Department for Digital, Culture, Media & Sport

5G

FIFTH GENERATION MOBILE COMMUNICATIONS

5G Planning – geospatial considerations

A guide for planners and local authorities

For Department for Digital, Culture, Media and Sport
February 2018

Ordnance Survey

Acknowledgements

This document has been developed by Ordnance Survey following joint research with Surrey Universities 5GIC department, The Met Office and Bournemouth University investigating the effect of the built and natural environment on high frequency radio waves transmission. Further guidance in creating this report has been provided by The Department for Digital Culture Media and Sport.

Contents

1 Intended Audience

This document is for telecommunications network planners deploying mmwave sites and Local Authorities considering 5G mmwave technology.

The contents of this document are restricted to the UK market as we refer specifically to UK National mapping data provided by Ordnance Survey; OS MasterMap (OSMM). However, the principles defined in this document can be applied to any country to inform 5G planning scenarios across the world.

1.1 Assumptions & definitions

A key assumption is the planning authority will be making use of a recognised network planning tool that can work with OSMM. This is because this document introduces the concept of new objects not covered within the standard mapping specification, but which can be integrated to provide a realistic representation of the chosen area of interest.

When we refer to the term 'site', we mean the location of the radio antennae's. A full glossary of terms used in this document can be found in Annex A - Glossary.

Licencing of spectrum is controlled by Ofcom. It is assumed that solutions will be targeting mmwave technology for use in dense urban areas and radio technologies operating at frequencies in the 26GHz band. We anticipate Ofcom supporting the use of this frequency.

Large and less dense coverage areas are likely to use lower frequencies being considered for 5G; 700MHz and 3.5GHZ. This document does not discuss planning for these.

2 Purpose of document

This document focuses on how the geo-spatial environment (man-made and natural) impacts the propagation of mmwave signals and what network planners and local authorities need to consider when planning a new network. It aims to provide a comprehensive approach to help assess the environment being considered for deployment, identifying which geo-spatial features are important to consider, how to identify them and, where new features need to be captured, which techniques and associated indicative costs may be involved to assist planners in budgeting.

3 Background

5G is the fifth generation of mobile communication technologies. 5G is not yet fully developed, with early standards only due to be agreed in 2019 and incremental deployment expected over the following decade. However, its expected to deliver a step change of ultrafast, low latency (i.e. quicker reaction times), reliable, mobile connectivity, that is able to support ever larger data requirements, as well as wide-ranging new applications. We refer to these applications as 'use cases'. These use cases might include autonomous vehicles; advanced manufacturing and robotics; augmented reality; smart agriculture; and smart homes and cities. 5G is not simply about faster internet connections.

It is generally expected that 5G will ultimately deliver the following range of capabilities:

- enhanced mobile broadband connections
- massive machine-type communications - between intelligent machines that require no human input (e.g. advanced manufacturing)

- ultra-reliable and low latency communications (i.e. communication services which are available nearly 100% of the time)

As part of this, additional frequencies are being allocated to open new spectrum over which communications can take place. Frequencies in the 26GHz and 28GHz spectrum are candidates for use in areas of high density and footfall and are referred to in this document as mmwave frequencies.

Radio signals at all frequencies are affected by the surroundings of buildings, vegetation and material types to a greater or lesser extent but the effects are much more noticeable at mmwave frequencies to the point where signals can be stopped or heavily reduced when operating under certain circumstances.

4 Top level principles

While it is understood signals can degrade (experience "loss") as outlined above, in a real-world environment, the effect of objects potentially blocking or reducing the signal may not be as dramatic as suggested and depends on the circumstances in which mmwaves are being used. However, this does not mean all currently un-mapped objects can be ignored and it will be necessary to consider certain new objects as part of the planning exercise. The following sections of this document aim to help guide how these can be assessed.

5 Planning Approach

Why do we need to plan our radio networks? Surely, we can deploy as many antennae as we see fit to cover a specific area and provide the capacity needed? A major factor to be considered is cost, and good planning will at least consider three elements, capacity, coverage and cost of deployment. Figure 5-1

Determining the 'sweet spot' will be based on the specific use case(s) that are to be addressed. For example, if there is a location where large crowds gather frequently, and access is limited for emergency services, you might consider ensuring there is more coverage and capacity made available than would normally be required. i.e. building in redundancy but, at a cost.

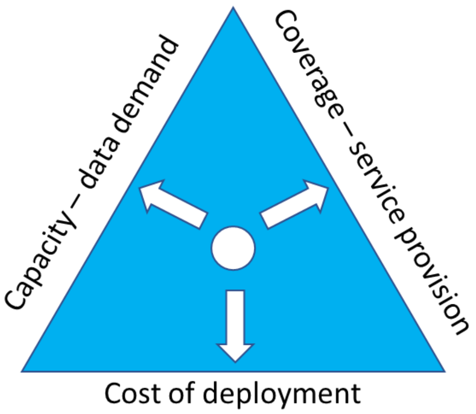


Figure 5-1 Cost, Capacity and Coverage trade off

Capacity may be a major factor to ensure reliable communications where as in other situations broad coverage with limited capacity may be better for areas of lower footfall on for example the periphery of city centres.

Budgetary constraints will always come into play and with the relative high cost of the radio equipment it may be both capacity and coverage need to be compromised. Planning your 'use case' must therefore consider all three components to determine an optimum solution.

The simple flowchart (

Figure 5-2) below, shows a process of determining how you might go about planning your 5G network and considers the three candidate frequencies of 700MZ, 3.6GHz and 26GHz.

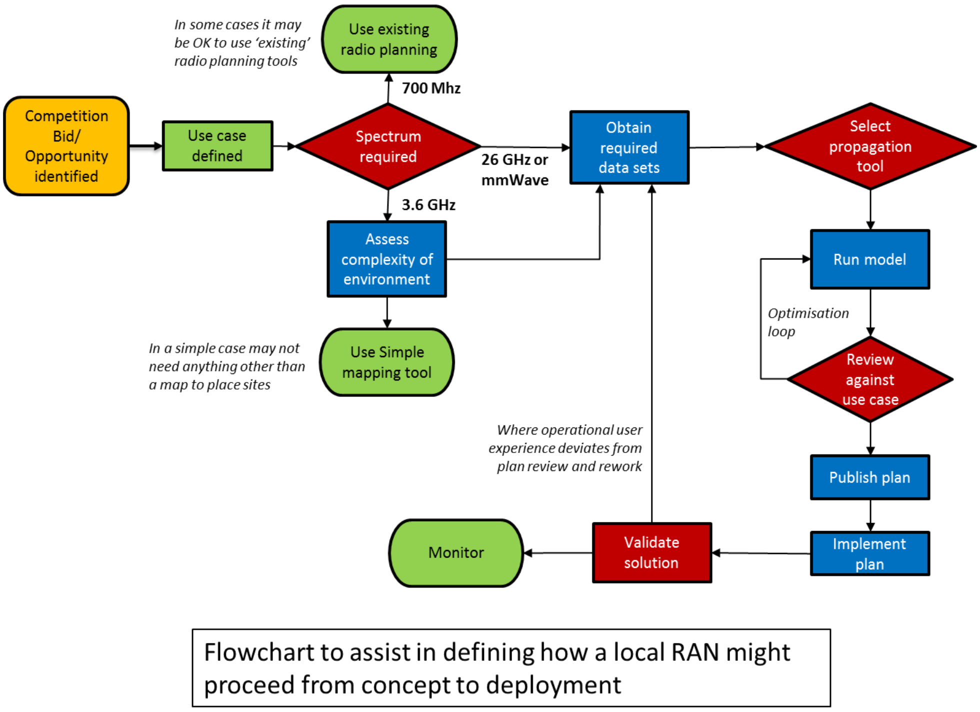


Figure 5-2 Network planning flowchart

Working left to right, an opportunity will be identified to exploit 5G communications either in response to a bid, competition or self-instigated. The use case will then be determined (see section 6) and depending on that use case you will then identify the spectrum requirements. If the spectrum is at 700MHz, then existing radio planning tools can be deployed. If the spectrum is 3.6GHz then it will be necessary to assess the complexity of the physical environment as there will be some impact by objects and materials, but the complexities associated with higher frequency (26GHz) operation are unlikely to be significant. It would be recommended to consider the complexity before deciding to gather additional data. In most cases planning can take place using simple tools based on mapping and terrain data. This will allow you to identify and plan suitable sites.

For the higher frequencies (26GHz) additional data will need to be acquired (see section 7) and used to inform a suitable planning tool. Having gathered the required data, the model can be run and reviewed against the use case requirements and optimised. Once satisfactory, the plan can be published, implemented by chosen suppliers and validated through measurement either by running site tests with mobile equipment or once the network is deployed.

As the world is a dynamic environment, care needs to be taken to monitor change and where necessary re-model as these changes occur or as the use cases develop further.

6 Defining the use case

Key to conducting the planning is knowing the area you wish to deploy and the type of connectivity demand you are trying to fulfil. This will be defined and documented in one or more of the 'use cases'.

6.1 Where do you wish to deploy?

Typically, mmwave is designed to cover specific geographic areas which tend to have a dense infrastructure and potential high demand. When thinking about the types of area to be considered as candidates for mmwave coverage, these as we will see later are typically transport hubs, paved pedestrian areas, waterfront developments, shopping malls, stadia and small-town centres.

Through observation, these areas are typically between 0.5 Km^2 – 1.5Km^2 although the precise area to be covered will depend on the specific use case. In a large City it would be fair to say that the area to be covered will be vastly bigger, but it is likely that any rollout would be done in phases, targeting the most critical areas first. Each of these areas could be planned individually as part of a programme and therefore broken down into perhaps 1.5km areas or less. Rail and road present different challenges as these will tend to focus on linear coverage which may only serve these network links for perhaps connected autonomous vehicle use or train communications. Different planning approaches and models would apply which are not discussed in this document.

The locations depicted below in Figure 6-2 and Figure 6-1 represent similar areas (about 1.5 Km^2) but as can be clearly seen the density of buildings are considerably greater in the urban area and radio coverage would be more challenging on this environment; requiring more sites and more cost.

Figure 6-2 Dense Urban area

Figure 6-1 Sparsely populate rural area

A new mmwave network can be provided to serve several demands be they for consumer communication using mobile devices or for machine communications such as connected autonomous vehicles, virtual reality, real-time diagnosis and drug administration.

In the case of consumer mobile devices, we need to identify the locations to be served which could be based on; meeting demand to provide a better service to business users in cities, business parks, busy retail and residential areas. It may be that the service is provided to improve reliability and quality of service at locations where health and safety may be paramount. It could simply be that the goal is to provide better communications at busy locations where crowds gather such as transport hubs, stadia and tourist hot spots.

Mmwave communication is not just aimed at the consumer. mmwave communications will also be used for a range of services in addition to consumer mobile applications. These include the increasing array of sensor technologies and the growth of autonomous vehicles all of which will have different demands on the features that mmwave offers. For example, the Internet of Things (IoT) creates a market for any device to be connected to a radio network ranging from a simple flood sensor through to complex machinery. The growth of these devices will be rapid and the demands on bandwidth, coverage and reliability high. In the example of Autonomous Vehicles also referred to as Connected Autonomous Vehicles (CAV), vehicle movement in a public environment creates safety challenges where a highly responsive, reliable, and ubiquitous communication service is required. Network planning needs to be thorough and rigorous to ensure safety criteria can be met. Deploying redundant technology and integrating with other sensing and machine learning technologies is likely to be mandatory in this case.

6.2 What demand are you trying to fulfil?

Having identified an area of interest, the network capacity must be considered. For example; the area of interest may be a transport hub such as a railway station or coach station. The volume of people visiting that area will vary daily and seasonally and perhaps experience peaks of demand during times of special events or when other transport services may be compromised.

When planning you should consider what level of service you are prepared to offer versus the demand. You may choose to plan for maximum capacity throughout the year or, perhaps consider a skewed average. The major considerations being:

- How critical is the service (all things considered)?
- How much will it cost to deliver that service?

There is always a trade-off here. Providing 100% coverage and maximum capacity all the time may be great for the consumer but if the demand is low, then additional sites may have been unnecessarily deployed at additional cost.

In determining demand, you may draw on many sources of data (see section10 for further details).

Accessing this information is not always easy, reliable, or in a usable format but will significantly assist in determining the capacity and coverage required and the challenges being presented.

Determining capacity also depends not only on volumes of users, be they people or machines but the type of information they are expecting to exchange over the 5G network. For example, there may be many thousands of commuters simply exchanging SMS type data during a commute but, when this is compared to downloading video information at a stadium event or using AR, the data volumes will be significantly greater.

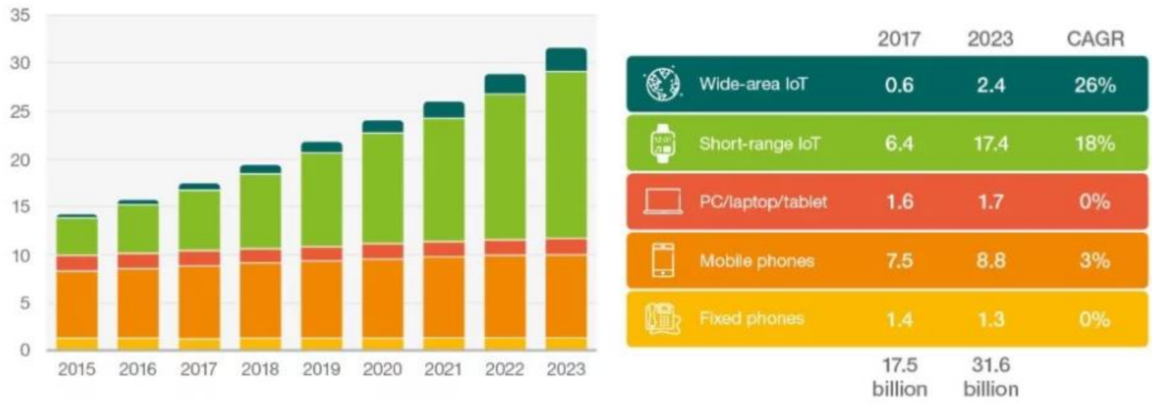
Internet of things (IoT) devices are considered are most likely to send and receive small packets of data, e.g. a change in water level for flood monitoring or a frequent feed of air pollution data. In these examples each device does not demand high speed communications, high bandwidth or low latency but as more and more of these devices become available the sheer volumes of devices anticipated will soon demand the greater bandwidth which 5G offers.

One estimate[1] from Ericsson predicts:

"By 2023, over 30 billion connected devices[1] are forecast, of which around 20 billion will be related to the IoT. Connected IoT devices include connected cars, machines, meters, sensors, point-of-sale terminals, consumer electronics[2] and wearables. Between 2017 and 2023, connected IoT devices are expected to increase at a CAGR of 19 percent, driven by new use cases and affordability."

---

[1] Ericsson IoT predictions



Ericsson Mobility Report November 2017

Connected autonomous vehicles will become highly dependent on reliable fast communications to react to the real-world environment. Safety alone will be a key driver and ensuring full uninterrupted coverage, capacity and low latency in a specific location is crucial. Reliable planning of a network to achieve this is a must. The UK Government have issued a comprehensive report on the growth of CAV some key conclusions from this report are:

- In the UK, L3-L5[2] CAVs account for 31% of total annual sales by 2035, equating to vehicle sales of 1.1 million CAVs (including cars, vans, HGVs and buses).
- UK CAV demand is ahead of the rest of Europe, with L3-L5 CAVs accounting for 58% of total sales by 2035, equating to 2.1 million vehicles.
- UK CAV sales result in a projected domestic market size of £28bn in 2035 for the central scenario, with a market size of £2.7bn for CAV technologies.

Similarly, Augmented Reality (AR and Virtual Reality (VR) are becoming more popular in the market place initially in gaming but more recently as tools to assist in for example, improved tourist experiences, remote medical diagnosis, real-time training experiences. Many more use cases are expected to be developed using this technology over time.

In summary, the demand for 5G will accelerate in the next 5 years with growth continuing well in to the late 20’s. Planning ahead to deliver a robust and ubiquitous communication infrastructure early on in this journey will be essential to provide the necessary foundations for these emerging technologies.

[2] L3/4/5 refers to the Level of vehicle automation as defined by SAE International Standard J3016

7 Planning scenarios

7.1 Overview

Before you can plan your network, you need to understand the three-dimensional spatial environment that your service will operate in. i.e. what objects exist that may affect the signals and ultimately where you choose to site antennae.

7.2 Static features

mmwave signals are affected by objects in their path, buildings, monuments, statues and bus shelters to name a few. Within the UK, Ordnance Survey provide detailed mapping of many of the objects that will have an affect but not all objects as these do not form part of the OS Mastermap specification. Consideration must be given to these additional objects Figure 7-1of significance Figure 7-1 and, although not exhaustive, will include:

- High walls
- High railings
- Smaller statues and monuments
- Bus stops and shelters
- Street Telecoms cabinets
- Large bill boards
- Temporary buildings (not on the map – e.g. portacabins™)
- Seasonal objects such as Decorations or temporary horticultural exhibits
- Small trees
- Large trees and tall hedges

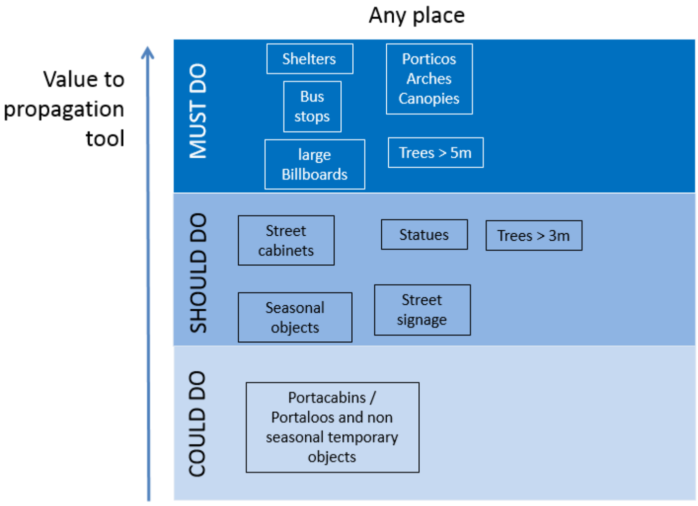


Figure 7-1 Additional geo-spatial features for consideration

Evidence from the project work conducted alongside Surrey University 5GIC and MetOffice identified that any object over 10cm should, be considered when planning your network. This implies that mapping of these objects must be done at 10cm resolution or better for best results. In practice this may not always be necessary for every use case as we will see.

The example diagram of Figure 7-1 places typical objects on a chart relative to their importance **(value to propagation tool)** in terms of ensuring these are captured when planning the mmwave network.

Must do implies these objects will have a significant impact on the propagation of mmwave signals and therefore must be captured through some form of survey.

Should do implies these objects are likely to provide additional value and are worth considering whilst surveying other objects. Depending on the use case they may benefit the planning to a greater or lesser extent. For example, there may be some street signs that are of reasonable size and due to their specific location could influence propagation. Conversely, Telecom street cabinets are useful to capture from a planning perspective if you wish to know where connections to fibre can be obtained. However, they have a limited impact on the propagation model.

Could do is really the 'nice to have'. Some objects will be known to influence propagation but in the overall scheme of things and the environment to be served, these features will not make a significant difference to the prorogation model. However, if surveys are being conducted by third party techniques then to ensure value for money it might be worth capturing these additional objects, perhaps for other uses such as maintenance.

7.2.1 Resolution of data capture

We have identified that any object over 10cm will influence mmwave propagation but depending on the use case being fulfilled, this effect may or may not be important. For example, in the case of CaV deployment ubiquitous and reliable coverage may be essential for safety reasons so a full understanding of the signal propagation is critical. This implies that any data capture for new objects must be surveyed at 10cm resolution or better. If for example the use case is to provide service to mobile devices (handsets) as the user will most likely be moving, the probability of losing a connection is very low and it may be that objects less than 0.5m can be ignored. If this is the case, then survey could be conducted in line with Ordnance Survey standard resolution of 0.4m. There are no hard and fast rules around this, particularly when you consider the dynamic environment, building material types and, the modelling tools to be employed.

Establishing the best resolution can result in some complex decision making and if there is any doubt then 10cm resolution data capture is recommended.

In chapter 8 we will provide simple guidance as to what resolution should be used. This will be indicated by symbology as shown below:

OR

7.3 Building Material types

Materials used in the construction of buildings and other objects can have a profound effect as to whether the signal will get through (propagate). For example, a building clad in a fine metal mesh Figure 7-2 would present a challenge for good signal propagation as this will both reflect and scatter signals.

Figure 7-2 Fine metal mesh on building surface

Your microwave oven at home has a metal mesh on the front door to deliberately stop microwaves from escaping the oven! That keeps us safe from high power radiation but is not good for propagation of low power 5G radio communications.

Other materials also have different effects on propagation and a number called its permittivity is assigned to each material type which allows calculations to be undertaken to determine just how much a signal will be able to propagate.

These effects may become important in certain environments and need to be considered when planning radio networks. Good radio planning tools will incorporate these critical factors in their calculations.

Given the need to identify these objects and potentially complex material types, it is therefore necessary to survey the area of interest to identify whether any of these potential 'blocking' or signal reducing objects and surfaces exist. The term 'survey' does not automatically imply full detailed street survey using highly specialised equipment. Each area must be assessed on their individual circumstances and against use case requirements to determine the best approach to be adopted.

It may be that there are only a small of objects identified that do not fall within Ordnance Survey Standard mapping and it may be possible to survey those objects using basic manual techniques to capture location, width, breadth, height and circumference. Some local authorities may have the skills and capacity to undertake this themselves or may have already captured some of these objects within their local plans.

In section 8 Scenario planning and object identification, the simple matrix in *(Figure 7-1 Additional geo-spatial features for consideration)* is reproduced to act as guide to identify features and their relative importance applicable for each scenario.

7.4 Site (antenna) locations and the role of the lamp post

Whilst this document is focused on the impact of objects and how they affect radio propagation, an important aspect to consider is the location of sites. mmwave sites will need to be spaced within a few 100 metres of each other as the signal power is relatively low and reduces rapidly with distance. Therefore, with many sites, these locations need to be very cheap to rent or, ideally zero cost. To keep costs low, the generally agreed premise is public assets owned by local authorities are good candidates. In particular those which have good access to power and, connectivity to core telecoms networks through microwave of fibre links commonly referred to as the 'backhaul'.

Lamp posts and public buildings have been cited as prime candidates for sites however, a specific use case may demand deployment on other assets at additional cost. It is also interesting to note that the days of landowners charging high rents for siting of masts are numbered. Recent legislation is proposing amendments to the existing Electronic Communications Code relating to access to land which may offer greater freedoms of access see ECN Code (Access to land). Therefore, good planning to capitalise on low cost accessible assets is vital to keep deployment costs to a minimum.

7.5 Dynamic features

So far, we have considered the physical environment as a static three-dimensional world, but busy urban areas will often provide transport systems such as buses, trams, trains that will act as large metal objects blocking mmwave signals Figure 7-3. Where these transport types occur frequently, e.g. buses in Oxford street London, these are most likely to block signals from one side of the street to the other. If your use case demands ubiquitous coverage and high capacity demands, it may be reasonable to consider buses as a permanent feature (object) essentially dividing the road into two halves.

Figure 7-3 buses as a blocker

7.6 Temporal versus spatial considerations

Each environment will have a different dynamic associated with the movement and volumes of people or machines at any one time. For example, if the area of interest is one where people are moving frequently (temporal) such as along a busy street then the user may experience frequent connection switching in small cell networks without degradation of signal. For example, if we consider a feature such as a telephone box as being a potential 'blocker', because the user is passing by they are unlikely to lose signal or have perceived to have lost the signal. If, however the user stops at the telephone box for a long period of time then the signal strength may, depending on the position of the antennae, be so low that the user experiences a loss of connectivity. This is the spatial consideration. For a CAV this could without built in contingency in the technical design present a safety issue.

When planning your network, it is therefore important to consider whether you anticipate users to frequently pass by or, whether the chosen area actively encourages the user to stop; bus shelter, tourist attraction, stadium queuing for example. If this is the case, then a more detailed understanding of the physical and geographical environment will need to be considered as there will be a higher probability of encountering 'not spots' or locations where signal is too weak. Detailed mapping is likely to be required to ensure any planning tool caters for this situation.

7.7 Modelling approaches and planning tools

Network planning tools make use of well understood physics as to how radio waves propagate, and for 2G/3G/4G networks these tools will typically use simplified geo-spatial models to provide a representation of the real-world. These models have limitations at the higher frequencies being considered for mmwave as a more detailed representation of the real-world is needed. In broad terms two major approaches for modelling can be considered; statistical modelling and ray tracing.

7.7.1 Statistical modelling

Data are collected from a large body of real-world observations in specific environments (e.g. 'dense urban'). These observations are then combined into a model that can predict how signals will propagate in similar environments. These models work well in general cases at predicting coverage and capacity across a wide area, but are much less useful when considering precise placement of individual pieces of equipment (as they do not take into consideration real-world clutter or surface materials). Tools built using this approach can offer good performance on commodity hardware.

7.7.2 Ray tracing

This is a much more sophisticated approach that requires a comprehensive understanding of the real-world environment. Ideally this would include a detailed 3D model including clutter objects (e.g. street furniture) and building surface materials (e.g. glass, concrete). This technique gives a high degree of accuracy and can be beneficial in very dense urban environments where this additional information is most impactful. However, it is significantly more complex than a statistical model, requiring more capable hardware to perform successfully. It also requires data that is of a comparable level of detail to be effective, which can be expensive & difficult to capture & maintain.

When choosing a planning tool, it is worth considering the benefits and costs associated with each compared to the use case being implemented. It is recommended to discuss this with this subject with the chosen planner and tool provider.

Ordnance Survey have demonstrated experience in working with both these tool variants and have had good results from work conducted for a local authority using a model closer to that using the statistical approach. Regardless of the tool there will always be a need to capture additional data to a greater or lesser extent and this is covered in the following chapters.

8 Scenario planning and object identification

The sections below aim to assist planners in how to identify what objects may need to be considered in certain environments and how to decide whether these need to be manually surveyed for inclusion or, whether it may be more effective to request a detailed area survey using techniques such as mobile mapping. Eight scenarios are considered:

- Urban Streets and pedestrian areas
- Transport Hubs
- Retail complexes (shopping centres)
- Large event sites and stadia
- Points of Interest
- Business Districts
- Residential areas
- Small Town environments

All the pictures and associated maps show areas of approximately 1.5km^{2}, slightly larger than may normally be considered for individual coverage areas for small cell deployment but at this scale it helps understand the context of the environment and offers a good degree of legibility for this document.

8.1.1 Urban streets & Pedestrian areas

In Figure 8-1 below, we have identified a typical urban area for 5G exploitation shown by the yellow shaded area. This is a simple area to consider with wide open spaces, but identifies that there are temporary features such as street markets, hidden features such as underpasses and dynamic activity created by a busy bus route.

Figure 8-1 Typical Urban area(Aerial)

Traditional mapping of the same area Figure 8-2 provides high quality detail, but it is not easy to identify the dynamic aspects of the environment or visualise some of the subtleties of the physical environment such as the covered shopping mall underpass.

Figure 8-2 Typical Urban area (OS Mastermap)

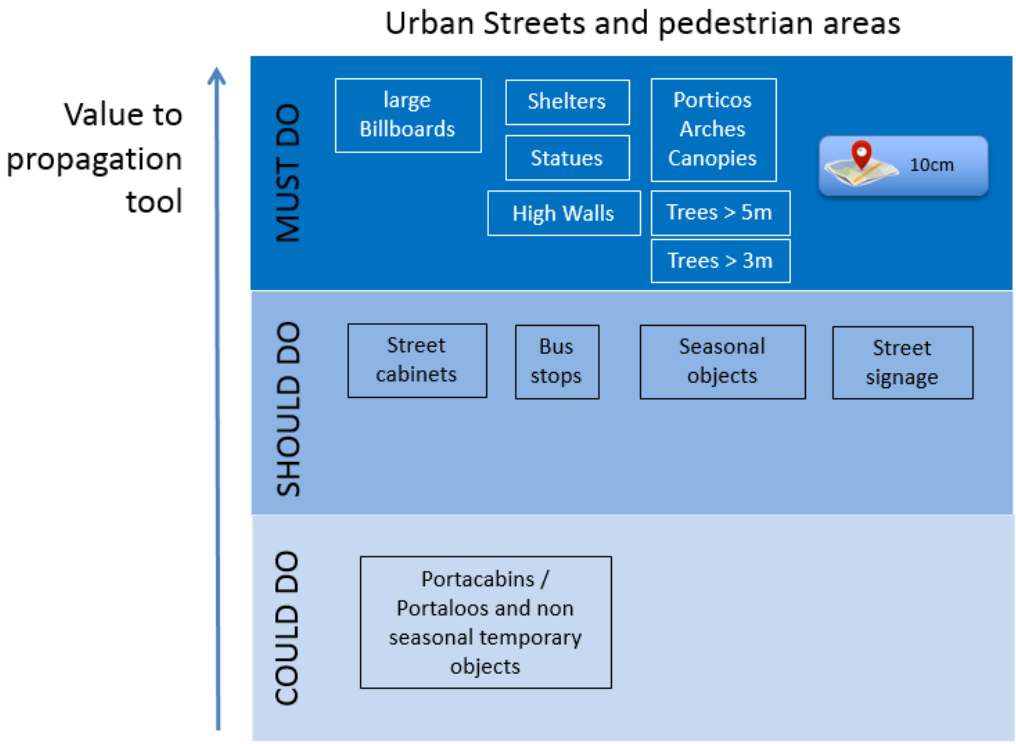
Urban streets will have a varying demand depending on time of day, specific events and season. Planners will need to consider what level of service they wish to offer whether the network should be designed for peak use or averaged over a time period. E.g. tourist and festive seasons. This decision will affect cost.

Consider whether the area has a significant traffic flow and in particular buses and lorries. If this is the case, then these are signal blockers effectively splitting the area along the path of traffic flow. A road can then be treated as two requiring sites each side of the road. Similarly, if a Metro / Tram way splits a pedestrian area then the same approach could be applied.

Next, identify any significant objects typically > 0.5m x 0.5m and, over 4m tall that do not already appear on OSMM mapping. This includes for example:

- High walls
- High railings
- Smaller statues and monuments
- Large bill boards
- Temporary buildings (not on the map – e.g. portacabins™)
- Seasonal objects such as Decorations or temporary horticultural exhibits
- Large trees and tall hedges

If any of these are constructed of metal or high-density materials such as brick or stone then these must be considered as signal blockers and added as new object to base mapping.


Urban Streets and pedestrian areas
Value to propagation tool
MUST DO
large Billboards
Shelters
Statues
Porticos Arches Canopies
10cm
High Walls
Trees > 5m
Trees > 3m
SHOULD DO
Street cabinets
Bus stops
Seasonal objects
Street signage
COULD DO
Portacabins / Portaloos and non seasonal temporary objects

8.1.2 Transport Hubs

Transport hubs include coach stations, taxi ranks, bus stations and railway stations in the picture below we have a typical City railway station.

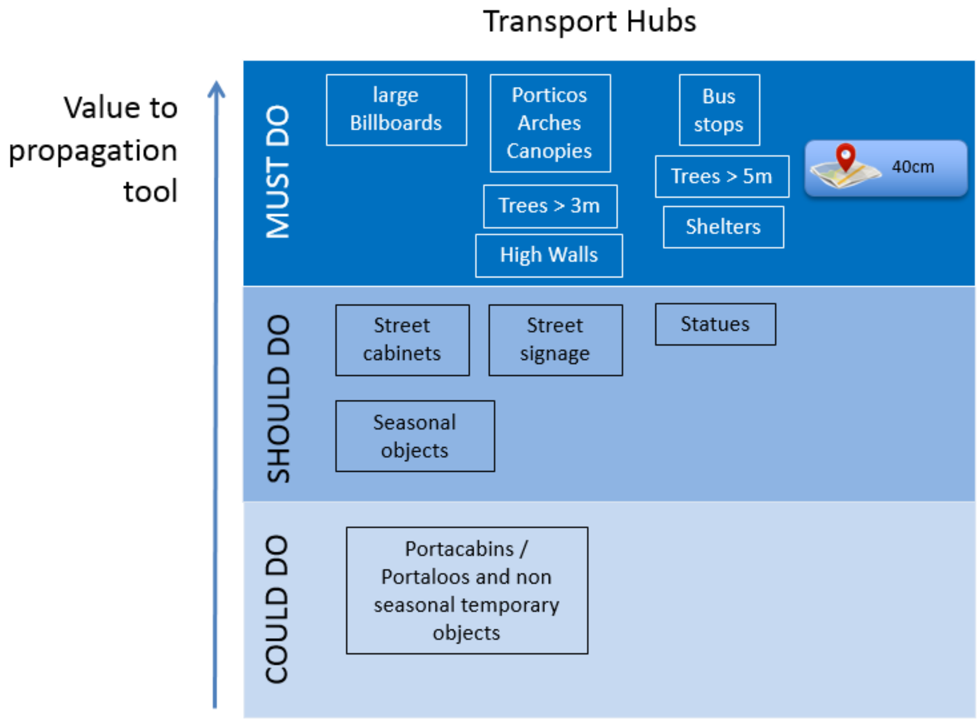
Figure 8-3Typical City Rail station

In this example the aerial imagery gives a good indication of potential volumes of people indicated by the cars in the car park although it would be expected to use ticketing information to gather more accurate information. Traditional mapping does not offer this but in this scenario, would most likely provide adequate geo-spatial information for use by a planning tool.

Figure 8-4 Typical City railway station (OS Mastermap)

Transport hubs are likely to have high footfall and high levels of communication taking place therefore the demand and capacity may be high. Usage of these hubs to determine capacity will need to be established by acquiring additional data. Consideration must be given to the object identification in 8.1.1 but more importantly in this scenario planning should consider a constant level of demand and supporting capacity.

If the transport hub serves a major stadium then regular events and commuter activity occurring at peak hours every day may require that the 'use case' offers an increased amount of capacity.



8.1.3 Retail complexes (shopping centres)

Retail complexes such as shopping centres are purpose built to serve the consumer and tend to be self-contained. In the example shown in Figure 8-5 Large retail complex we can see a large building containing retail outlets, but surrounded by pedestrian areas. In this example car parking is beneath the complex.

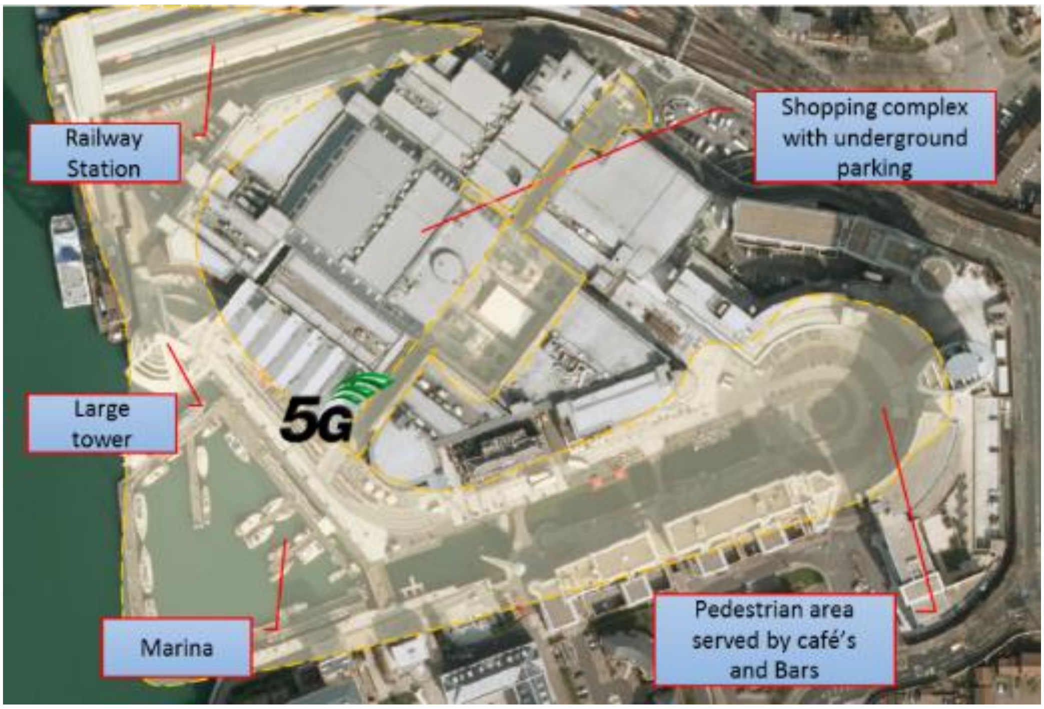


Figure 8-5 Large retail complex

Retail complexes tend to be surrounded by car parks either underground, surface or multi-storey, and often connecting to transport hubs. These developments are often made of dense material and in particular 'out of town' retail areas make use of metal warehousing construction that will present to mmwaves as signal blockers and signal reflectors. Most of the objects identified in (8.1.1) may need to be considered alongside the parking facilities especially if these are multi-storey.

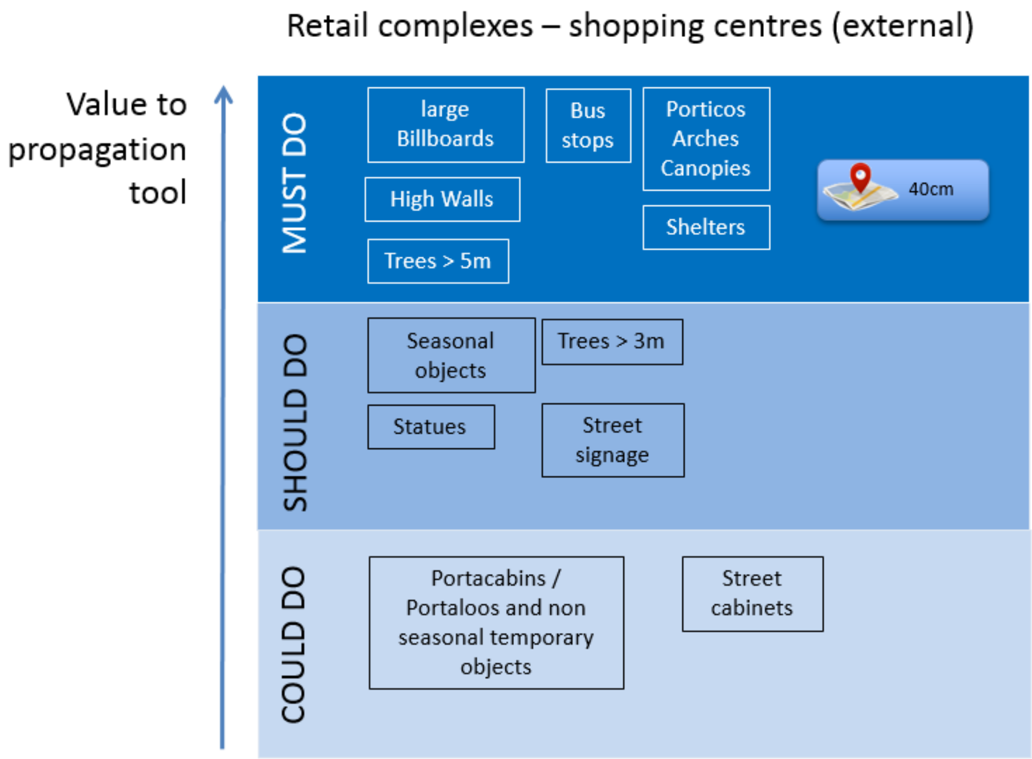
Because pedestrian flow is more tightly controlled predictions of capacity and coverage could be obtained by using anonymised retail information.

Figure 8-6 Large Retail complex (OS Mastermap)

Large complexes also present a good opportunity for the siting of antennae and if privately owned can be beneficial in providing coverage for customers as well as providing a source of revenue. Additionally, seamless integration with internal WiFi solutions will need to be considered.

In terms of the Geo-spatial considerations signage and foliage may be less of a problem than in urban pedestrianised areas but future planning may see the emergence of green spaces which could impact signal propagation. Predictions on future developments and how that may impact demand should be considered such that planning of green spaces and the effect of planting new trees is taken into consideration.

In this example the mapping Figure 8-6 provides a very good indication of the pedestrianised areas as distinct from the buildings and many features will be adequately captured. What needs to be considered in more detail is the building materials. Modern retail complexes are more likely to have detailed information about the building structure and these may be possible to obtain from the contractor. Older complexes may not have this information readily available and additional survey should be considered.


Retail complexes – shopping centres (external)
Value to propagation tool
MUST DO
large Billboards
Bus stops
Porticos Arches Canopies
High Walls
Shelters
Trees > 5m
40cm
SHOULD DO
Seasonal objects
Trees > 3m
Statues
Street signage
COULD DO
Portacabins / Portaloos and non seasonal temporary objects
Street cabinets

8.1.4 Large events and Stadia

Stadia are often less inhibited by additional geospatial features in their immediate vicinity. They are designed to allow rapid movement of large volumes of people. The infrastructure often lends itself to position antennae where good line of sight can be achieved and therefore additional survey requirements are likely to be low.

Predictions of capacity requirements can be based simply on the overall capacity of the stadium or

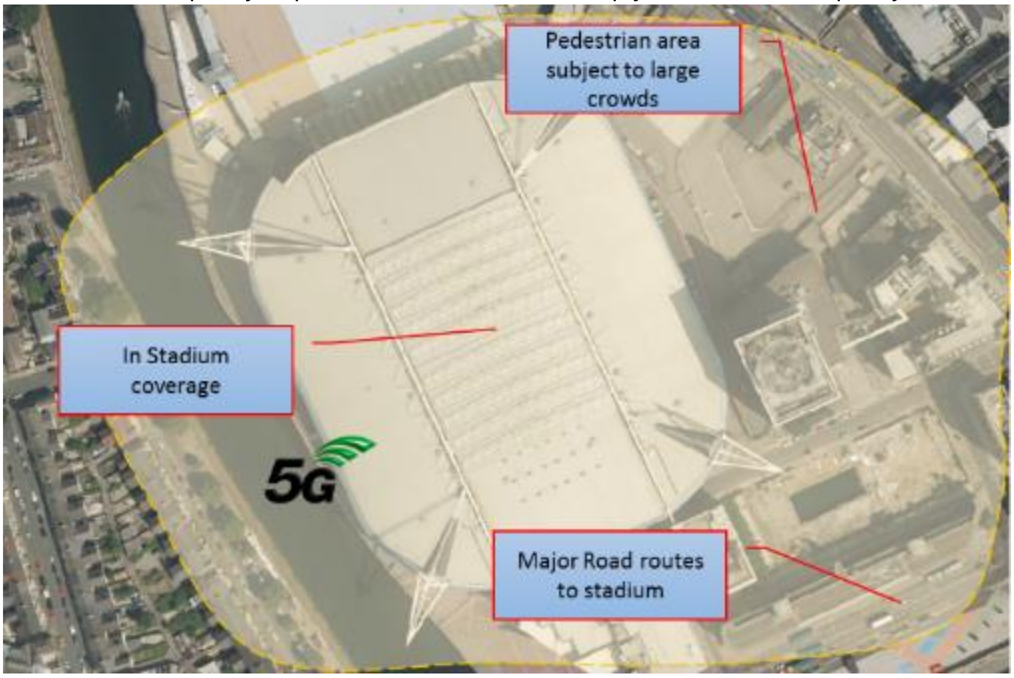


Figure 8-7 Typical sports event stadium

predictions based on, ticket sales from previous events. It is likely that demand inside and outside the stadia is high particularly when sporting events are being streamed live. Another factor that may need to be considered in time is the proliferation of virtual reality experiences associated with sporting events. These will eventually consume vast amounts of bandwidth which mmwaves will need to offer.

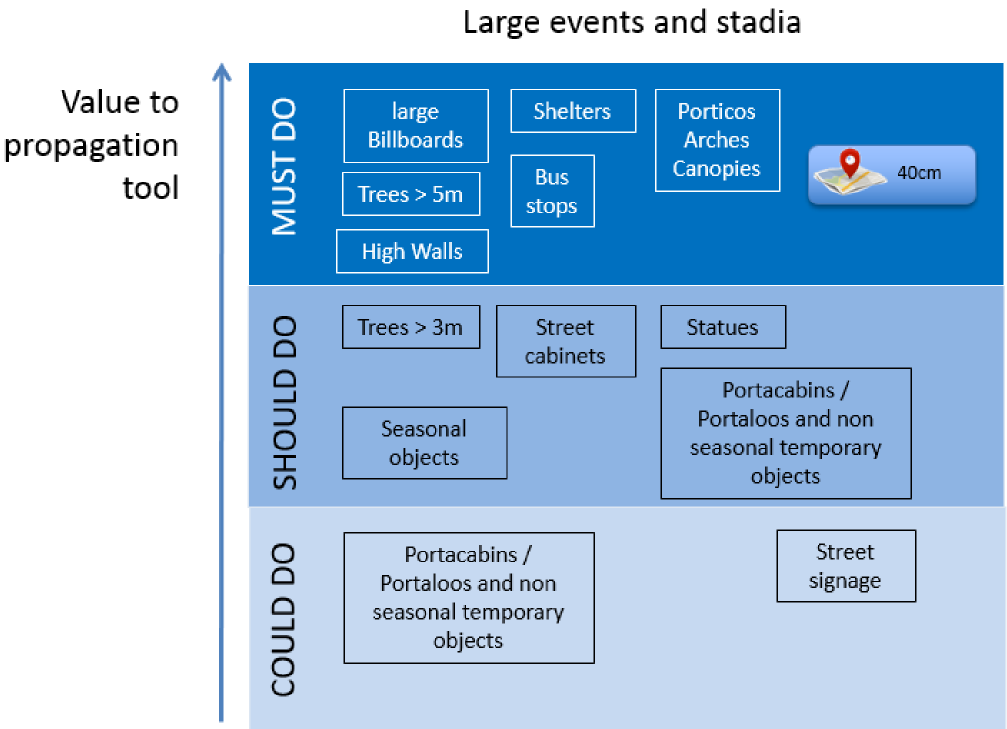
Attention will need to be given to entrances and exits as these will require a good level of service. People movement may be slow so any objects likely to interfere with these must be taken into account. Consider for example the impact of temporary signage.

As with retail complexes construction materials may need to be understood too.

The outside area presents a hybrid of a transport hub (buses, coaches, taxis) and potentially a retail complex where parking is provided. The scale of this complexity will vary significantly depending on the events being held and specific location.

Figure 8-8 Typical sports event stadium (OS Mastermap)

The mapping in Figure 8-8 shows a very clear are in front of the stadium with few buildings impacting the entrances. The major roads are also clearly seen and additional survey for such a site would be minimal as discussed. Generally existing mapping will be adequate to inform a planning tool.



8.1.5 Points of Interest

In this context, a point of interest is anywhere where crowds of people may gather, such as event locations. E.g. Buckingham Palace, Edinburgh Castle, Seafronts etc. It is likely that service demand may be averaged for such locations with special events being treated in the same way as for Stadia. It is worth considering that for major events, shortfalls in coverage and capacity can be fulfilled with temporary sites being erected. Some of the objects identified in 8.1.1 may also be prevalent.

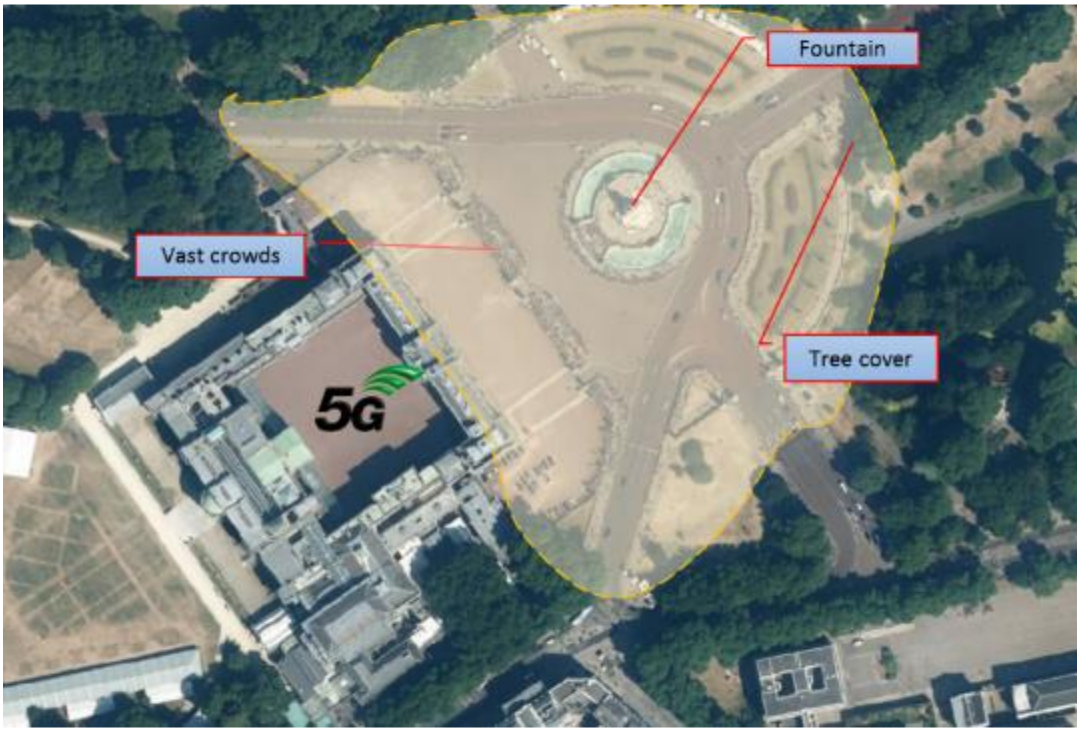


Figure 8-9 Tourist location

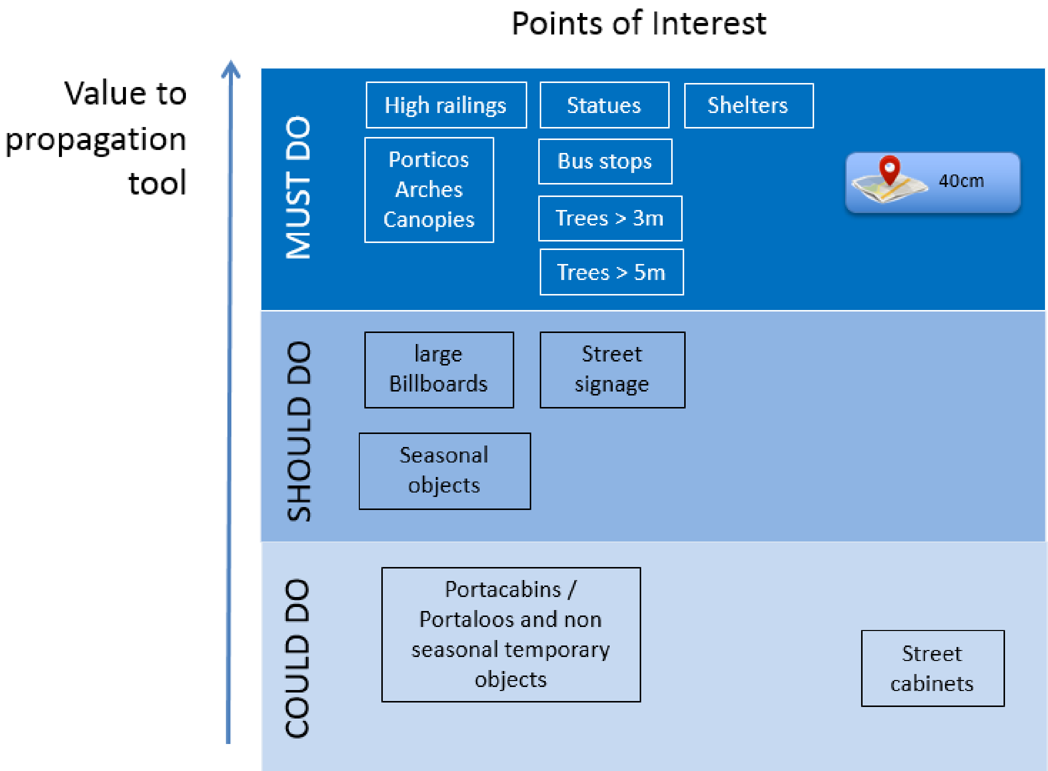
The example above of Buckingham Palace may not be typical of all Tourist locations across the country. They may be found to be small locations of great interest but in very dense urban environments (City of Westminster – Houses of Parliament) or conversely in wide open spaces (Stonehenge). What is common is the need for high capacity in a relatively small area to serve large volumes of people. Tourists also enjoy photographing and videoing these locations and, where possible stream that information live.

The amount of additional survey for tourist locations will vary with existing mapping being adequate in some cases but additional survey being required perhaps where there is a significant amount of tree cover, monuments or statues and high fences and railings that may provide security barriers.

The standard mapping in Figure 8-10 Tourist location (OS Mastermap), clearly depicts the roads, pedestrian areas and where foliage may be. However, this is not in any detail. For this type of environment additional survey requirements are likely to be considered depending on the actual location and the seasonal nature of activity at the location.

One approach for tourist spots and those in particular that may only experience large crowds a few times throughout the year, is to provide temporary infill. This is not a new concept and many events, such as Glastonbury and other large shows across the country will contract out provision of 4G services using mobile antennae. This principle can be equally applied to 5G and therefore does not require theses areas to be fully planned in advance and as such the need for survey reduced

Figure 8-10 Tourist location (OS Mastermap)



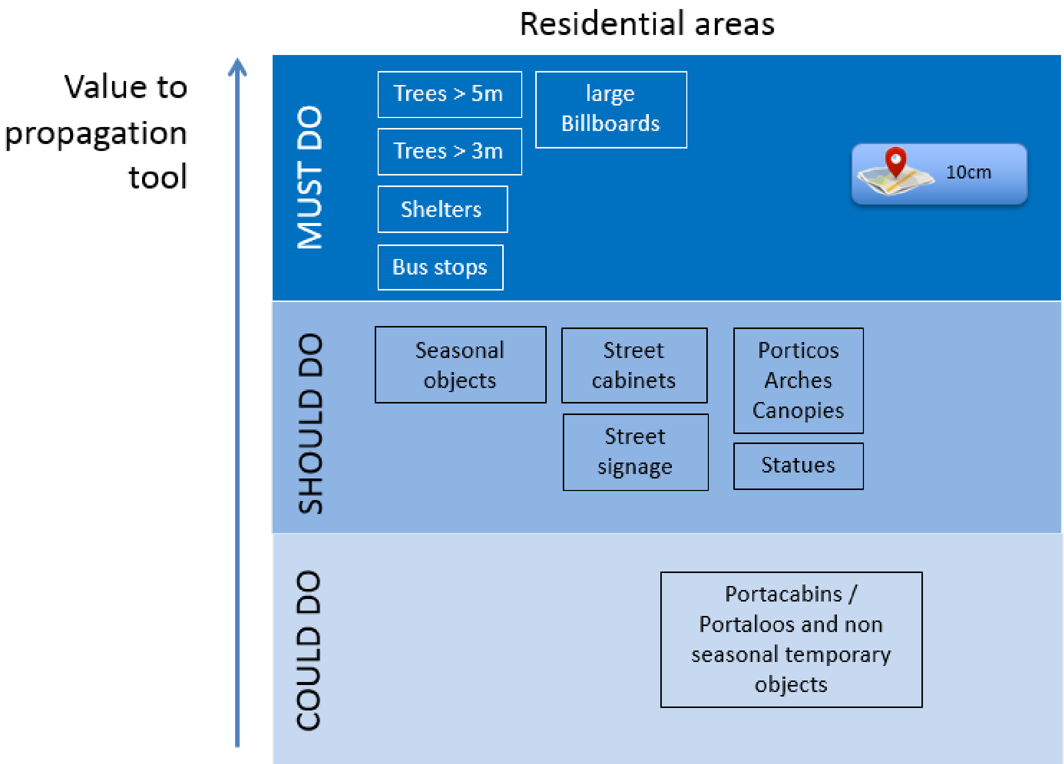
8.1.6 Residential areas

Residential areas may offer mmwave communications at busy intersections, small shopping areas and local community facilities. Within homes, broadband is likely to prevail. For the community areas, coverage is likely to be in very small concentrated locations and where capacity can be relatively low resulting in fewer few sites being required. Careful planning may avoid having to consider many of the blockers discussed beyond a quick observation of any significant objects.

Figure 8-11 Typical residential area

Because the areas of coverage may be relatively confined to small areas and specific corridors, existing mapping Figure 8-12 is likely to be adequate to inform the planning tool. However due to the density of these environments attention may need to be given to ensure coverage remains consistent along corridors with citing of additional antennae at key road junctions. Little additional survey is expected for such environments unless the areas to be covered has significant foliage i.e. tree cover.

Figure 8-12 Typical residential area (OS Mastermap)



8.1.7 Business districts

Business districts are defined as those areas where significant volumes of commuters will travel to and from, mostly at predictable times in the morning, evening and with fewer volumes of people migrating in and out of offices during mid-day. For the majority of the time, Business users will be operating on their office premises and will have access to highspeed internal networks. However, Business users expect a seamless communication service and therefore mmwave small cell sites have a key role to play in delivering this service. New sites may be best positioned at social networking areas and major routes to and from the business area. This area could be large and therefore may demand large volumes of sites to maintain service. Objects defined in 8.1.1 may all be applicable especially as there are trends to increase green spaces (which may include trees).

The imagery below shows a typical London business district illustrating the fact that outside coverage is likely to require several antennae to provide both high coverage and capacity.

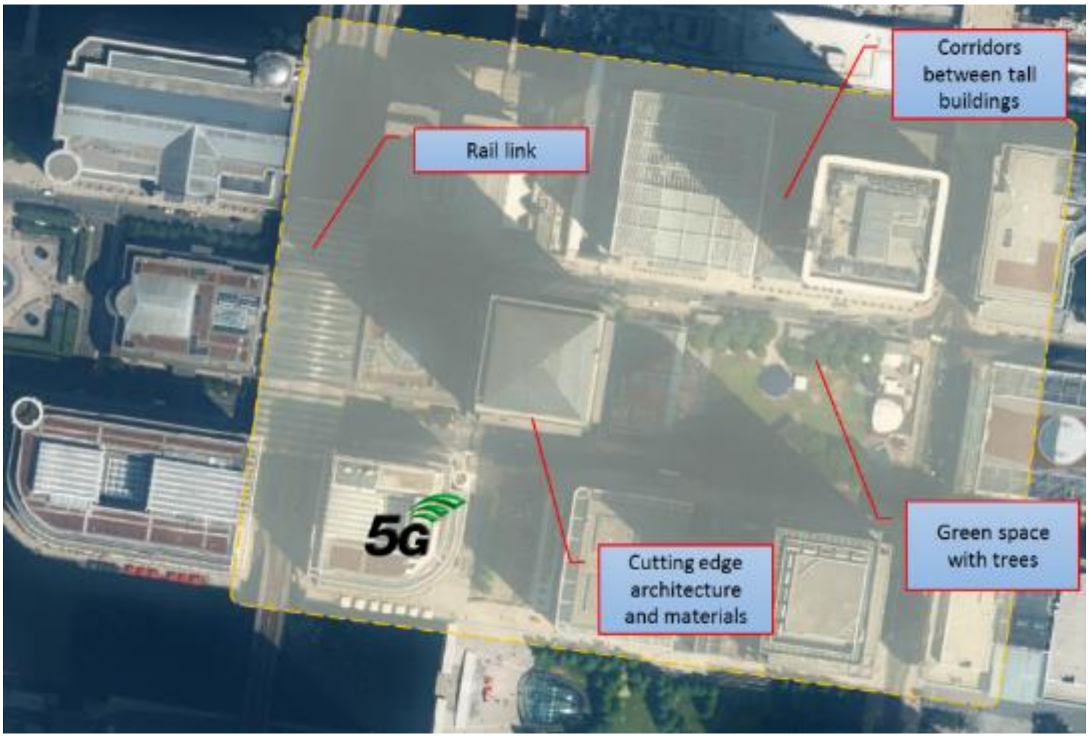


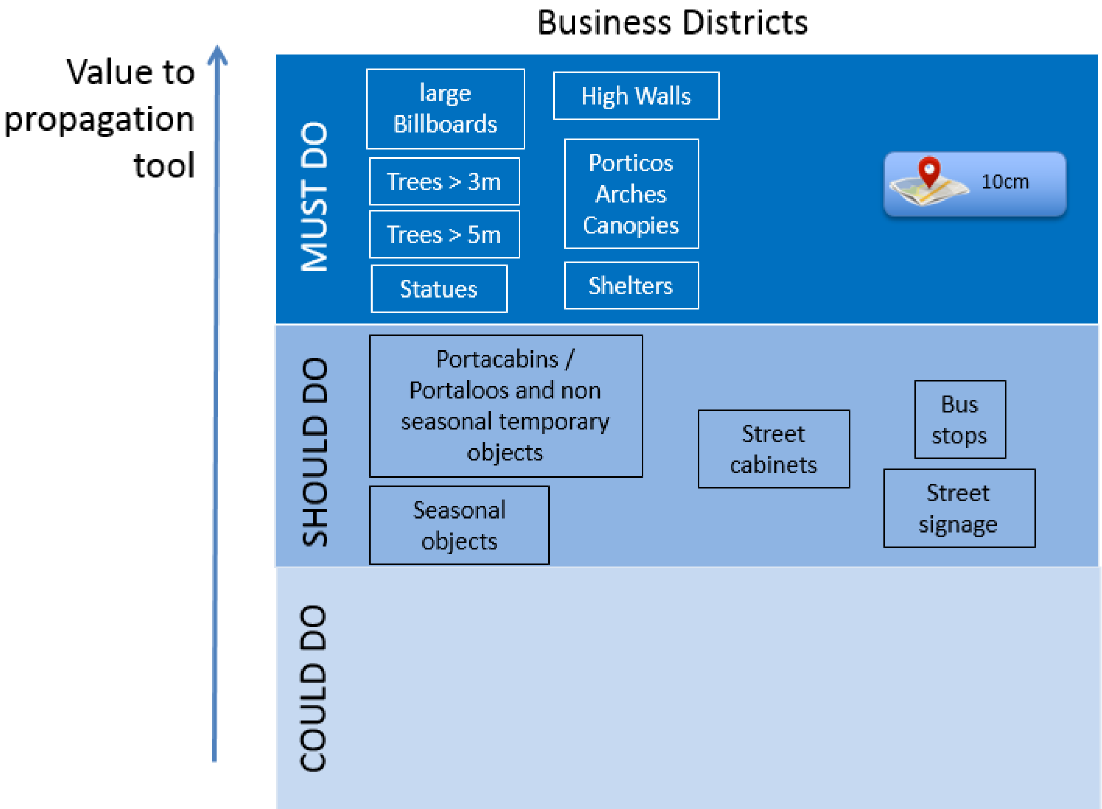
Figure 8-13 Typical Business district

Many business centres are well mapped but ensuring ubiquitous coverage outside the building means that attention to detail in planning with regard to building materials and the effect of newly created green spaces may require some additional survey work to inform the planning tool. Where materials are concerned details may be made available from the contractors or where this is difficult to obtain may in some circumstances require specialist services to assess the building materials.

It is also important to note that many buildings in Cities are being constructed with living walls i.e. plants that are hung from the sides of the building to reduce pollution. The plants will inhibit signal propagation and may need to be factored in.

Figure 8-14 Typical Business district (OS Mastermap)

In the above map Figure 8-14 Typical Business district (OS Mastermap), the main corridors are clearly identified as are the green spaces. Tree detail is not present in this map and could be important if the green space is used for socialising during the day.



8.1.8 Small town environments

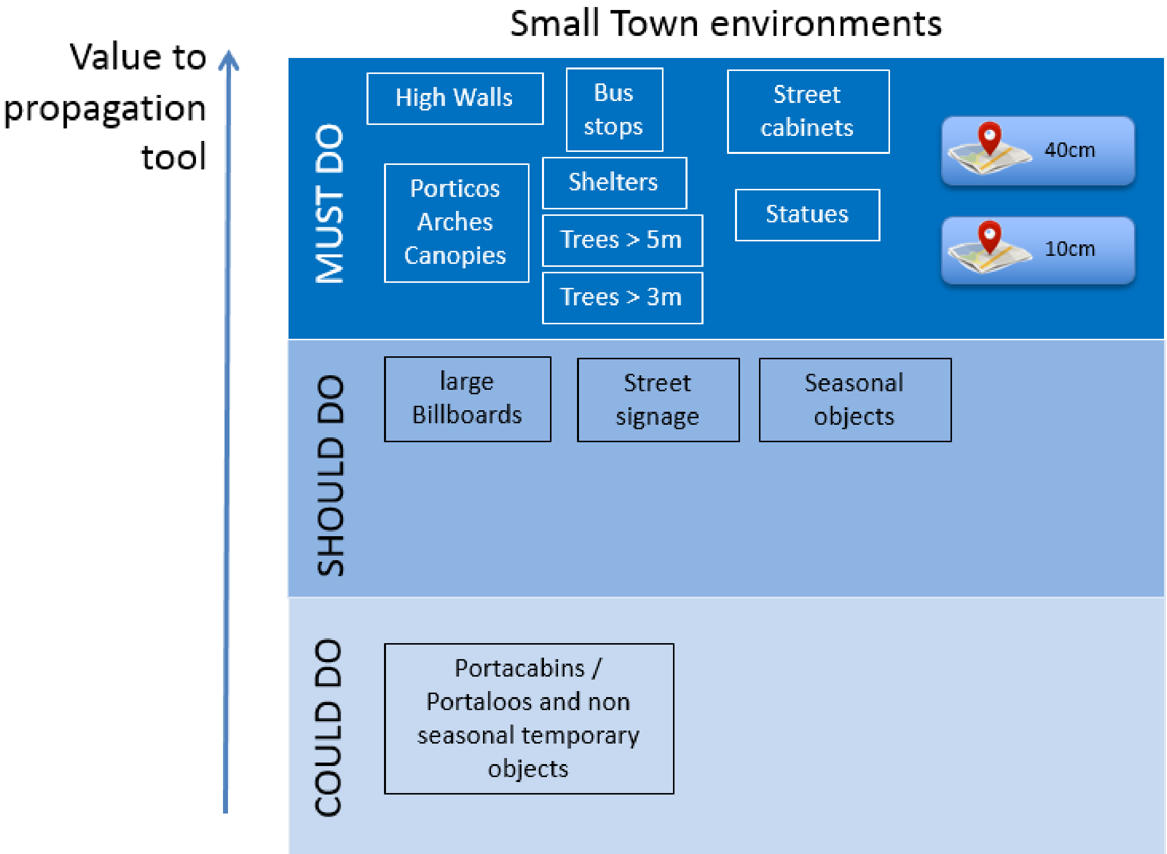
Small towns are typified by having a main centre with a small number of busy streets like Urban streets & Pedestrian areas 8.1.1 described above but then quickly turning into a more suburban and rural landscape. the considerations in 8.1.1 apply but the footfall is likely to be lower than in major towns and cities. This may well allow for a reduced level of coverage and capacity to be offered and attention to blocking objects may be less of a prime consideration.

Figure 8-15 Typical small town

The example town above in Figure 8-15 Typical small town, is connected to the mainline railway implying increased footfall at early morning and evenings. It has a relatively densely populated centre and some green space. There is also a great deal of residential properties which will generally be connected to broadband services and therefore coverage of small cells over a wide area is not likely to be required as a priority. Property in the town centre is relatively old and makes use of traditional brick and glass building materials presenting less of a problem to a planning tool and less need to conduct specific survey.

We have identified that the resolution for survey could be 10cm or 40cm. This is because the features of small towns will vary dramatically as will the use cases. We would suggest planners take professional advice, in particular where budget constraints may be imposed.

Figure 8-16Typical small town (OS Mastermap)



9 Survey and cost trade off considerations

In the above section, we have identified several scenarios and determined that all of these will have to consider potential 'blocking objects' to a greater or lesser extent where they do not fall into Ordnance Survey's standard OSMM specification.

For each scenario, in the table below a suggested volume of blocking objects has been identified but each area for consideration may be very different. The purpose of identifying the volume is to help in deciding how additional objects can be captured.

We consider three options:

1. Local authority identification and placement of new object on base mapping
    - Good for when there are a small number of objects

2. Contracted simple survey
    - Better suited when there are several objects to be captured and, where these may not be readily accessible.

3. Contracted Mobile data survey (LiDar)
    - Where there are a significant number of objects a more appropriate survey technique it may be necessary to may make use of mobile mapping. Known as LiDar (Light Detection and Ranging) this is a technique where specially equipped 2 or 4 wheeled vehicles or, sometimes a person wearing a special 'back pack', traverse the area capturing at detail all the objects covering a full 360 Degree radius. From this data, the important objects can then be extracted and positioned on the existing map as a new feature or object.

The decision to manually capture or use an automated technique will come down to coverage and capacity (quality) required versus cost. It is therefore important that planners, such as Local Authorities can identify the types of area over which they may wish to deploy 5G and, with guidance through this document, build an understanding of what they may need to look for in terms of objects that may affect mmwave coverage and capacity.

Area type	Object Volume estimates	Preferred method	Budget allowance / Km^2
Urban Streets and pedestrian areas	5 to 20	Contracted Survey	£7,500
Transport Hubs	5 to 10	Local authority manual capture	£5,000
Retail complexes (shopping centres)	10 to 20	Contracted Survey	£5,000
Large event sites and stadia	5 to 10	Local authority manual capture	£5,000
Points of Interest	10 to 20	Contracted Survey	£1,500
Business Districts	5 to 10	Local authority manual capture	£1,500
Residential areas	10 to 30	Contracted Survey or Contract LiDar mobile mapping	£2,000
Small Town environments	20 to 50	Contract LiDar mobile mapping	£3,500

9.1 Estimating costs

The above table shows a range of costs which have been derived from real examples of contracted work to survey regions in the UK using the preferred methods identified. A common question is whether the costs relate to traversing a linear kilometre or whether they relate to a specific area.

In truth the answer depends on the density of the region to be covered. For example, if the chosen region has one road going through it then survey costs are going to be low and managed by simple survey techniques. If the region has several roads or complex junctions, then survey will take longer and may require introduction of LiDar to affect the capture. If the survey now consists of several traverses to ensure each street, or selected area in the region is covered this will take longer and the cost will rise accordingly. As such these figures can only be offered as guidelines as every situation will be different.

10 Local authority Data requirements

In addition to identifying blocking objects that affect propagation, for successful planning, the connection back to the network (backhaul) must be considered. This includes provision of fibre to and, provision of power for each site.

Laying fibre in existing ducts where known and, can save £1000's if these can be utilised to deploy new high-speed fibre as opposed to creating new ducts. It is therefore important that planners know where existing key assets are located such as CCTV as well as obtaining details of existing fibre routes in the area of interest.

Similarly, power networks are essential for powering new sites. It is expected that new sites will be deployed on lamp posts or public buildings to reduce costs. In these cases, power may be readily available (subject to electrical loading requirements) and in many cases a suitable connection is possible. However, there may be areas that requiring new sites to be placed at locations without easily accessible power and knowledge of nearest usable power connections will be required.

In addition to fibre and power, to satisfy the demands of the scenarios defined above, the more information you can obtain to assist in informing the decision the better. For example:

- Footfall in a shopping centre
- Individual retail unit customer counts
- Car park usage
- Transport timetables and ticketing information
- Major events planning
- Ticketing for events
- Professional surveys of people movement such as that provided by Health and Safety Labs (HSL)
- Others as available

Obtaining this information can be difficult and even if available may not be accurate, provided in a useable format or up to date. Ordnance Survey liaise regularly with many local authorities and from experience in the role of providing our public task are exposed to data sets that are incomplete, incorrectly referenced and not well maintained. This is reality, and where a dependency exists on this data, additional checks and new processes may need to be put in place. This implies further cost that needs to be considered and budgeted for.

Ideally additional data sets need to be fully geo-referenced and in a format, that can be readily integrated by a planning tool. Geo-referencing of this data could be outsourced.

Most important is the overall quality of the data that can be defined as:

- **Currency** - when was it last updated and what is the update period and method?
- **Provenance** – Can you trust the source of this data? Who created it and how?
- **Accuracy** – Does it provide figures commensurate with the intended use?

11 Annex A - Glossary

4G: Fourth generation mobile phone standards and technology. Provides faster mobile data speeds than the 3G standards that it succeeds.
5G: As yet there is no recognised 5G standard, although planned for definition by 2020. Almost certainly it will be higher frequency and hence higher capacity but lower cell size.
Attenuation – the reduction in power of the signal.
Backhaul: For fixed networks the term refers to segment(s) of a communications network that connect(s) segments of an access network (e.g. from the Digital Local Exchange to the Premise or from a Cabinet to the Premise) with the core network and for mobile networks from the mast to the core network.
Bandwidth: This is the measure of the maximum capacity of a data link in the network.
BTL – Bulk transport link Openreach product, site to Openreach handover point transport.
CATV: Cable television (originally community antenna television) a broad term for a network that was primarily designed for providing multichannel TV through fixed line services but now also carries voice and data.
Ducts: Underground pipes which, inter alia, hold copper and fibre lines.
FTTB (Fibre-to-the-building) – Access network topology using optical fibre to provide the connection between the exchange and the customers' premises. Generally, there is then a distribution network within the building.
FTTC (Fibre-to-the-cabinet) – Access network topology using optical fibre to provide the connection between the exchange and the street cabinet. The street cabinet is usually located only a few hundred metres from subscriber premises. The remaining segment of the access network from the cabinet to the customer is usually a copper pair but could use another technology, such as wireless.
FTTDn (Fibre-to-the-distribution node) – Access network topology using optical fibre to provide the connection between the exchange and the distribution node. The distribution node is usually located only a few tens of metres from subscriber premises. The remaining segment of the access network from the cabinet to the customer is usually a copper pair but could use another technology, such as wireless.
FTTH (Fibre-to-the-home) – see Fibre to the premise.
Fibre To The Premises (FTTP): An access network topology using optical fibre network to provide the connection between the local exchange and the end user's house or business premises. The optical fibre may be point-to-point – a dedicated fibre connection for each home – or may use a shared infrastructure such as GPON (Gigabit passive optical network)
Fixed wireless. Broadband services using fixed radio equipment. WiMAX is a fixed wireless standard capable of offering speeds of up to 1 Gbps.
FTTx Fibre based solutions generically – see FTTB, FTTC, FTTDn, FTTH and FTTP**.**
Freeview: DTT, radio stations and interactive services through an aerial. Freeview is a company owned and run by the BBC, BSkyB, Channel 4, ITV and Arqiva.
Gbps: Gigabits per second. Bit rate is the rate at which digital information is carried within a specified communication channel.
GHz: Gigahertz. 1,000,000,000 oscillations per second.
Internet: A global network of networks, using a common set of standards (e.g. internet protocol), accessed by users with a computer via a service provider.
HSL Health and safety Laboratory. Part of UK government, a world-leading provider of health and safety solutions to industry and government. Combining scientific, medical and technical expertise.
I.M. Instant messaging. Commonly known as text messaging which is ubiquitous amongst the mobile phone user community and enables short messages to be sent between two or more people.
LiDar Light Detection and Ranging. A remote sensing method used to examine the surface of the Earth.
IoT: Internet of Things. There is no universally agreed definition of the Internet of Things but in general it is used (like M2M) for communications that involve communication with at least one machine. IoT implies many IP addresses needed but low data requirement for most implementations.
Mmwave millimetric wave. Millimetric waves refer to radio frequencies from 20GHz to 300 GHz. Within this document we specifically consider 26GHz.
Mbps: Megabits per second. Bit rate is the rate at which digital information is carried within a specified communication channel.
MHz: Megahertz - A unit of frequency of one million cycles per second.
Mobile broadband: Various types of wireless high-speed internet access through a portable modem or dongle, mobile telephone or other device.
Modulation – the changing of a signal in a way that can be detected so that the data transmitted can be recovered
Ofcom – The Office for Communications – independent UK regulator of electronic communications.

Permittivity - The ability of a substance to store electrical energy in an electric field.
Propagation – RF signals moving in time and space.
OSMM™ Ordnance Survey Master Map. This is the base mapping surveyed by the Ordnance prepared in the United Kingdom and offers a definitive representation of the geo-spatial environment from which other map products and data sets are derived.
Site location of radio equipment. In this document this refers to physical locations where a radio antennae could be 'sited'.
SMS – Short message service, 140 character text service carried in the signalling channel of 2G mobile networks and supported in later generations of mobile technology.
Spectrum: The descriptor of the range of electromagnetic frequencies which can be modulated to carry information.
Wi-Fi: Commonly used to refer to wireless local area network (WLAN) technology, specifically that conforming to the IEEE 802.11 family of standards.

12 Annex B – Millimetric wave (mmwave) & Propagation

Ordnance Survey, The University of Surrey (5G Innovation Centre), Met Office and Bournemouth Borough Council embarked on a detailed project to understand the effect of geography on mmwave. From this work conducted in the early part of 2017 they have been able to understand which aspects of geography must be considered when planning new 5G networks.

Summary conclusions are that for mmWaves, any object wider than 10cm will cause significant signal loss through what is termed 'diffraction'. Also, any object wider than 0.6m could be potentially classified as a total blocker depending on the material the object is built from.

Vegetation wider than 1m will offer significant signal loss, losing over 90% of the power regardless of whether leaves are present or not.

12.1 About Millimetric Waves (mmwave)

Mmwaves are radio waves and are essentially no different to those that are used to broadcast radio and television. They are typically represented pictorially as what is termed a 'sine' wave Figure 12-1 that has two key features amplitude and wavelength. Amplitude can be considered a measure of how strong the radio wave is (power) and the wavelength represents the distance between each peak or trough of the signal. These waves 'carry' the data between radio devices.

We freely talk both about mmwaves and frequency; e.g. in this document we talk about 26 GHz (frequency) so how does

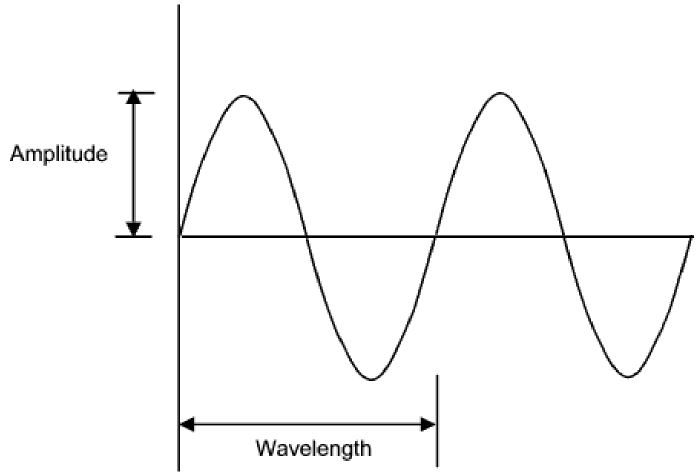


Figure 12-1 Signal sign wave

that relate to wavelength? There is a relationship between frequency and wavelength determined by the speed of light and can be written as:

Wavelength = speed of light divided by the frequency

Or mathematically $\lambda = \frac{c}{f}$

Using this calculation, for a **26GHz** signal and with the speed of light being 300 million metres per second, the wavelength is 0.0115 metres or **11.5 millimetres**; hence defining this frequency as being a millimetric wave.

12.2 Propagation

Having understood that the wavelength of these signals is small, this means that when these waves interact with an object their behaviour can be modified and by objects which are of a similar size. This results in the signals not reaching their destination or reaching it with little usable power. In for example a consumer application for a user on a mobile device this means potentially means a loss of communication be that audio, video or other data.

However, at these high frequencies other physical phenomena come into play as well called 'diffraction' . in simple terms this is the ability for signals to travel around objects and therefore provide a signal at a location where it would be naturally thought none exist. In Figure 12-2 a radio source is placed in front of an object (bottom left). If the object blocks the signal in total, imagine a torch light beam blocked by an object, then no signal (light) appears the other side – zero signal power, identified by the white squares.

Where 'diffraction' is considered, the signal actually 'forms' around the object (this is true of light too) and is visible the other side although at a reduced power level to that transmitted.

Radio planning tools take this phenomena into consideration.

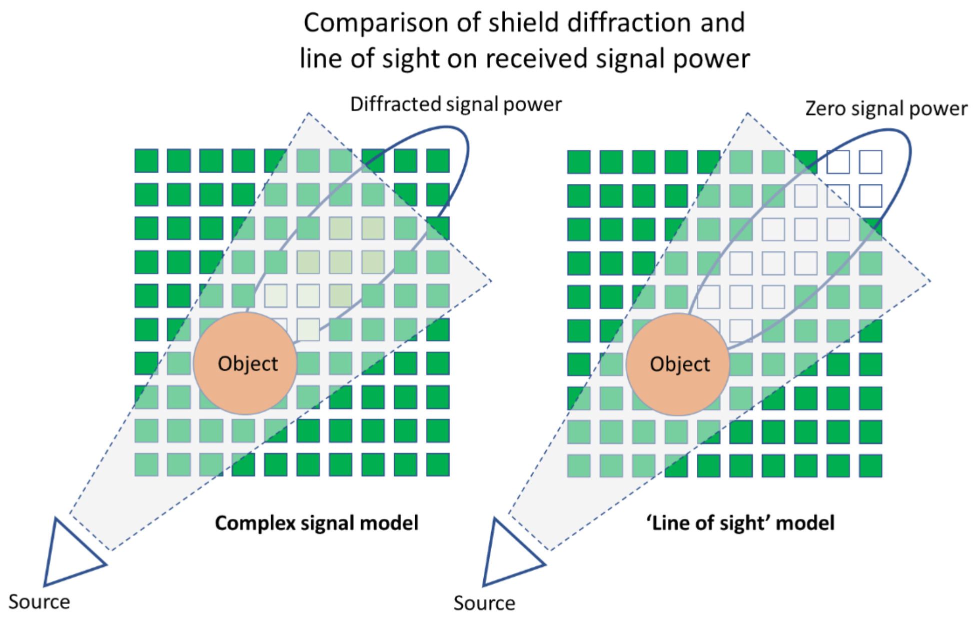


Figure 12-2 Diffraction of radio signals

This is why, when planning a radio network, it is important to consider these physical objects that can naturally reduce or block signal power and reduce quality and availability of service between radio devices.

13 Annex C – Spotting problematic features – some examples

Below are a few examples of typical locations where 5G mmwave might be offered. Every location has to be considered on its own merit and the decision on how and, whether to capture additional features will vary depending on the use case to be fulfilled.

	This stadium area has two interesting features that should be a considered as potential signal blockers. 1. The supports outside the stadium made of a complex steel structure 2. The walkway to the left that is lined with trees potentially blocking signals emanating from sites mounted on the stadium Due to accessibility and the tree line additional LiDar survey may be required.
	This small town centre has a small monument that could present a temporal signal impact should a user be stood close to the monument. If the user is simply transitioning past the monument this may be less of a problem. In this case simple survey of height and base dimensions may be required
	This is a good example of a large hoarding that would not appear on any mapping due to its temporary nature. In this case it is both wide and tall and being an electronic hoarding would be made of materials that would certainly block mmwave signals. Recommend specialist survey to capture this but using simple techniques

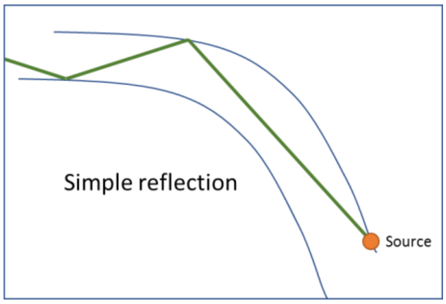
	Shown here is a busy pedestrian area close to a ‘candidate’ lamppost for 5G use. Two key features are considered 1. There are deciduous trees and these may offer limited signal degradation in winter months but, in Summer with leaves on could have a significant effect. 2. The road above the pedestrian area Simple Survey may be adequate for this situation but if 5G mmwave is to penetrate under the road into the pedestrian area more detailed LiDar based mapping might need to be considered.
	This is a busy statin entrance with slow moving crowds. The canopy to the left may inhibit 5G signals depending on siting of the antenna. If these volumes of crowds are typical then this scenario may need to focus more on siting additional antennae to provide capacity and coverage. Attention therefore needs to be paid to surveying and identifying suitable candidates for site locations. In this case the poles in the concourse may be ideal but not mapped. Simple Survey may be adequate or use of existing asset registers.
	This aerial view of a typical shopping centre shows wide open spaces with very few features that may block 5G signals. There are a small number of trees around the car park and if any survey needed to be done this could be managed at a local level with a few select measurements being taken of features that may be seen as significant.

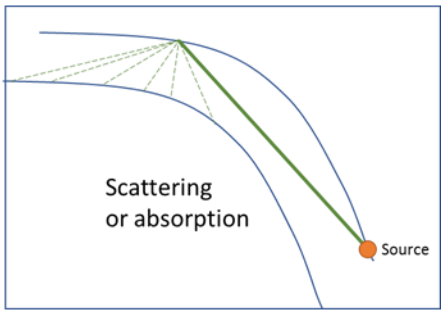
	In this example we have a building with an architectural feature represented by a high wall. This would not be shown in any detail on standard mapping and must be considered in any planning. Survey may be performed locally or specialist survey contracted to capture height and width of wall.
	This waterfront shows a retail area with cafes' s and shops. It is likely that there wold be a mix of users passing by but with others sitting spending significant time at one spot whilst drinking and eating. This location has two interesting features. 1. structures forming small jetties 2. the berthing of small ships and craft This is a complex environment that may benefit from detailed LiDar survey but in addition usage of the waterfront should be considered to forecast demand.
	In this residential street there are a large number of trees clearly blocking any line of site for antennae that may be sited on lamp posts. Initially it would be correct to consider LiDar survey to capture the details of the trees but being residential activity may be limited during the working day and at other times users will tend to be resident In their homes with access to Broadband. A trade-off between coverage and demand needs to be considered before embarking on a more detailed survey

These tall railings at a popular tourist location experience crowds predominately static observing activity the other sides of the railings. These are potential blockers in terms of the materials and the height. If such an area is to be served by mmwave then simple survey will need to be undertaken to capture height before planning the position of antennae.

Covered walkways and pedestrian tunnels are in general unlikely to present themselves with objects that block the signal path (save pedestrians and anything they carry) but where the walkways are curved the surface of the walkway could have an impact on the signals propagation.

In very simple terms, depending on the surface type, the signal could be reflected (possibly to advantage) or scattered or absorbed to disadvantage weakening the signal for example:





Therefore, a good appreciation of surface types and predicted propagation modelling will be required.

	Multiple levels created by roads or railways crossing over each other can present challenges in determining where 5G sites need to be positioned. Standard 2D mapping will not provide a level of detail good enough to appreciate what the blockers; for example, bus shelters, art installations, billboards might be and, as the complexity increases, it is likely that mobile mapping will provide a better solution in understanding this type of environment.