Introducing radio spectrum

Spectrum primer series

GSMA

Produced February 2017

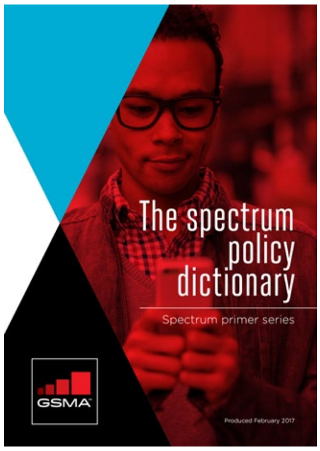
Introduction to the primer series

Radio spectrum

These handbooks provide a general introduction to mobile spectrum, how it is managed and the challenge posed by rapidly growing data usage. They have been designed for readers who don’t have a technical background in the subject. While this is only a very brief introduction to the subject, these handbooks should hopefully provide a useful overview.

The titles in this series are:

- ► Introducing radio spectrum;
- ► Introducing spectrum management; and
- ► The spectrum policy dictionary.



Introducing radio spectrum

This handbook introduces radio spectrum, why it matters, how it is used and the central role it plays in the rapidly evolving mobile industry.

1

Why spectrum matters

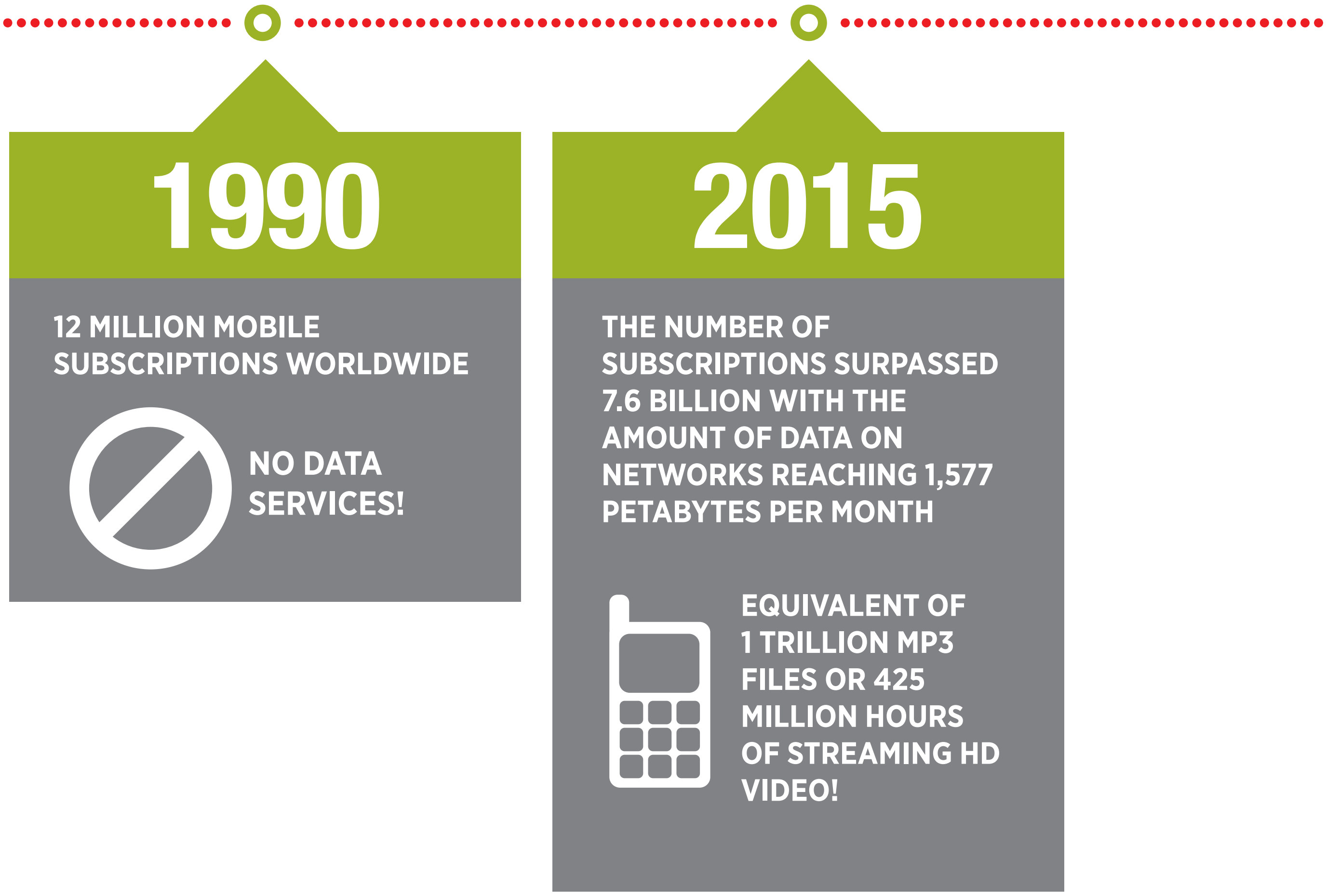
Radio spectrum is used to carry information wirelessly for a vast number of everyday services ranging from television and radio broadcasting, mobile phones and Wi-Fi to communications systems for the emergency services, baby monitors, GPS and radar.

So many vital services are completely reliant on spectrum that it forms an indispensable part of all of our lives and one that is often taken for granted. Yet in a world which demands ever increasing amounts of information, faster communications and higher definition media, it is important to be aware that useable radio spectrum is a scarce resource where rapidly growing demand exceeds supply.

Few examples illustrate this better than mobile services.

In 1990 there were around 12 million mobile subscriptions worldwide and no data services. In 2015, the number of mobile subscriptions surpassed 7.6 billion (GSMA Mobile Economy 2016) with the amount of date on networks reaching 1,577 exabytes per month by the end of 2015 — the equivalent of 1 trillion mp3 files or 425 million hours of streaming HD video.

(Source: Cisco Visual Networking Index, 1 February 2016)



And this is just the start

Most people on the planet do not yet have a mobile phone. Furthermore, a wide variety of machines — ranging from cars to electricity meters — are beginning to connect to mobile networks in a system known as machine-to-machine communications (M2M). This is set to create a more connected life where vast numbers of devices will be interconnected to create intelligent services and infrastructure.

The key ingredient for faster wireless services that can support the rising tide of data is more spectrum. However, it is a finite resource that is already heavily encumbered. This makes spectrum management a vital job for government. When spectrum is made available in a fair and reasonable manner to the services that will make the best use of it, the social and economic benefits are profound.

Direct and indirect revenues attributable to mobile services reached $3.1 trillion in 2015 (around 4.2 per cent of global GDP), showing how critical mobile services are for national economies. They also provide a crucial social function by keeping people better connected, informed and entertained. Mobile technology is now going even further by improving access to key services such as healthcare, education and financial services. This is most pronounced in emerging markets where large swathes of people cannot physically access a doctor, bank or learning resource. Mobile technology is transforming many lives by allowing these vital services to be provided remotely for the first time.

"In 2015, the mobile ecosystem generated 4.2 per cent of global GDP, a contribution that amounts to more than $3.1 trillion of economic value added."

(Source GSMA Mobile Economy 2016)

2

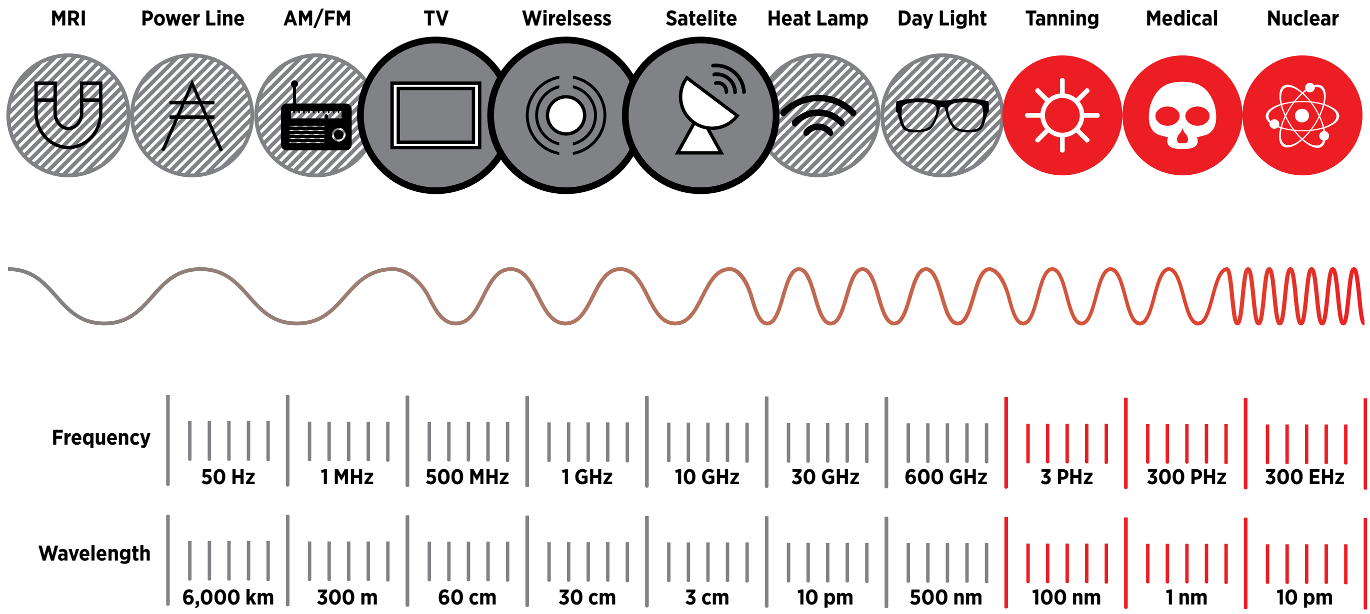
Radio
spectrum explained

Radio waves constitute just one portion of the entire electromagnetic spectrum, which also includes a variety of other waves including X-ray waves, infrared waves and light waves.

Measuring spectrum

The electromagnetic spectrum is divided according to the frequency of these waves, which are measured in Hertz (i.e. waves per second). Radio waves are typically referred to in terms of:

- kilohertz (or kHz), a thousand waves per second
- megahertz (or MHz), a million waves per second
- gigahertz (or GHz), a billion of waves per second



The radio spectrum ranges from low frequency waves at around 10 kHz up to high frequency waves at 100 GHz. In terms of wavelength, the low frequencies are about 30 km long and the high frequencies are about 3 mm.

This contrasts with visible light waves that operate at such high frequencies that they are measured in terahertz (trillions of waves per second) and are therefore nanometres in length.

The importance of bands

Radio spectrum is divided into frequency bands, which are then allocated to certain services. For example, in Europe, the Middle East and Africa, the FM radio band is used for broadcast radio services and operates from 87.5 MHz-108 MHz. The band is subdivided into channels that are used for a particular transmission, so the individual channels in the FM band represent the separate broadcast radio stations.

The wider the frequency bands and channels, the more information that can be passed through them. This move towards wider — or broader — frequency bands that can carry larger amounts of information is one of the most important trends in telecommunications and directly relates to what we refer to as a 'broadband' connection.

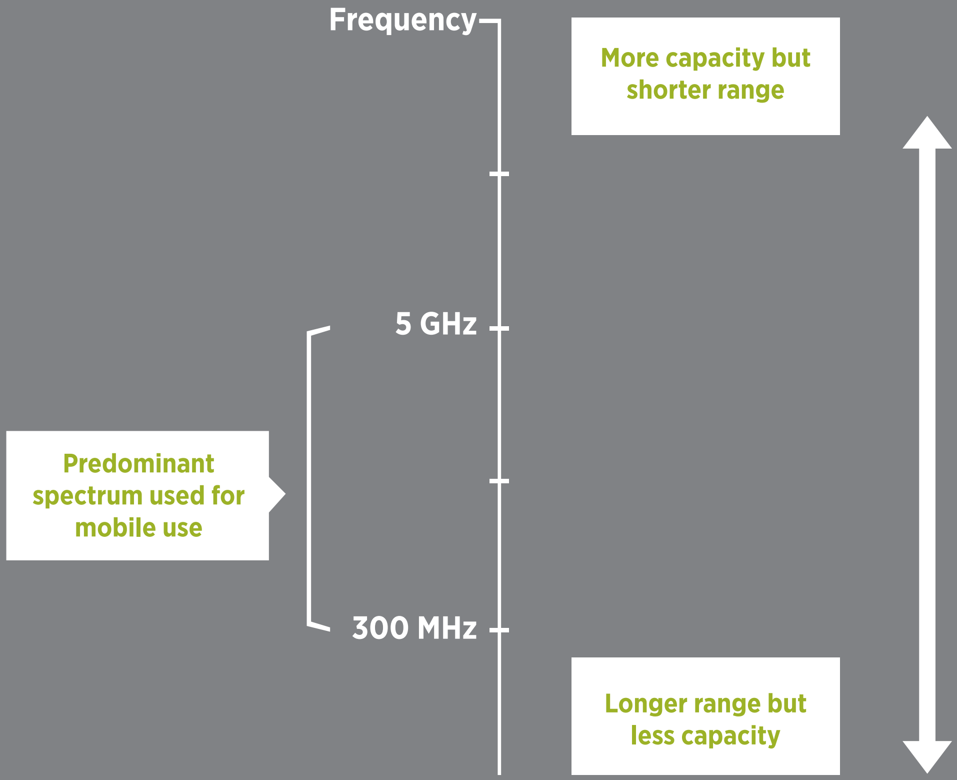
In the same way that wider roads mean you can add more lanes to support more vehicle traffic, wider bands mean you can add more channels to support more data traffic.

The right radio frequency for mobile communications

Radio frequencies are not all equal. They differ in how well they can provide coverage and capacity (i.e. the amount of data they can carry).

Lower frequency bands provide wider coverage because they can penetrate objects effectively and thus travel further, including inside buildings. However, they tend to have relatively poor capacity capabilities because this spectrum is in limited supply so only narrow bands tend to be available.

Contrastingly, higher frequency bands don't provide as good coverage as the signals are weakened or even stopped by obstacles such as buildings. However, they tend to have greater capacity because there is a larger supply of high frequency spectrum making it easier to create broad frequency bands, allowing more information to be carried.



The most extreme examples of this are light waves that operate at such a high frequency that they cannot get through walls but can carry lots of information, hence their use in fibre-optic networks.

The same holds true for radio waves. You can use an antenna connected to the top of your television to receive terrestrial TV broadcasts, which operate at low radio frequencies (e.g. below 700 MHz), but will require a dish to be installed on the outside of your home to receive the higher radio frequencies used for satellite TV broadcasts (e.g. 4-8 GHz or 12-18 GHz) as they cannot penetrate walls.

Because of these characteristics, low frequency bands allow mobile operators to provide very wide coverage including in rural areas without requiring many base stations. However, these bands have a limited capacity to carry large amounts of data so operators tend to use higher frequency bands in busy areas such as cities and town centres where lots of people use mobile broadband services — although this means lots of base stations are needed as the signals don't travel far.

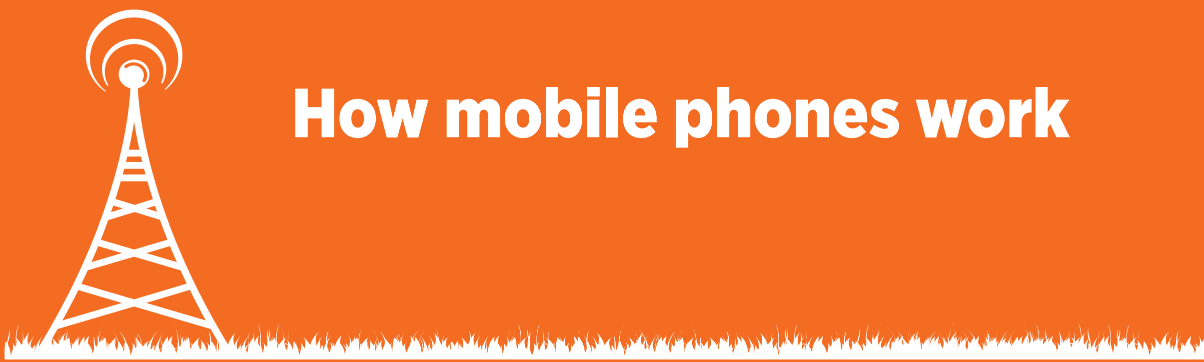
As a result operators are looking to acquire more sub-1 GHz spectrum to extend mobile broadband into rural areas, especially in emerging markets. Equally, they are also increasingly looking to higher frequency bands. That includes, for the first time, spectrum band above 3 GHz to accommodate busy urban areas.

3

How mobile devices communicate

Most modern radio communications devices operate in a similar way. A transmitter generates a signal that contains encoded voice, video or data at a specific radio frequency, which is distributed into the environment by an antenna.

How mobile phones work



A mobile phone sends and receives information (voice or data) by radio communication.

Base stations are positioned in networks of overlapping cells, to ensure mobile phone users are always within range of a base station.

This signal spreads out and a small proportion is captured by the antenna of the receiving device, which then decodes the information. The received signal is incredibly weak — often only one part in a trillion of what was transmitted.

In the case of a mobile phone call, a user's voice is converted by the handset into digital data, which is transmitted via radio waves to the network operator's nearest base station (aka cell tower), where it is normally transferred over a fixed-line to a switch in the operator's core network. The call is then passed to the recipient's mobile operator where it is directed to their nearest local base station, and then transmitted by radio to their phone, which converts the signal back into audio through the earpiece.

There are a number of different digital radio technologies that are used for transmitting signals between mobile phones and base stations — including 2G, 3G and 4G — that use increasingly efficient methods of coding signals on to radio waves creating faster data connections.

These increasingly spectrum efficient technologies mean more data can fit into a specific amount of spectrum. To return to the road analogy, this is the equivalent of controlling traffic more effectively and allowing more cars to fit on the same road.

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How is radio spectrum used and managed?

A country’s radio spectrum is a critical asset, and is therefore carefully managed by the national government (typically by a regulator).

Governments work collectively through the International Telecommunication Union, a United Nations agency, to allocate specific bands to certain services on a global or regional basis. This helps to limit international interference as well as reduce the cost of mobile phones because it encourages nations to adopt compatible approaches that drive economies of scale.

At the broadest level, spectrum is regulated in two ways, it is either managed through a spectrum licence or it is licence exempt (i.e. unlicensed).

Spectrum users

Licensed and unlicensed spectrum is used for a wide variety of everyday services:

Licensed spectrum

The vast majority of radio spectrum is licensed and encompasses a range of technologies that operate with enough power to allow the services to cover a relatively wide area.

National regulators control access to this spectrum through a licensing framework allowing them to grant an organisation the exclusive rights to use a certain frequency band in certain areas and at certain times.

Licence holders include commercial organisations, such as TV and radio broadcasters or mobile operators, and non-commercial organisations, such as the emergency services and the military.

Giving an entity the exclusive rights to use a certain band means it can guarantee a certain quality of service as it controls all aspects of the network operating on that specific frequency. These rights are protected so that if any other entity uses this licensed frequency band, or causes interference to it, it can be compelled to stop.

Weather radar

Military and national security systems

GPS

Satellite broadcasting

Mobile services

Radio astronomy

Satellite communications

Terrestrial broadcast television and radio

Aviation systems and air traffic control

Maritime communications and navigation

Unlicensed spectrum

Unlicensed frequency bands have more limited applications, and are designated for certain specific types of use. There is no need for a licence from the regulator as long as the devices used meet certain technical standards in order to minimise interference.

The most notable examples of ‘unlicensed’ technologies are Wi-Fi and Bluetooth, which both operate in the 2.4 GHz band, but there are several others which are used for cordless telephones, baby monitors, car key fobs and garage door openers.

The reason these bands are unlicensed is because the technologies used must operate at low-power levels, meaning they can only cover short distances. As everyone has an equal right to use these bands, it is not possible to guarantee the quality of service. For example, Wi-Fi users can become victim to the ‘tragedy of the commons’ as large numbers of networks and users cause services to slow down significantly.

TV remote controls

Microwave ovens

X-ray machines

Wi-Fi

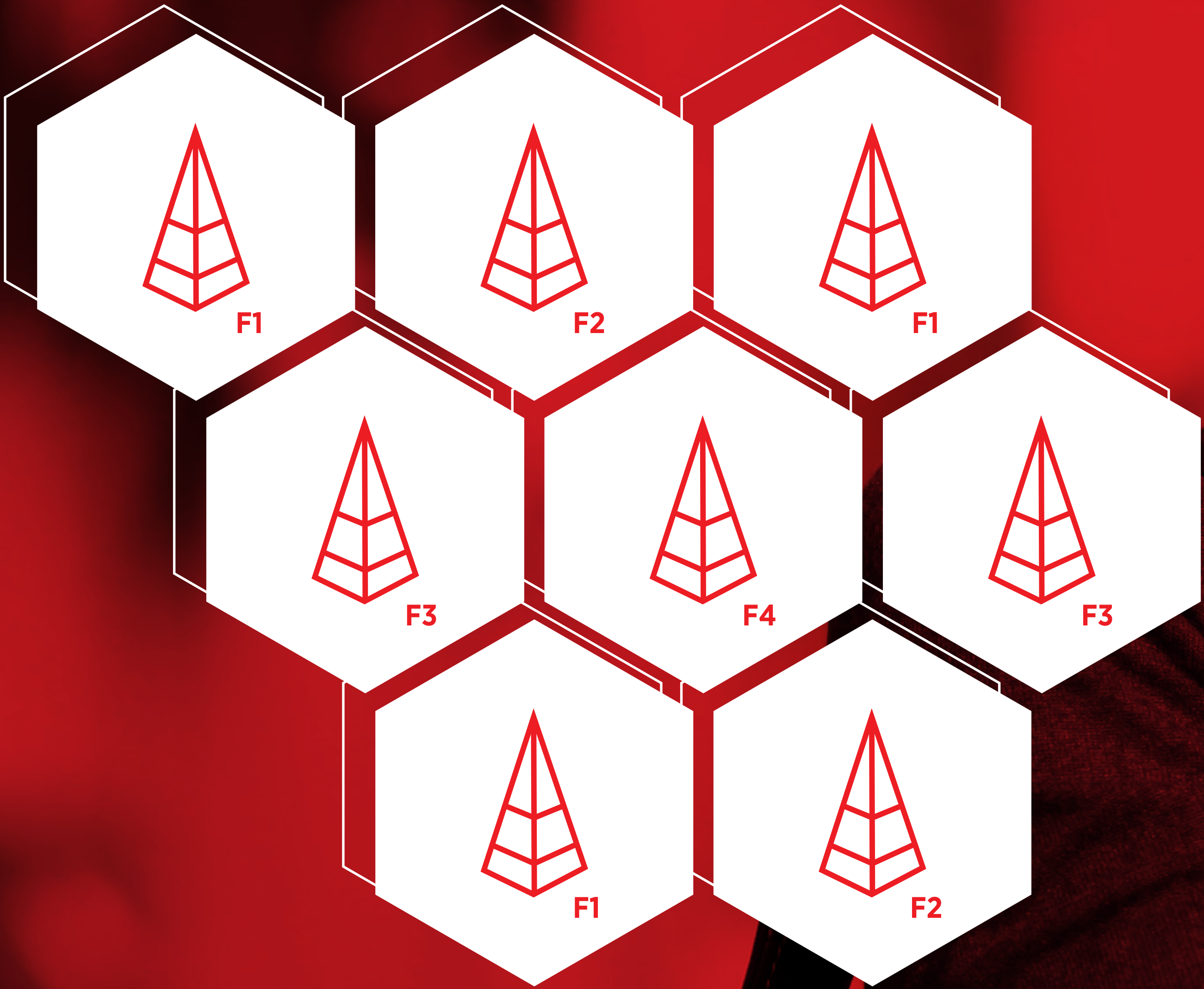
Cordless phones

Car key fobs

A history of mobile network and spectrum use

The birth of cellular

The concept of modern mobile communications was invented at Bell Labs in 1947, when engineers proposed that wireless networks could cover wide areas through a number of low-power radio base stations laid out in a hexagonal, cellular-like grid.



Prior to the adoption of cellular networks, early mobile communications systems used a single high power base station to cover a wide area. The problem with this approach was that due to the finite amount of available spectrum, only a small number of users could be supported and when they dropped out of range they lost their connection.

The beauty of the ‘cellular’ approach is that vastly more users can be accommodated because spectrum is re-used across a given area. This means several phones can use the same frequency channel as long as they are connected to different “cells” (i.e. base stations) that are sufficiently far apart. It also means that when a user drops out of range of one base station their call can be handed over to another allowing them to continue the conversation. Hence, mobile!

1G networks

Cellular technology took time to catch up with the theory so it was not until 1973 that a Motorola engineer, Martin Cooper, made the first cellular phone call using a prototype mobile phone. It was then not until 1978 when the first generation of cellular networks (i.e. 1G networks) were launched initially in Bahrain and shortly afterwards in Chicago.

A variety of different types of 1G mobile network technologies rapidly grew up around the world including:

- **Advanced Mobile Phone System (AMPS) –** which mostly used the 800 MHz band
- **Nordic Telecommunication System (NMTS) –** which mostly used 450 MHz & 900 MHz
- **Total Access Communications (TACS) –** which mostly used 900 MHz

However these different, and incompatible, analogue systems meant using a phone abroad was impossible and they soon became oversubscribed and prone to cloning and eavesdropping.

2G networks

In the early 1990s, a new generation of digital-based mobile networks appeared that could support far more users and featured better security leading to mass adoption. By converting phone calls into binary digital code (i.e. ones and zeros) it was possible to encrypt and compress the data making the services more secure and spectrum efficient (i.e. more data can be squeezed into less spectrum).

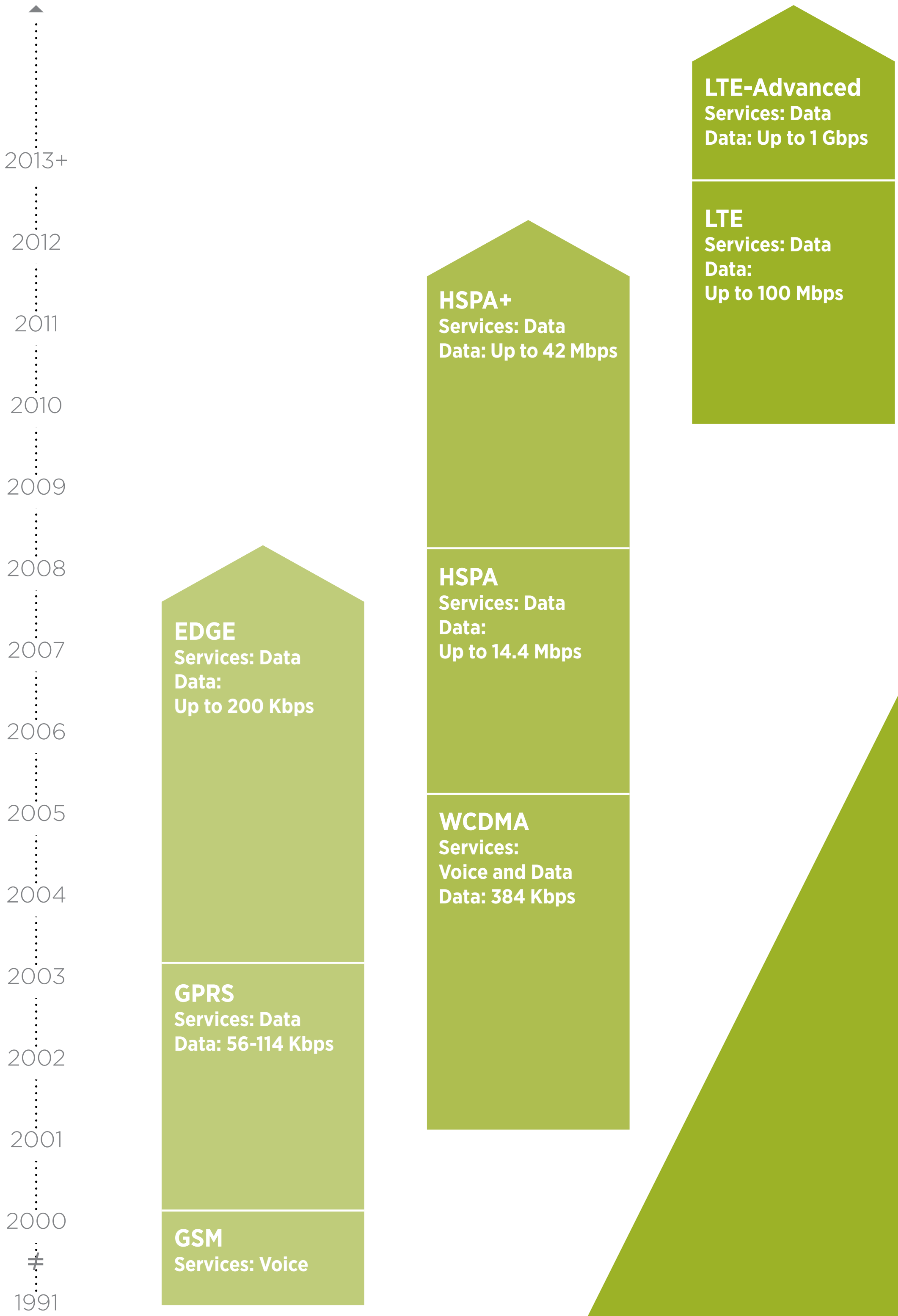
Global System for Mobile communications (GSM) technology allows a single frequency band to support several different users. As GSM was designed by the mobile community to be fully interoperable, the same devices and network equipment could be sold globally, helping to bring down prices and allowing consumers to roam on foreign networks for the first time. These networks largely operated in the 900 MHz, 1,800 MHz, 850 MHz and 1,900 MHz bands.

However, there were other 2G systems such as cdmaOne, which is still used by a large number of operators around the world, as well as several others which are no longer used including D-AMPs, PDC and iDEN.

Although 2G networks were designed for voice communications they started to support data services initially with Short Message Services (SMS), then subsequently with a dedicated general-purpose data connection.

The most notable of these data technologies was General Packet Radio Service (GPRS) that became known as 2.5G and provided data speeds of around 56–114 Kbps (kilobits per second). This was succeeded by Enhanced Data Rates for GSM Evolution (EDGE), which became known as 2.75G and could support speeds of over 200 Kbps.

"The vast majority of 2G mobile networks around the world used Global System for Mobile communications (GSM) technology."



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Up to 100 Mbps
HSPA+
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Data: Up to 42 Mbps
HSPA
Services: Data
Data:
Up to 14.4 Mbps
WCDMA
Services:
Voice and Data
Data: 384 Kbps
EDGE
Services: Data
Data:
Up to 200 Kbps
GPRS
Services: Data
Data: 56-114 Kbps
GSM
Services: Voice

3G networks

The growing use of 2G networks for data services led to the first smartphones and data cards that could connect laptops to the mobile network enabling email and web access. However the rise of the internet in the 1990s coupled with the first fixed broadband deployments led the mobile industry to plan third generation mobile systems that were built from the outset to support highspeed data services.

The new 3G networks that went live early in the new millennium used Code Division Multiple Access (CDMA) technology, allowing individual voice and data sessions to be sliced up and spread across different frequencies, enabling more efficient spectrum use.

The vast majority of networks globally used Wideband CDMA (WCDMA) technology, which was the natural evolution from 2G GSM systems. However, a number of operators used the alternative CDMA 2000 system and a China-specific TD-SCDMA version was also developed. Most 3G networks operate in the 800 MHz, 850 MHz, 900 MHz, 1,700 MHz, 1,900 MHz and 2,100 MHz bands.

“The 3G networks eventually led to a dramatic growth in the use of mobile data, initially through USB dongles connected to laptops, and later through widespread smartphone adoption.”

In order to improve the mobile data experience, and drive up connection speeds, a series of upgrades were made to 3G networks. Initially, the WCDMA networks were capable of reaching just over 2 Mbps in ideal radio conditions but in reality actual speeds were closer to 300 Kbps.

In 2005, the first network was upgraded to support High Speed Packet Access (HSPA) which allowed download speeds of up to 14.4 Mbps and became known as 3.5G. Since then further upgrades including HSPA+ accelerated speeds up to 42 Mbps and beyond.

4G networks

The growth in mobile data usage was so fast that the industry started planning a major new network upgrade based on the Internet Protocol (IP). The new technology, Long Term Evolution (LTE), would eventually become known as 4G and enable data speeds of up to 100 Mbps. The introduction of LTE-Advanced opened the door for even higher speeds.

The first network was launched at the end of 2009 and within four years there were over 250 more, making it the fastest growing cellular technology in history. In 2013, the first upgrades took place with LTE-Advanced networks being used in South Korea — a trend that accelerated in 2014.

4G uses Orthogonal Frequency Division Multiplexing (OFDM) technology which is far more spectrum efficient — and is also used for fixed broadband systems (e.g. DSL), Wi-Fi and digital TV. However, the combination of surging growth in data usage and the need to simultaneously support 2G, 3G and 4G networks means mobile operators face spectrum challenges.

Each new cellular generation uses wider channel bandwidths as well as improved radio technology to drive faster connection speeds, requiring the use of increasing amounts of spectrum.

This means operators are permanently trying to secure additional frequency bands to keep up with the expanding requirements of the latest technologies. However, as spectrum is such a scarce resource and new bands take so long to become available, mobile operators must also adopt new technologies to help solve the issue in the short term.

5G networks

5G is expected to support significantly faster mobile broadband speeds and increasingly extensive mobile data usage — as well as to enable the full potential of the Internet of Things. From virtual reality and autonomous cars, to the industrial internet and smart cities, 5G will be at the heart of the future of communications. 5G is also essential for preserving the future of today's most popular mobile applications — like on-demand video – by ensuring that growing uptake and usage can be sustained.

Although the mobile industry, academic institutions and international standards-making bodies are busily developing the technologies that will be central to 5G, the success of the services will also be heavily reliant on national governments and regulators. Most notably, the speed, reach and quality of 5G services will be heavily dependent on governments and regulators supporting timely access to the right amount and type of spectrum, and under the right conditions.

Heterogeneous networks

Where once operators used a small number of radio and base station types, they are now building new base stations that simultaneously support 2G, 3G, 4G and Wi-Fi, and come in a range of different sizes — this increased technological variety means they have been dubbed 'heterogeneous networks'.

Most notably, they are starting to use small cells, which are very low power base stations that bring the full data capacity of a conventional cell to a much smaller area. The result is much faster and higher quality services. These include femtocells that cover a home, picocells that cover a business and microcells that cover small urban or rural areas.

By using very large numbers of small cells, mobile operators can re-use their spectrum more efficiently, thereby increasing the capacity of their networks significantly. In the pre-cellular mobile age, one base station would spread its radio capacity over an entire city. Modern small cells mean one base station can serve a single coffee shop, containing only a few people, resulting in faster and more responsive mobile services.

The evolution of mobile services

Mobile networks have evolved from providing simple voice communications to supporting an array of data services ranging from simple SMS and email to a wealth of different mobile apps. These apps and services range from maps, games and social media tools to mobile banking and mobile commerce.

The biggest change to mobile services is coming from the staggering growth in connected machines, which could outnumber human mobile subscribers by 2020. This is creating a more connected life where almost anything can be remotely monitored, controlled, upgraded and fixed.

This is already changing many industries:

Automotive
Connected cars will make journeys faster and safer by warning drivers about traffic and potential hazards as well as automatically alerting the owner to maintenance issues or the emergency services when an accident occurs;

Utilities
Connected metres and infrastructure allow energy and water companies to remotely monitor their network to improve performance and customer billing;

Healthcare
Connected medical devices mean doctors and patients can easily monitor vital signs to improve treatment, fitness and research;

Logistics
Connected sensors mean that products, especially perishables, can be monitored to ensure they are delivered on time and stored in the right condition.

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Produced February 2017