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MOBILE NETWORKS: WHAT THEY ARE AND HOW THEY WORK

MOA, Russell Square House, 10-12 Russell Square, London WC1B 5EE, www.mobilemastinfo.com

Introduction

Almost every aspect of everyday life is now increasingly reliant on easy and ubiquitous access to mobile networks. People want to make voice calls and send text messages, and there is a rapidly burgeoning demand for high-speed data to enable social networking, video streaming, web browsing and many other applications supporting today's social and business needs. This increasing demand for mobile connectivity inevitably drives demand for more radio base station sites in all areas. Only a minority of base stations are sited on free-standing 'masts', and although the terms are often used interchangeably, they are in fact two different things. A 'mast' is simply a freestanding structure that supports antennas at a height where they can transmit and receive radio waves, and a radio base station can be on a roof top, on a pylon or water tower, or on many other types of structure.

The challenge for mobile network operators and for local planners is to balance environmental considerations with the provision of an advanced, high quality communications infrastructure which is essential for sustainable economic growth and plays a vital role in enhancing the provision of local community facilities and services. This short booklet explains why we need these base stations, and how they work. It explains the different types of base station, and outlines the factors that determine where we need to build them.

Why Do We Need Radio Base Stations (Cell Sites)?

In order for mobile networks to function, they need a substantial network of base stations to provide sufficient radio coverage in any geographical area to handle customer voice, text, or data. A mobile device, such as a phone or tablet, converts data or the human voice into radio waves. These signals are transmitted from the device to the nearest base station. Radio is the only way of providing the total device mobility demanded by today's users. People have an increasing expectation that mobiles will connect them anytime and anywhere, and both private and public sector organisations are increasingly relying on mobile communications to increase efficiency and reduce costs.

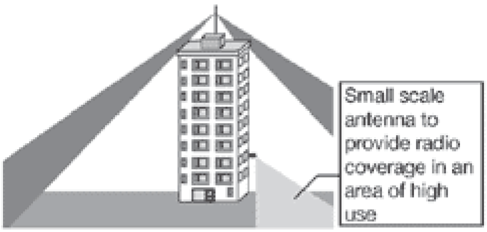
What Are Radio Waves?

The radio waves that allow mobile devices to work are part of the electromagnetic spectrum, travelling from point to point at high speed. Other common uses of radio waves include 'Bluetooth' headsets, baby monitors, television signals, and, unsurprisingly, broadcast radio. Radio waves travel at speeds very close to the speed of light, and just like light, they travel in straight lines and are affected by obstructions that can alter the radio signal. The main factors that affect radio signals in this way are 'shadowing', 'attenuation', 'diffraction', and 'reflection', as explained below:

Shadowing

This is where terrain or buildings partially reduce the signal. It is similar to light being blocked by an obstruction that is totally opaque.

Signal loss due to shadowing from terrain. Shadowed areas may be covered by other transmitters in view of the shadowed area.

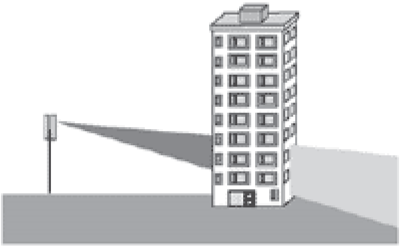


Signal loss due to shadowing from buildings. Needs to considered in urban scenarios in particular and may require lower infill antennas to cover the shadowed areas.

Attenuation

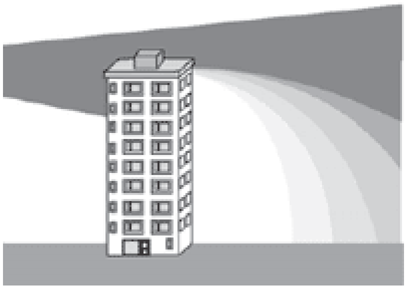
This is where the strength of signal is reduced when passing through a building or other obstruction such as a wall, in much the same way that light is reduced by curtains.

Signal strength reduced by attenuation. Materials such as brick, stone and steel will weaken radio signals depending on the material. This must be considered when providing coverage within buildings.



Diffraction

To a limited extent, larger radio waves can bend around an object. Unlike shadowing and attenuation, which hinder mobile coverage, diffraction helps it: it can 'illuminate' areas not in direct view of the transmitting antenna, just as a hall light can illuminate parts of a room not in direct view of the hall light bulb.



Signals can 'bend' round obstructions to some extent (diffraction). This can help to 'fill in' shadowed areas.

Reflection

Reflection reduces signal *strength*, but may also aid *coverage*. Once again, the hall light analogy is useful here – imagine light entering a room from the hall and reflecting off a mirror, for example.

Reflection can sometimes help to "fill in" shadowed areas in urban scenarios

Why Do Cell Site Antennas Need a Clear View of the Surrounding Area?

As we have already seen, obstructions or 'clutter' in the path of the radio signals will weaken them through attenuation, diffraction and reflection – just like light from a torch – so to maintain acceptable signal strength (which you might see in terms of the signal 'bars' on a mobile phone) mobile antennas need to be sited with the clearest possible view of the area for which they are intended to provide coverage. In an area that has no clear view of the antenna, the service will be relying on attenuated, diffracted and reflected signals, which may not be reliable and can lead to calls failing unexpectedly. The final choice of antenna site is, therefore, often a compromise between ensuring the clearest possible view to provide the best signal, whilst meeting relevant planning and aesthetic or environmental considerations.

Can't We Use Smaller Antennas to Reduce the Visual Impact?

Antenna dimensions are related to the radio wavelength, and this is fixed for any given service. Antenna designers are constantly striving to make smaller antennas but for a given wavelength and set of performance criteria, there is a limit to how small the antennas can be. Given the current state of technology, the antennas in use today are probably as small as they can be. In general, antennas for macrocells are the largest, while those for small cells, such as microcells and especially picocells, are much smaller.

It is also important to remember that antennas on large, free-standing mast structures, such as those found by the side of motorways or on industrial estates, represent only about a third of mobile base station sites. Mobile networks are made up of a mix of different types of infrastructure: free-standing masts, rooftop antennas, streetworks (which often resemble lamp-posts, for example), and small cells. The latter are an increasing proportion of networks, but all types will continue to be needed for the foreseeable future. The following sections explain the differences between the different types of base station, and the role each plays in providing coverage and capacity on mobile networks.

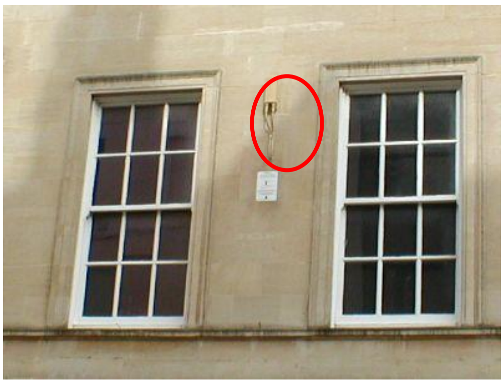
What's the Difference Between Macrocells, Microcells, Picocells and Femtocells?

Macrocell Macrocells provide the main radio coverage infrastructure for a mobile network. Antennas for macrocells are mounted on ground-based masts, rooftops and other existing structures, at a height that provides a clear view over the surrounding buildings and terrain. Macrocells provide radio coverage over varying distances, depending on antenna height, terrain, and obstructions or clutter. In an open 'green field' area with antennas at 25 - 30 metres in height, the area covered could be as much as 5 – 10 km. In an urban area, with rooftop antennas at, say, 12 metres above ground, the coverage could be only 300 – 500 metres.

The photographs below show examples of free-standing and rooftop macrocell antennas

Microcell Microcells provide 'infill' radio coverage and additional capacity where there are high numbers of users ('hotspots') covered by urban and suburban macrocells: each base station can only handle a finite amount of traffic at any one time, and so additional base stations are needed in areas that experience high demand. The antennas for microcells are generally mounted at street level (i.e. below the height of surrounding buildings and terrain) typically on the external walls of existing structures, lamp-posts and other street furniture. Microcell antennas are not a replacement for or alternative to macrocells, as they perform a different function. They are much smaller than macrocell antennas, and can often be painted and sited in such a way as to blend in with the surrounding environment. Microcells typically provide radio coverage over distances - depending on antenna height and street clutter – of around 100 metres. Many microcell antenna systems do not have a material effect on the external appearance of the building on which they are installed, so will not fall within the legal definition of 'development': many will be covered by the principle of 'de minimis' in planning terms. Most conventional television aerials and their mountings or poles have long been treated this way.

The photograph below shows an example of a microcell antenna



Picocell Picocells provide more localised coverage than microcells, inside buildings where coverage is poor, or where there are high numbers of users. They are served by very small, discreet antennas within the building. As with microcells, picocells should not be seen as a replacement for macrocell sites.

An example of picocell providing indoor coverage

Femtocell-Indoor An indoor femtocell is a small base station, about the size of a laptop PC, with an integral antenna. It is designed to provide very localised coverage within a building – typically a house but possibly a small business – and is usually connected into the mobile network via the user's broadband connection.

An indoor femtocell

Femtocell- Outdoor

An outdoor femtocell is a small base station, providing localised area coverage over a greater area and to more users than an indoor femtocell. Outdoor femtocells are typically used to provide a signal in areas which traditional mobile coverage has been unable to reach. A number of outdoor femtocells would be placed at several locations across a rural village. The units, about the size of a small carry on suitcase, use existing broadband services to deliver a mobile signal. Outdoor femtocells should not be seen as a replacement for macro sites.

The photograph below shows an example of an outdoor femtocell

Why Do We Need So Many Radio Base Stations (Cell Sites)? And Why Do We Need New Sites - Why Not Just Upgrade Existing Sites?

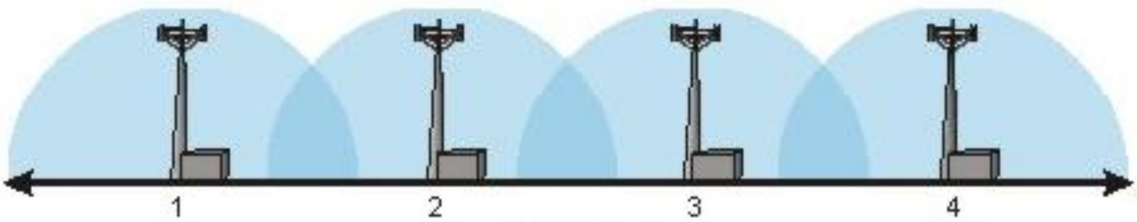
There are various reasons that can lead to the need for new cell sites. Two main ones are the need for additional coverage and capacity. Other factors that can lead to the need for new sites include the introduction of new technologies and services; new property developments in an area requiring new coverage or additional capacity; or redevelopment of an area requiring existing sites to be replaced.

Coverage

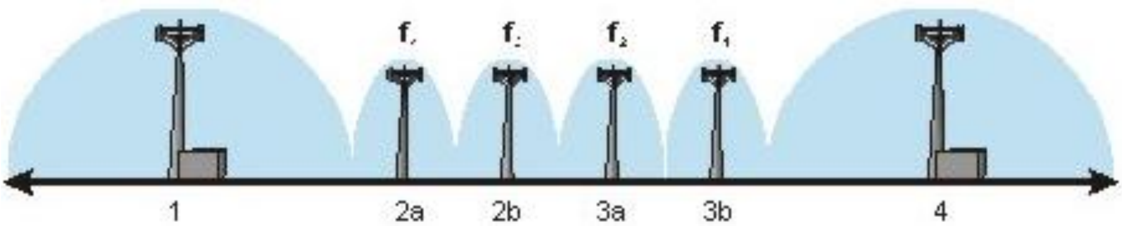
Base stations are sited to maximise coverage to a locality. A base station covers a limited geographic area, and needs to be sited where there is customer demand for connectivity. Mobile services use a range of different frequencies on the radio spectrum, and the frequency used on a particular base station will have an impact on the size of the area covered by that base station. As outlined above, each base station, depending on type and location, may cover areas ranging from a few tens or hundreds of metres in urban or suburban areas, up to several kilometres in open rural areas. In general, a greater number of sites will be needed to support urban areas than rural areas.

Capacity

Each base station has a finite capacity to handle the traffic generated by users of mobile devices. The number of voice calls or text messages each base station can handle at any one time is much greater than the number of mobile connections used to access data, i.e. the Internet, and especially the number of users downloading video. In recent years, the greatest growth in mobile traffic has been in data, and this trend is projected to continue to grow, some of this is driven by the increasing demand for mobile access to social networking such as Facebook and Twitter, and streaming video such as YouTube. Not all of this is ‘recreational’ use, as these media are now widely used by charities in awareness-raising or fundraising campaigns. Good data capacity on mobile networks also supports the delivery of public services, such as telehealth. This is especially important in rural areas, partly because of the long physical distances between patients and specialist healthcare services in particular, and partly because mobile broadband is often more cost-effective to deploy than fixed-line in rural areas. The capacity of existing sites can, in some cases, be increased, but there is a limit to this and once this is reached it becomes necessary to split each cell into smaller areas, each served by its own base station. In the example shown below, sites ‘2’ and ‘3’ are split, so that four sites now cover the area previously served by two, thus doubling capacity in that locality. Typically, this might happen in areas where many mobile users congregate, such as shopping malls or railway stations.



Before Cell Splitting



Sites 2 and 3 Split for Greater Capacity

New Technologies and Services

As outlined above, the coverage offered by a base station depends on many factors such as antenna height and the surrounding terrain and clutter. Radio coverage also depends on the radio frequency in use. Mobile networks operate on a range of frequencies. The higher the radio frequency, the less distance the signal will travel. So when a new service using a higher frequency is deployed, a network operator will not necessarily be able to provide coverage using existing sites and will need additional sites to infill the gaps.

Property and Area Development

Existing base stations will generally have been strategically located to cater for the perceived or anticipated demand for services at that time they were built. Additional base stations are therefore likely to be required when subsequent residential or commercial developments take place, creating new demand in new areas.

Replacement of Sites

Many base stations are mounted on existing structures such as buildings or water towers. When one of these is to be demolished or redeveloped, the base station will need to be decommissioned, and a replacement site found nearby. This can also happen with free-standing masts, if the land on which they are sited is to be redeveloped for building, infrastructure, or other development, again requiring a replacement site to be found.

Conclusion

This guide is not intended to be comprehensive, in the sense that it could explain the siting of every single mobile base station in the country – nor could it be. However, what it aims to do is to illustrate the general principles that govern these decisions.

As we have seen different factors, such as extending *coverage* - or expanding *capacity* in an area where there is already coverage - may drive the need for new base stations, and this, in turn, will determine the type of installation required to meet demand. It has also explained that mobile signals use radio waves, and there are a number of factors that affect radio signals: 'shadowing', 'attenuation', 'diffraction', and 'reflection'. It will often be the case that in a particular place, operators will need to take into account two or more of these factors in combination – it will rarely be the case that there is a 'perfect' location for the base station; rather that there will be some potentially viable options, both from a technical perspective, given the local topography and built environment, and taking into account relevant planning policy and guidance. Ultimately, however, without the infrastructure on which networks rely, there will be no service.

Glossary

This glossary covers terms used in this paper, and also some other technical terms that might commonly be encountered when discussing mobile networks.

2G
2G, the second generation or GSM, was the first digital technology used in the operation of mobile phones. It was introduced in the early 1990s, replacing earlier first generation analogue technology, and enabled mobile access to some data services, such as email.

3G
3G, or third generation, is the generic term used for the mobile communications systems first introduced in the UK in 2002. 3G allows multimedia and internet access and the ability to view video footage, as well as the voice and text messaging provided by 2G. The third generation technology used in the UK is called UMTS.

4G
4G, or fourth generation, is the successor to 3G and 2G. It delivers significantly faster mobile broadband services – approaching today's ADSL home broadband speeds – and thus support a wide range of data services. 4G is sometimes also referred to as 'LTE' (see below).

Antenna
A device that transmits and receives radio waves. There are different designs in operation including omni-directional antennas, sectored antennas and dual/triband antennas.

Analogue
First mobile phone technology, which was phased out in the UK in 2001 with the introduction of second generation technology (GSM).

Base Station
A base station is a macrocell, microcell, picocell or femtocell site and consists of radio transmitters and receivers

Cabin/Cabinet
A structure that protects radio transmitters and receivers from damage. They can be in the form of large cabins or smaller cabinets.

Cell
A geographic area over which a radio base station transmits and receives radio signals to and from customers to provide service coverage.

Dish Antenna
Dish antennas operate on a line of sight basis and transmit and receive highly focussed low powered radio waves in one direction. Dish antennas usually have the function of linking a base station, sometimes through a series of links, to a base station control site. It is often by this means that a base station is integrated into the

wider network, although alternatively, many base stations may integrated into the network by connecting cables.

Electromagnetic Waves/Fields
Electromagnetic waves are emitted by many natural and man-made sources. Electromagnetic waves are used to transmit and receive signals from mobiles phones and their base stations. The type of electromagnetic waves mobile phones use is called radio frequency waves/fields.

Feeder Cable
The co-axial cable that connects an antenna to a base station transmitter or receiver.

Femtocell
A femtocell is a small base station. Indoor femtocells allow mobile phone users to make calls inside their homes via their Internet broadband connection. The base station tends to be of the size and appearance of a typical Wi-Fi router used in homes to connect a computer wirelessly to the Internet. It is a plug and play device that allows a mobile phone subscriber to use their mobile phone to make voice and data calls via their broadband connection to their mobile phone provider’s phone network. Outdoor femtocells provide localised area coverage over a greater area and to more users than indoor femtocells. They are typically used to provide a signal in areas which traditional mobile coverage has been unable to reach. A number of outdoor femtocells would be placed at several locations across a rural village. The units, about the size of a small carry on suitcase, use existing broadband services to deliver a mobile signal. Femtocells should not be seen as a replacement for macro sites.

Fourth Generation
See 4G.

Frequency
Frequency is the number of times per second at which an electromagnetic wave oscillates. It determines the wave’s properties and usage. Frequencies are measured in hertz (Hz). 1 Hz is one oscillation per second, 1 kHz a thousand, 1 MHz is a million and 1 GHz is a thousand million. Frequencies between 30 kHz and 300 GHz are widely used for telecommunication, including broadcast radio and television, and comprise the radio frequency band. Mobile telephone systems currently operate at between 800 MHz and 2600 MHz.

GSM
GSM - Global System for Mobile Communications is the international, pan-European operating standard for the current generation of digital cellular mobile communications. It enables mobile phones to be used across national boundaries.

Hand-off
As a mobile customer moves from one cell to another the call is automatically transferred from one base station to another in a process known as hand-off.

International Commission on Non-Ionizing Radiation Protection
Is an independent scientific body that has produced an international set of guidelines for public exposure to radio frequency waves. The Government has adopted these guidelines, and all mobile network base stations operate within them.

LTE
Long Term Evolution (LTE) was the next step from 3G technology, and delivers very fast data speeds of up to 100 Mb/s downlink and 50 Mb/s uplink (peak rates), and is compatible with existing GSM networks. LTE is sometimes also referred to as '4G' (see above) and in practice, there is little difference between the two.

Macrocell
A macrocell provides the largest area of coverage within a mobile network. The antennas for macrocells can be mounted on ground-based masts, rooftops or other existing structures. They must be positioned at a height that is not obstructed by terrain or buildings. Macrocells provide radio coverage over varying distances depending on the frequency used, the number of calls made and the physical terrain. Macrocell base stations have a typical power output in tens of watts.

Mast
A ground-based or rooftop structure that supports antennas at a height where they can satisfactorily send and receive radio waves. Typical masts are of steel lattice or tubular steel construction. New slimmer versions of masts are now available which can be painted to blend in with their surroundings, disguised as trees or telegraph poles or used in conjunction with street lighting and CCTV cameras. Masts themselves play no part in the transmission of the radio waves for mobile telecommunications.

Microcell
Microcells provide additional coverage and capacity where there are high numbers of users within urban and suburban macrocells. The antennas for microcells are mounted at street level, typically on the external walls of existing structures, lamp-posts and other street furniture. Microcell antennas are usually smaller than macrocell antennas and when mounted on existing structures can often by blended into building features. Microcells provide radio coverage over distances, typically around 100 metres, and operate at power levels substantially below those of macrocells. Microcells should not be seen as a replacement for macro sites.

Mobile Network Operators
Mobile Network Operator means a firm that owns both mobile network infrastructure and is licensed by Ofcom, under section 1(1) of the Wireless Telegraphy Act 1949, to hold spectrum and for the purpose of providing a public phone network using a radio link. There are currently four Mobile Network Operators in the UK – EE (formerly Orange, & T-Mobile in the UK) Telefónica UK, Three UK, and Vodafone.

Mobile Switching Centre
All base stations have to be linked to a Mobile Switching Centre, which will have a significant number of radio dishes linked by direct line of sight to outlying base stations. These can be installed on large radio masts or on buildings. The Mobile Switching Centre integrates each base station into the network and enables the calls

to be connected within the same or a competing network. The Mobile Switching Centre also controls the handing off process as customers move from one cell to another.

Picocell
A picocell provides more localised coverage than a microcell. These are normally found inside buildings where coverage is poor or there are a high number of users such as airport terminals, train stations or shopping centres. Picocells should not be seen as a replacement for macro sites.

Pole Mounts
Roof mounted supports normally between 4 – 6 metres in height from the base of the roof, used to affix a combination of sector and dish antennas and unlike a stub mast (see below), used in series to provide 360 degree coverage in sectors.

Radio Base Station
See base station.

Second Generation
See 2G.

Sectored Antenna
Antenna which transmits or receives higher signal levels in a horizontal direction. The antenna is split into several sectors (typically 3 or 6) to provide 360 degree coverage.

Small Cell
Small cell is a catch-all term covering a variety of small base stations, such as femto-cells, microcells, and picocells.

Stub Mast
A roof-mounted mast structure that supports multiple antennas at a height where it can satisfactorily send and receive radio waves. A stub mast is typically 4 – 6 metres high and of steel lattice construction. Stub masts themselves play no part in the transmission of radio waves.

Third Generation
See 3G.

Transmitter
Electronic equipment that generates radio frequency electromagnetic energy and is connected to an antenna via a feeder cable.

UMTS
Universal Mobile Telecommunication System (UMTS) is part of the international vision of a global family of third generation mobile communication systems. The UK refers to this as 3G.

Wavelength

Wavelength is the distance in metres between any two ‘similar’ points on a radio wave. This portion of the wave is referred to as one complete cycle. The lower the frequency of a wave, the longer the wavelength.