB in the Movistar Datos Contract and in the current Contract L rate with a fee of €15/month you surf at maximum speed up to 8 GB, which means a price of €0.002/MB. Over a 20-year period, the price per MB of data has been reduced by about 500 times. But in addition, it is surfing at much higher speeds, in the order of 100 kbit/s at the beginning and at speeds in the order of 100 Mbit/s today, or a factor of 1,000.

Apart from other considerations, this has been possible thanks to the technology developed by network manufacturers (Ericsson, Nokia, etc.) and handsets (Apple, Samsung, etc.) and the good work of Telefónica in marketing, building and operating them. And this chapter is precisely what it is about, showing and acknowledging an almost miraculous evolution of data transmission in mobile networks over the last twenty years.

2. First there was the voice

Mobile communications have been around for more than a century. When the Titanic sank, back in 1910, radio telegraph communication already existed. But it wasn't until well into the 1940s that the first commercial mobile phone system was established in St. Louis, USA, in 1946.

The cellular era begins with the first generation 1G mobile phone systems, where all of them were analog systems for voice services, using FDMA technology. These are NMT and AMPS/TACS, from 1981 to 1986. Telefónica also deployed first-generation systems: TAV, TMA-450 and TMA-900 (MoviLine).

But, despite having 3 kHz telephone bandwidth channels, the characteristics of the radio channel were very different from those of the telephone lines that, at that time, in the 80s, were part of the Iberpac/X25 data transmission network with data rates of up to 64 kbit/s. Only low-speed data transmission and for alarm, message, status services, etc., were allowed.

To overcome the difficulties of 1G, most countries opted for digital technology and a new era, called 2G, began. These systems enjoyed: improved spectral efficiency achieved through the use of advanced modulation techniques, lower bitrate speech coding, good channel coding techniques for greater resistance to interference.

The best known of the 2G systems is the pan-European GSM, still in use today, which used the 900 MHz band with FDD frequency duplex, GMSK modulation and 200 kHz channeling; an 8-channel TDMA multiple access per carrier and a gross per-channel rate of 22.8 kbit/s.

3. Internet in the palm of your hand

GSM in 1995 incorporated circuit-mode data transmission, CSD, at 9.6 kbit/s, which made it easier for a PC to connect to the Internet via a radio modem, e.g. the Nokia 30, also initiating machine-to-machine, M2M communications.

Also the short message service SMS, which allowed you to send and receive messages of up to 160 characters and which was so popular until the arrival of instant messaging such as WhatsApp. It should be borne in mind that, by 1995, data transmission by telephone line was already well advanced: Internet access had begun with Infovia at 33.6 kbit/s and the ill-fated ISDN, with 128 kbit/s, was being deployed.

In the 1996 specification called GSM phase 2+, already developed by ETSI (European Telecommunications Standardisation Institute), which took over from CEPT in 1998 and of which Telefónica was a founding member, two new data services were included: HSCSD (High Speed Circuit Switched Data) or high-speed data transmission system using switched circuits, allowing data rates of up to 57.6 kbit/s and consuming 4 voice channels; and the GPRS General Packet Radio Service.

In 1999, with CSD and SMS carriers and then with GPRS carriers, a micro-browser called WAP (Wireless Application Protocol) was developed, which simplified the websites to make them easier to view on the mobile phones of the time. On WAP, Telefónica developed the e-motion content portal and numerous data services. Also this year, ADSL arrives with download speeds of up to 2 Mbit/s over the telephone line.

In 2001, Telefónica implemented GPRS technology, also known as Generation 2.5, which added a Nokia packet network core to GSM, thus constituting a mobile data transmission network.

The GPRS packet core will be reused when 3G/UMTS is deployed, see Figure 1.

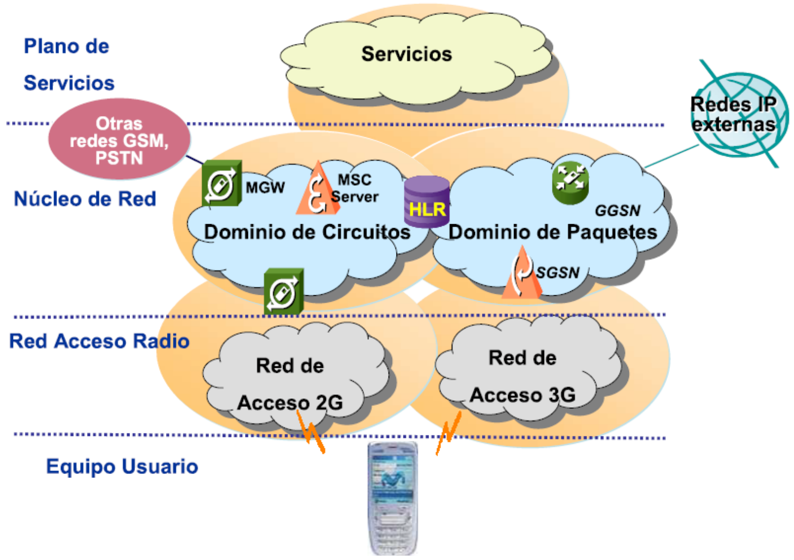

Figure 1. 2G/3G Network Structure

The packet domain continues to handle voice calls and the 2G access network now handles GSM/GPRS voice and data traffic. Fortunately, the deployment of GPRS was also an opportunity to deploy a new type of voice encoder called AMR (Adaptive Multi-rate speech transcoder), which handled twice as many voice calls as with the original vocoder.

It was GPRS that started the mobile internet, internet in the palm of the hand was advertised. All previous data services developed for GSM switched to GPRS at a rate of up to 115 kbit/s. Due to the delay of 3G/UMTS technology until 2004, GPRS was the support of data services during these years. However, in 2002, GPRS services accounted for only 0.1% of total mobile revenues.

Based on GPRS and WAP, Telefónica implemented a Service Development Centre, where many data services were developed: mobile office, mobile mail, etc. Movilforum in 2021. Also MMS (Multimedia Messaging Service) in 1992, making it feasible to send text messages along with color images, animations, applications, sounds and video. Mobile phones with a color screen appeared in 2001 and with a built-in camera in 2002. It started with "always on", which was billed by volume of data, not by connection time. By the early 2000s, Blackberry had succeeded in bringing e-mail to mobile phones, but its use was limited to the professional realm.

Another of GSM's early radio design features that was revealed to be a shortcoming, the data rate cap, was also subject to several changes to the standard. One of them is the so-called EDGE (Enhanced Data rates for GSM Evolution), also known as Enhanced GPRS (EGPRS) or Enhanced GPRS, which involved the transition from binary modulation methods, where the discrete levels of the modulating digital signal are two (1 and 0), to other multilevel or multi-level (always a power of 2, so that with 2n levels the velocity is multiplied by n with respect to a binary regime, since with each level it is possible to designate n bits). This made it possible to increase the speeds of the system, although only for radio channels with sufficient quality). It can reach a transmission rate of 384 kbit/s in packet mode. Telefonica upgraded GSM stations to EDGE in 2009.

4. Mobile Broadband

4.1 The third generation arrives. A global standard

The third generation 3G was not European but global. It was defined by ITU, which established in 1999 a general framework called IMT-2000, referring to the 2,100 MHz band, identified by the World Radiocommunication Conference (WRC) in 1992.

ITU selected 5 technologies for IMT-2000, including the UMTS (Universal Mobile Telecommunication System), presented by the 3GPP (3rd Generation Partnership Project), which had been established in 1998 by telecommunication standards bodies from Asia, Europe and North America, including the European ETSI. In 2001 3GPP and ETSI released the Rel-99 and Rel-4 specifications for the implementation of UMTS. CDMA 2000 technology, presented by the other contending consortium, 3GPP2, was also selected

3G/UMTS meant the abandonment of GSM TDMA and the adoption of a new multiple access technique: CDMA, which multiplies the digital signal in baseband by another of significantly higher speed, thus achieving a modulating digital signal of much greater bandwidth than that of the baseband. whose speed, like that of the multiplier sequence, is not expressed in BPS (bits per second) but in CPS (chips per second). In RF, what is achieved is that the bandwidth of the modulated carrier is much greater than that which would be obtained by modulating directly with the baseband, which gives it interesting properties of immunity to the multipath fading typical of the radio channel.

Each transmission is multiplied by a sequence different from that of the others with which it shares the radio space. In reception, after demodulation, a sum of digital signals corresponding to all the transmissions existing simultaneously in the air, within the same frequency, is obtained. This sum is multiplied by the sequence of the corresponding transmission and, thanks to the properties of the sequences, in the case of the transmission affected by that sequence the signal is recovered in the baseband, while for the remaining transmissions a signal very similar to noise is generated. Therefore, in CDMA, the other communications that share the frequencies with the one of interest provide a certain amount of noise (or in other words, it is an access technique that offers perfect orthogonality, unlike FDMA or TDMA).

In other words, UMTS completely changes the radio access network, now called UTRAN, while the GSM/GPRS network core remains with a circuit-switched domain and a packet-switched domain.

For UMTS radio access (UTRA), two different modes of operation were defined in the spectrum: UTRA FDD (Frequency Division Duplex) in the band segment 1920-1980 MHz for the upstream band 2110-2170 MHz for the downstream band and UTRA TDD (Time Division Duplex) for the band segments 1900 – 1920 MHz and 2010 – 2025 MHz. In

UTRA TDD there is a TDMA (Time Division Multiple Access) component in addition to the DSCDMA. That's why this access has also been referenced as TDMA/CDMA. The spacing between the channels or channeling is already 5 MHz, for the chip speed of 3.84 Mchip/s and the modulation scheme is QPSK.

The network architecture is the same as GSM/GPRS except that a new radio access network, UMTS/3G or UTRA, has been added.

4.2 Mobile Broadband Is Born

It wasn't until the conception and deployment of UMTS that we can really talk about mobile data and data services, kicking off the mobile broadband race. Thus, in this technology, four classes of traffic were distinguished, which in turn required different quality of service.

- Conversational traffic, for voice, videotelephony and video game services
- Streaming traffic (tributary), for multimedia services (service in which the information exchanged is of more than one type, such as texts, graphics, sound, image and video), video on demand (on-demand television) and web cast or webinar (ss a webcast of audiovisual content, which allows live interactivity with the user, similar to a TV or radio show).
- Interactive traffic, for internet browsing service, web games and database access.
- Deferred traffic, for email services, short messages (SMS), and downloads.

The Spanish government established a merit-based competition to award four 3G licences in November 1999. Telefónica won one of these licenses in March 2000, with significant commitments to deployment, investment and quality of service. In addition to the commitments to deploy infrastructure and services, and to employment, Telefónica committed to promote and invest in the manufacture of private label mobile phones. Vitelcom from Malaga was in charge of manufacturing these phones called TSM. This is how terminals such as the TSM 5, the TSM 30 or the TSM 100, among others, came out. All three were strong bets by Telefónica, especially the TSM 5, which was marketed for 99 euros in prepaid and was the protagonist of an intense Christmas campaign in 2003-2004.

But at that time we were in the middle of the dotcom bubble, a strong speculative cycle that took place between 1997 and 2001, with an uncontrolled growth in the value of companies linked to the Internet that ended up bursting and causing a serious global crisis. And there was also the UMTS auction crisis in Europe, with a sharp fall in the stock market of telecommunications companies due to the 270,000 million euros they had to pay to obtain licenses. This caused a considerable delay in networks and terminals. These crises also frustrated the Administration's intention to call for two new GSM licences in the 1800 MHz band in 2001.

The success of GSM technology did not immediately spill over into that of its successor, UMTS, which had a rocky start. Thus, after the awarding of licenses, the standard still went through a stage of immaturity, where a multitude of modifications to the specifications (around a hundred or more) were made at the meetings of the 3GPP groups, with some of them of significant significance. In addition, the high outlays that operators had to make to provide themselves with the necessary spectrum, in the auctions that took place in Europe throughout 2000 and 2001, contributed to casting doubts on whether 3G would not be doomed to failure. With the intention of counteracting this pessimism, Telefónica launched the so-called "UMTS Technology Promotion Plan", made up of a series of initiatives focused on sending a signal of confidence and commitment to UMTS technology by Telefónica, and encouraging R+D in it. This plan, developed in 2003, involved fifteen Spanish universities.

Once the license to operate a UMTS network in Spain was obtained, Telefónica began a process of selection and certification of UMTS suppliers (PSCS), which took place during the years 2001 and 2002. To this end, suppliers Alcatel, Ericsson, Lucent, Nokia, Nortel, Motorola and Siemens were required to provide information on their UMTS solutions, as well as to install and make available to Telefónica for testing and evaluation of models of the same. Following this UMTS technology validation process, Telefónica's UMTS/3G radio access network was awarded to Ericsson and Siemens, which would later merge with Nokia

Telefónica launched 3G/UMTS in 2004 with a data-only PCMCIA. This was the beginning of data bonuses with PCMCIA and USB cards, which were the great consumers of data as they were associated with portable PCs. In the beginning, once the bonus was consumed, you paid per additional MB. For example, Movistar UMTS 3G data contract from 2004 with a tariff of €0.5/Mbyte up to a consumption limit of 30 MByte. Once this limit was exceeded, the price was €1/Mbyte. As this pricing gave rise to large bills involuntarily, in 2006 once the limit of the bonus was reached, the speed was limited to GPRS speed 128 kbit/s.

It was also the case that the frequencies assigned to UMTS, which were higher than those of GSM, resulted in lower coverage. It was not until the so-called "refarming" of 2009 that good coverage was provided to UMTS by being able to use the 900 MHz band of the GSM, which, on the other hand, had obtained more band in 2005 due to the so-called E-GSM tender, which made available to operators 2x8 MHz freed up as a result of the completion of analogue mobile telephony (Moviline) and Rural Cellular Access Telephony (TRAC).

4.3 And then came smartphones

The origin and need of mobile networks was to facilitate mobile telephony or personal telephony, but the internet and video telephony were being born, and television already existed, so it was inevitable to evolve to mobile networks also being mobile data networks. The terminals were shaped for voice services, but not for data, which needed larger screens, see Figure 2.

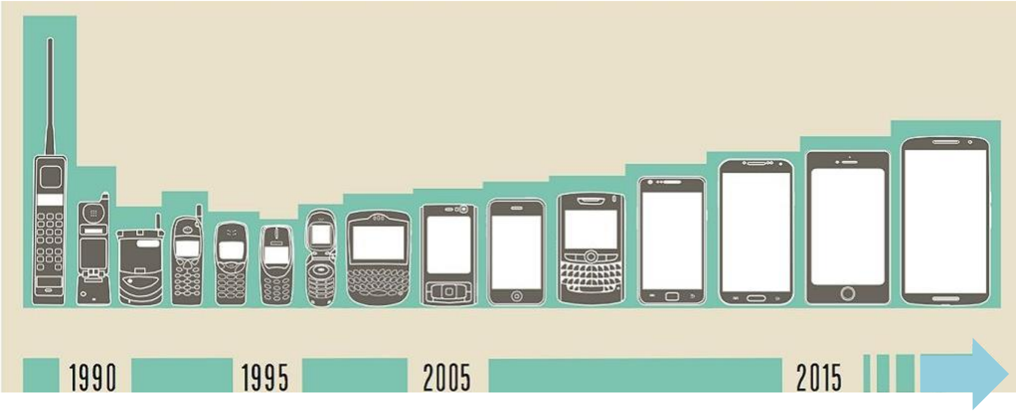

Figure 2. Evolution of the shape and size of mobile phones

Mobile phones were incorporating other functionalities such as: Bluetooth (2001) for wireless headphones, Wi-Fi (2004), GPS (2007). But in 2008 came Apple's iPhone 3G, which forever changed the shape of mobile phones, which were renamed smartphones, smartphones or simply mobiles.

With the release of the first iPhone and its iOS operating system, mobile operating systems begin. In 2008, Google's Android operating system was released; these are the ones that remain today.

On the other hand, the evolution of the processing power of mobile phones has been incessant. In 1997, Nokia released the Communicator, with a CPU derived from an Intel 386 and 8 MB of RAM. The first iPhone came with a 412 MHz ARM1176 processor and 127 MB of RAM. In 2019 the iPhone 11 came with its Apple-designed A13 Bionic processor, clocked at 2.66GHz, 4GB of RAM and 7nm technology.

It was also the beginning of the era of web applications, App, which use browsers to run and are usually written in CSS, HTML5 or JavaScript. Thus, 2008 saw the launch of Apple's App Store and the publication of the first SDK for Android. Obviously, the native apps on phones were disappearing and so was the WAP microbrowser.

The handset market, which had necessarily been intervened and subsidised by operators, who also had to introduce native applications, ceased to be subsidised by Telefónica in 2012. Also, in 2012, Fusion, Telefónica's convergent fixed-mobile offering, was introduced.

Telephones were not big consumers of data, not like today when they are usually used as a modem through a Wi-Fi connection, using the tethering function. Thus, in 2020 and in Spain, a total of 49.2 million mobile lines accessed the Internet through mobile communications networks (2G, 3G, 4G and 5G). Most of these lines, 47.9 million, connected to the Internet via their mobile phone. The rest were datacards or USB modems, also called USB "spikes." These grew to a maximum of 3.4 million in 2010, and then decreased to 1.5 million in 2021. Telefónica developed a "Movistar desktop" PC program that made it easier to install and operate.

In 2007, Amazon launched the Kindle e-book. In 2010, Apple introduced the iPad, based on its successful iPhone, and achieved notable commercial success. It was followed by virtually all electronic equipment manufacturers. They usually include optional 3G, 4G connection, but Wifi in all of them. But really, with a mobile phone you have access to the internet.

For the first time, data traffic via mobile phones in December 2009 was higher than voice traffic worldwide. Traffic on 3G networks also surpassed that of 2G networks, when there were only 400 million mobile broadband subscriptions, compared to the 4.6 billion 2G mobile subscribers worldwide. This increase in data traffic was made possible by social media connections on mobile devices and 3G traffic from PCs.

4.4 Decoupling Traffic and Revenue

According to CMT data, in 2002 GPRS services accounted for 0.1% of total mobile telephony revenues. In 2006, already with UMTS, data traffic in UMTS/GPRS networks accounted for 3.3% of total billing. In 2010, having deployed HSPA, data traffic accounted for 10% of total billing. Mobile broadband revenues accounted for 60% of total revenues in 2020.

As a result of the increase in traffic that was taking place with mobile broadband, operators had to look for a growth model that would allow them to match the increase in traffic with that of revenues. This occurred naturally in the case of voice (since it was charged by talk time), but not in the case of data, where the influence of the model followed by fixed networks, based on flat rates, raised the risk of requiring greater and greater investments in network infrastructure without equivalent counterparts in revenues. In other words, there was a decoupling between traffic and revenue. The challenge was to achieve strategies and mechanisms to increase capacity and speed with minimum incremental costs.

From this perspective, the network operator must size the capacity of the radio network in order to meet the aggregate demand of all users at any given time in an economically feasible way.

The solution is to apply Shannon's formula to the capacity of a communications channel, see Figure 3. Thus, to increase the capacity, it is possible to: densify or increase the number of cells, have more spectrum, or use it more efficiently through technology.

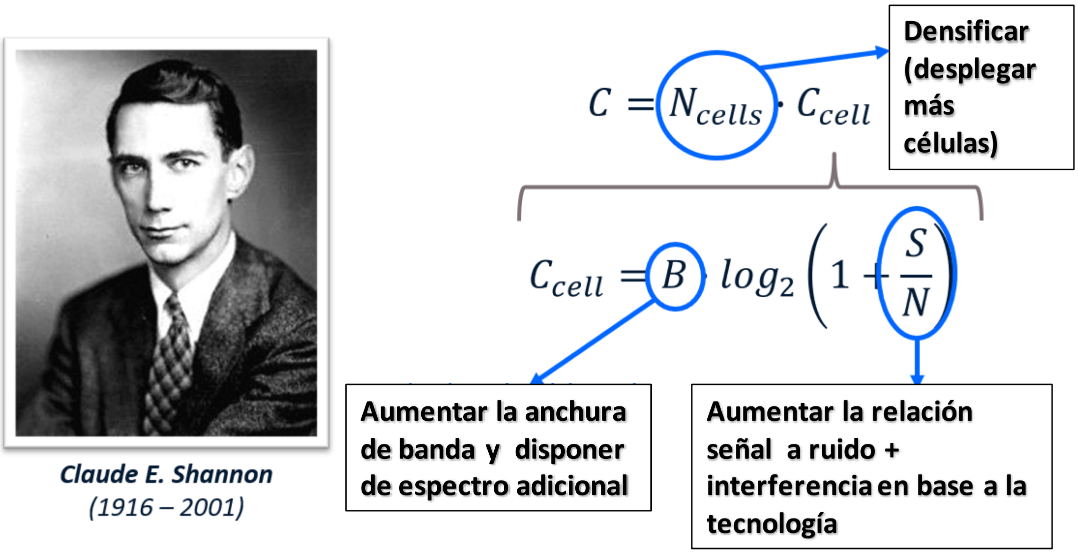

Figure 3. Shannon's Formula

As will be seen, in the evolution from 2G to 5G, these factors have been applied to increase the speed of data transmission and increase spectral efficiency.

4.5 Having a band is key

Sufficient spectrum has been essential to facilitate this evolution, starting with the global allocation of the necessary frequency bands, facilitated by the various ITU World Radiocommunication Conferences (WRCs), and ending with the national allocation of spectrum to operators. In this sense, it is to be appreciated that each generation has been preceded by an allocation and allocation of the necessary bandwidth in the appropriate bands.

Thus, in the Figure 4 The distribution of the spectrum assigned to Telefónica for mobile phones in Spain is shown, with the amount of spectrum in MHz, the band, the year and the generation to which it was first attributed. Telefónica has always resorted to any tender or auction to obtain the necessary spectrum from the Administration.

In addition, from 2011 onwards, Technological Neutrality has been applied: the possibility of using the different systems or technologies harmonised within the European Union in the different frequency bands. In other words, each new generation has spectrum for its initial deployment and then, at the operator's will, it can use other bands.

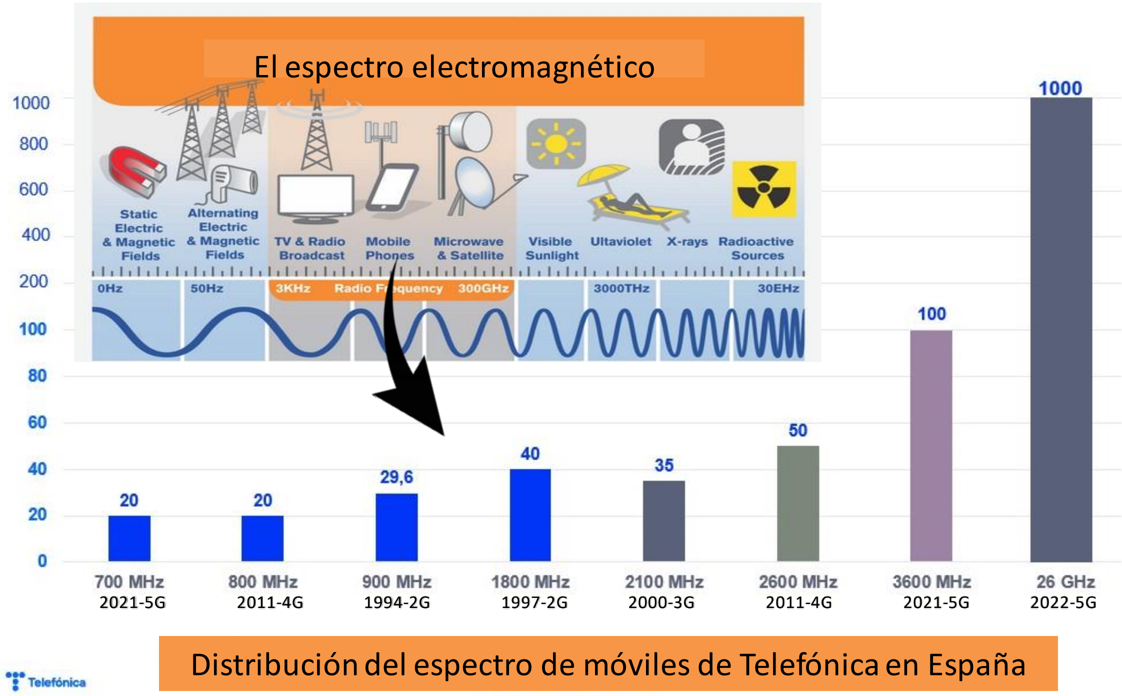

Figure 4. Spectrum allocated to Telefónica

The time sequence in Spain has been: 1994: 900 MHz for GSM/2G; 1997: 1,800 MHz for GSM/2G expansion; 2000: 2,100 MHz for initial deployment of UMTS/3G; 2011: 800 MHz and 2,600 MHz for initial deployment of LTE/3G and LTE-A/4G; 2021: 3600 MHz for LTE-A/4G and initial 5G deployment; 2021: 700 MHz for 5G and 2022: 26 GHz for 5G.

Most of the bands have been allocated for frequency duplex operation, FDD (different uplink and downlink carrier frequencies), except for some band segments and the 3600 MHz and 26 GHz bands, which have been allocated for temporary duplexing (same frequency in both link directions) and which requires synchronization of all carrier frequencies of all networks in the same area.

4.6 More speed on 3G

From the first phases of UMTS, it soon moved on to the gradual introduction of a first package of improvements encompassed under the acronym HSPA (High Speed Packet Access), which includes several improvements aimed at providing higher speeds; among them, the use of multilevel modulations (in line with what was done at the time in GSM with the EDGE), which in this case even reaches 16 levels, which means multiplying the speed by four with respect to binary modulations (although with the nuance that such increases are only achieved for good quality radio links, that is, for coverage radii fairly close to the cell or, in other words, for low percentages of the cell surface). HSPA can be broken down into improvements for the downlink, grouped under the acronym HSDPA (High Speed Downlink Packet Access) which gave peak speeds of 14.4 Mbit/s and for the uplink, which in this case are encompassed in the acronym HSUPA (High Speed

Uplink Packet Access), which gave peak speeds of 5.7 Mbit/s. Telefonica put HSPA technology into service in 2007.

Another package of improvements was HSPA+ technology, with new speed increases and latency reductions, up to 64-level QAM modulations and the optional use of MIMO (Multiple Input Multiple Output) techniques, based on the establishment of several simultaneous channels through several transmitting and receiving antennas. The peak downstream speed reaches 28 Mbit/s and up to 42 Mbit/s with MIMO. Telefónica put this technology into service in 2010.

HSPA+ can be considered as the set of technical solutions that allow you to take full advantage of the UMTS standard according to the CDMA access technique. Although the Dual Cell HSPA technology was still developed, which joined two 5 MHz carriers to achieve a peak downstream speed of 42 Mbit/s, and which Telefónica also put into service in 2010.

4.7 Genesis of almost 4G. LTE

What 3GPP did to go beyond UMTS was to specify what they define as the long-term evolution of UMTS (LTE or Long Term Evolution), which is nothing more than identifying a new radio interface, based on a new access technology. Therefore, CDMA is abandoned and another solution is used, in this case the so-called OFDMA (Orthogonal Frequency Division Access).

OFDMA is a sort of second youth of the old FDMA, based on placing each transmission on a different frequency. Only now what is done is to distribute the signal in baseband among a set of subcarriers. Thus, if, for example, you want to transmit a digital signal of 100 Mbit/s, and you have 100 subcarriers, each of them would be modulated with a signal of 1 Mbit/s. The advantage with FDMA is that it is no longer necessary to over-separate the subcarriers because, thanks to the fact that their frequencies are integer multiples of the same frequency, the spectra of all of them can be located very close, in such a way that the maximums of each coincide with the nulls of those of the others. This orthogonal interweaving of the spectra, without interfering with each other, is what is hidden behind the "O" of OFDMA, and is one of its hallmarks. According to this way of organizing transmissions, each user at a given time can be assigned a set of subcarriers during a given period of time, which in the jargon of the standard is called a chunk; Therefore, the system now has two parameters for organizing transmissions: subcarriers and time windows.

It is a technique that allows intersymbol interference to be alleviated due to selective channel fading when the channel bandwidth is expanded.

LTE is therefore a new radio interface, a new system that, however, cannot be described as 4G, but 3G. In fact, ITU considers it an evolution of the IMT-2000 UMTS interface. The changes brought about by LTE go beyond the simple increase in speed, which is already significant. To begin with, it is a standard capable of handling channels that are significantly larger or smaller than those of UMTS (5 MHz), since it is designed both for deployments in areas where only patchwork bands are available, and for others where there is the possibility of channels of up to 20 MHz. The highest speeds are obviously achieved with these last 20 MHz channels, reaching peaks of 100 Mbit/s downstream and peaks of 50 Mbit/s upstream. In addition, it uses MIMO techniques, reaching 150 Mbiy/s downstream and 75 Mbit/s upstream with 2x2 MIMO (two transmitting antennas and two receiving antennas).

In addition, LTE is the triumph of what in GSM was a later addition: packet dominance for GPRS. And this is because the LTE architecture represents the next great qualitative leap in the architecture of the mobile systems of the 3GPP family, where some elements that until now had been common disappear: specifically base station controllers and circuit mastery. With LTE, all information, including voice, takes the form of data packets and is treated as such within a single domain, the packet domain, which constitutes the core of the network according to a new architecture called EPC (Enhanced Packet Core). Figure 5.

As there is no circuit-switched domain to handle voice calls, as was the case in traditional 2G/3G networks, 3GPP envisioned a CSFB (Circuit Switched Fallback) voice fallback solution for the initial stages of LTE deployment or until the operator deployed a new IMS (IP Multimedia Subsystem) domain. Thus, although LTE was used for data communications, through CSFB the terminal is redirected to the 2G/3G network to initiate or receive a voice call and the call remains in the domain of switched circuits until it is completed.

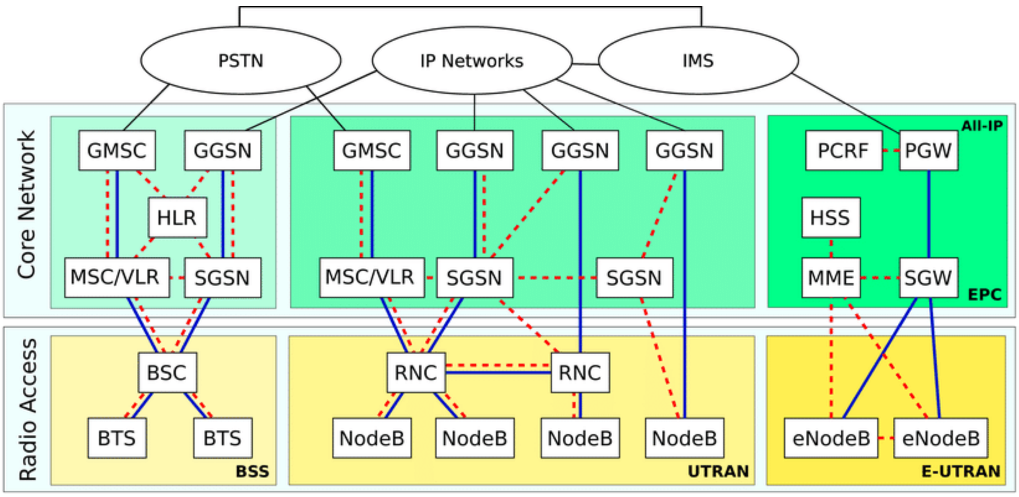

Figure 5. Evolution of the network core

Telefónica deployed LTE with CSFB in 2013 using the 1800 MHz band, 2600 MHz in a very punctual manner when in some locations the 1800 MHz band was full. And the 800 MHz band in 2015, when it was freed up by the so-called digital dividend of the UHF TV band.

4.8 Now if 4G

LTE was the first step towards 4G, which followed a scheme very similar to that of 3G, within the general framework at ITU in 2008, which now takes the name IMT-ADVANCED. The overall targets of this new generation were around 100 Mbit/s (for the whole cell) in full motion (with users moving at up to 250 km/h), and 1 Gbit/s in static situations. In 2010, ITU approved LTE-Advanced (3GPP Release 10) as the standard for the new generation 4G. The other was Wimax (IEEE 802.16m).

Advanced LTE-A is an improvement over LTE and meets all standard requirements for a 4G network. LTE-A is up to 50% faster than LTE with downstream broadband speeds starting around 200 Mbit/s.

The main difference with standard LTE is the handling of the available frequency bands. LTE-A uses multiple frequency bands and antennas simultaneously to transmit and receive signals. This is called carrier aggregation, and it greatly reduces congestion while increasing bandwidth and connection speed. The antennas' MIMO and beamforming techniques are also improved.

In 2020 and in Spain, a total of 38.9 million mobile lines accessed networks equipped with 4G technology.

But, as stated, the EPC network core must facilitate voice over IP (VoIP) or, in this case, voice over LTE, VoLTE. To do this, it was necessary to add the new IMS domain and also the SRVCC (Single Radio Voice Continuity) function for handover between LTE and 2G/3G and vice versa.

IMS, which had been defined by 3GPP, found its first application for voice over IP, VoIP, in next-generation fixed networks, NGN. Thus, Telefónica deployed the first IMS domain in 2004 for the first customers with VoIP but, due to the complexity of the architecture and the absence of terminals, it was not until 2015 that the VoLTE tests were completed; and the service was launched in Colombia, Peru and Argentina in 2016. In 2019 in Mexico and Spain.

With VoLTE, 4G Voice was born, of higher quality and providing advanced features such as WiFi Calling, which allow mobile coverage to be extended to WiFi accesses. Also the RCS (Rich Content Suite) service, known by its commercial name Joyn or by "the WhatsApp of operators", to make video calls, instant messaging, file transfers, etc.

Thanks to 4G Voice, the smartphone remains in 4G coverage, being able to simultaneously call with other data connections at maximum speed. All smartphones approved by Telefónica since the beginning of 2021 are compatible with VoLTE.

With these VoLTE and VoIP technologies, the end of circuit switching, both in fixed and mobile networks, and the gradual disappearance of 3G begins.

4.9 Incorporating the Internet of Things

It soon became clear that M2M lines with GSM/GPRS, which have only reached 7.6 million in Spain in 2020, were unable to connect 50,000 million IoT Internet of Things devices that were predicted for 2020. Apart from the exaggerated forecast, the industry began, around 2005, to develop technologies for machines and short-range sensor networks: NFC and RFID, Low-Energy Bluetooth, ZigBee, Z-Wave, Wi-Fi)); and also, around 2010, for long-range LPWA (Low Power Wide Area) with low-power devices and low-speed data: LoRa, Sigfox, etc. In response to these initiatives, 3GPP also defined technologies for LPWA in Release 13 of 2016; NB-IoT and LTE-M.

NB-IoT (Narrowband IoT) technology is used for massively distributed devices. With a bandwidth of 180 kHz, data rate <100 kit/s, latency between 1.5 and 10 s and battery life of around 10 years.

LTE-M (Long Term Evolution for Machines) technology, or CAT-M1, uses installed LTE antennas and is optimized for higher bandwidth and mobile connections that include voice (VoLTE). With a bandwidth of 1.4 MHz, data rate up to 1 Mbit/s, latency between 50 and 100 ms and battery life of around 10 years.

At the beginning of 2020, Telefónica had more than 2.6 million IoT lines with NB-IoT and LTE-M technologies. These devices use eSIM (electronic SIM).

4.10 We've left things behind. Genesis of 5G

In all the evolution of mobile telephony, and after mobile broadband, we have left behind other radio communication systems that have evolved considerably less.

One of them is mobile systems used for security and emergency or radio communications for public protection and relief operations (PPDR, public protection and disaster relief). Although in the United States these systems have evolved using LTE technology at least for mobile broadband, in Europe and Spain systems derived from the 1G (Tetrapol) and 2G (Tetra) generations continue to be used, which lack the facilities of mobile broadband. In this sense, 5G, foreseeing its use in this type of services, has defined specific requirements, grouped under the name URLLC and which includes all types of critical services based on ultra-reliable and low-latency communications; not only PPDR systems but also Autonomous Vehicles (Self-Driving), Vehicle-to-Vehicle Communication (VXC), Industry 4.0, etc.

Other technologies, those of LPWA for IoT, have been defined, as we have seen, within the framework of 4G, but they have not yet achieved massive volumes at the level that was expected. Although they require low transmission speeds, some applications need low latency and a very low probability of error; what 5G IoT will undoubtedly be able to give them, for which the ITU has defined.

The demand for data continues to increase, so it is necessary to provide more frequency bands and continue to increase the speed and spectral efficiency. For this reason, 5G has defined minimum requirements for services that require enhanced broadband, eMBB.

Many of the requirements apply to businesses, but there is one feature that applies directly to them, Network Slicing; which is the network core technology in 5G that allows specific capabilities to be provided to different services and customers. It allows you to run multiple virtually independent logical networks on a single common physical infrastructure, in an efficient and economical manner. It offers the possibility of creating several custom virtual networks on a common shared physical infrastructure. Depending on the specific needs of applications, services, devices, customers, or carriers. .

Wi-Fi also fits into 5G, not because it hasn't evolved, but because it has always followed a parallel path, being used indirectly by mobile phones, either by switching to Wi-Fi at home, or by repeating Wi-Fi (tethering). But now 5G makes it possible to integrate unlicensed bands, especially WI WIFI6, also with OFDMA technology, into the New Radio (NR-U), which will provide an additional 1,200 MHz in the 6 GHz band.

With this in mind, ITU published in 2017 the minimum requirements for IMT-2020 or 5G in the radio interface for enhanced mobile broadband eMBB, ultra-reliable and low-latency communications URLLC and massive mMTC machine-type communications. For the eMBB scenario, the peak rate had to exceed 20 Gbit/s downstream and 10 Gbit/s upstream, with spectral efficiency of 30 and 15 bit/s/Hz, respectively. In addition, it defined the data rate experienced by the user with a requirement of 100 Mbit/s downstream and 50 Mbit/s upstream. As for latency, this should be less than 4 ms for eMBB and less than 1 ms (5G is the millisecond technology) for URLLC scenarios. And a minimum speed of 500 km/h, valid for high-speed trains in rural eMBB scenarios. The minimum requirements for Machine-Type Mass Communications (mMTC) are a device battery life of at least 10 years (preferably 15 years), coverage expansion of 20 dB, and support for one million devices per square kilometer.

4.11 5G is already unfolding

5G includes two technologies for the radio interface: 4G's E-UTRA/LTE, which defines a 5G NSA (Non-standalone) deployment, and New Radio NR, which defines a 5G SA (Stand Alone) deployment. Both technologies are designed to operate in the IMT spectrum of 5G.

In 2020. Telefónica launches its 5G network in Spain, which will be carried out in two phases. For the former, 5G NSA will be used in the 3500 MHz band. It will also use the mid-bands (1800 MHz and 2100 MHz) of 4G to offer 5G services by leveraging DSS (Dynamic Spectrum Sharing) technology. To deploy the 5G SA network immediately afterwards, when the technology is fully available.

The DSS dynamic spectrum sharing technique provides great flexibility in spectrum management, allowing an LTE carrier to be used simultaneously by LTE and NR services, making it easier to transfer LTE traffic to NR. In addition, the coverage problem posed by the deployment of NR in millimeter bands, 26 GHz, is solved by implementing DSS in low-band carriers by adding high-band carriers.

In addition, this initial deployment is making use of existing sites and infrastructures by taking advantage of the possibility of using New Radio equipment that can operate on both 4G and 5G technologies at the same time. In the medium and long term, it will be complemented with new base stations and microcells (small cells), as required by capacity or coverage.

As for NR, the basic LTE-4G OFDM is maintained, providing it with great flexibility, with the option of windowing and filtering to confine the spectrum, in case of multiple services sharing the same carrier, and multilevel modulations are extended to 256 QAM.

It should also be noted that Telefónica and Ericsson have successfully carried out a proof of concept by which they wanted to demonstrate the capabilities of Network Slicing. The dynamic partitioning of radio resources has been included and the end-to-end automation of Network Slicing in 5G Standalone networks has been achieved in the first phase.

Finally, the deployment of 5G in the 700 MHz band, which is used to host only 5G coverage, has also begun in 2022.

4.12 Conclusion

Figure 6 shows the evolution of data traffic up to 2021 but does not include the total data traffic consumed by mobile phones as a whole. This is because a very high percentage of these devices also connect to the internet via WiFi wireless networks. Thus, 76.1% of smartphone users reported regularly connecting to WiFi networks, while only 10.4% used mobile networks exclusively to access the Internet.

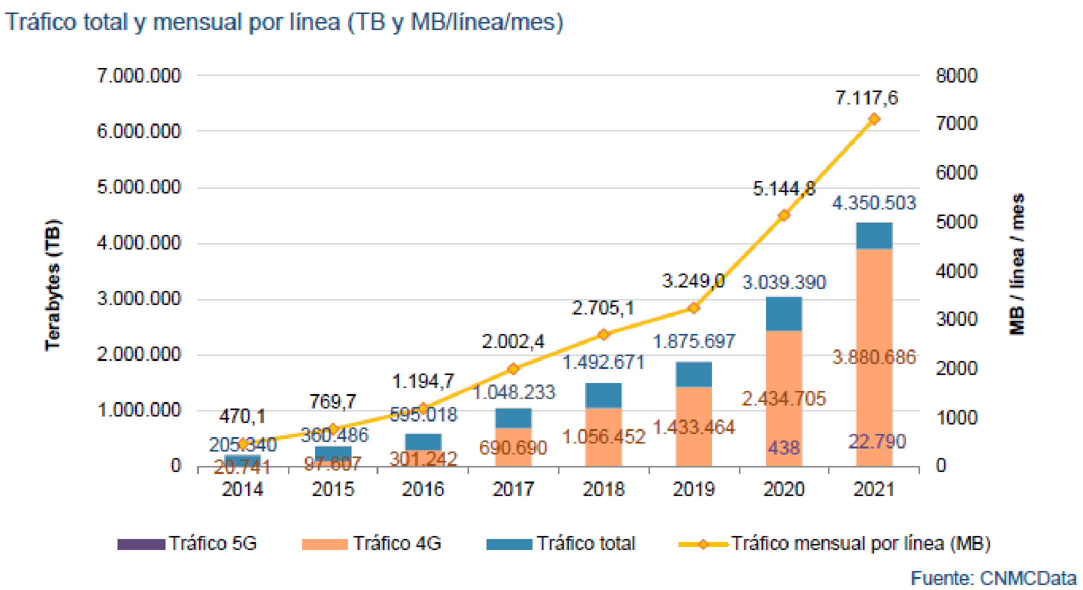

Figure 6. Evolution of data traffic

And this has been possible, as indicated in the section **¡Error! No se encuentra el origen de la referencia.** thanks to the availability of bands and the efficiency in the use of the spectrum of the different technologies used in the 3G, 4G and 5G generations, which is summarized in the following table.

	Tecnología	Ancho de banda de la portadora	Velocidad de pico en el enlace descendente	Velocidad de pico en el enlace ascendente	Latencia	Espectro inicial (MHz)	Eficiencia espectral de pico (bit/Hz)
2G	GSM/GPRS	200 kHz	114 kbit/s	58 kbit/s	500 ms	900/1800	0,17
	EDGE (MC-9)		236 kbit/s	118 kbit/s	300 ms		0,33
3G	WCDMA	5 MHz	384 kbit/s (2 Mbit/s)	384 kbit/s	250 ms	2100/900	0,51
	HSPA	5 MHz	14,4 Mbit/s	5,7 Mbit/s	70 ms		2,88
	HSPA+ (64QAM+Dual)	5 MHz 5+5 MHz	28 Mbit/s (42 Mbit/s)	14 Mbit/s	30 ms		12,50
	LTE	Hasta 20 MHz	100 Mbit/s	50 Mbit/s	10 ms	2600/800	16,32
4G	LTE-Avanzado	Hasta 100 MHz	1 Gbit/s	>500 Mbit/s	5 ms		Bajada >30 Subida >15
5G	5G-NR	Hasta 1 GHz	20 Gbit/s	10 Gbit/s	4 ms (eMBB) 1 ms (uRLLC)	700/3500/ 26 GHz	Bajada >30 Subida >15

The new 5G deployments will be accompanied by a gradual shutdown of the old second and third generation networks. 100% of the copper network will have been replaced by fibre by 2025, when the 3G network shutdown will also be completed.

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