Network Innovation Allowance

Next Generation Wireless Telecoms Analysis

JRC Ltd
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Contents

Executive Summary

This report presents the outcome of the Network Innovation Allowance (NIA) funded 'Next Generation Wireless Telecoms Analysis'. The Analysis builds on previous work undertaken by Western Power Distribution (WPD) at Portishead to assess the feasibility of LTE (Long Term Evolution) mobile data technology to support future Smart Grid electricity network functionality. The work has been undertaken by a joint team comprising WPD and Joint Radio Company (JRC) engineering personnel.

Radio base station trial at WPD Portishead Primary Substation.

A desktop model has been developed capable of defining a future network architecture necessary to enable the advanced connectivity required of an intelligent electricity distribution network. The study focuses on the forecast needs of a Distribution System Operator in the time frame up to 2030 and beyond.

Although modelled on the WPD LTE trial network at Portishead, the technical solution provides additional flexibility to accommodate alternative communications technologies, radio spectrum bands and physical parameters for both radio base stations and the terminal equipment at electricity substations. Because the maximum data rate achievable for each outstation connection depends on the precise nature of the radio path between the outstation and its associated base station, the model calculates the data rate for each path rather than relying on an average data rate based on path length.

Since the precise nature of future electricity networks is still emerging, the approach taken was to base connectivity around electricity distribution substations. Assuming resilient connectivity would be required, each of these substations could then act as a hub if additional connectivity is needed deeper into the electricity network. The parameters chosen in terms of data volumes, antenna heights & types etc were developed in joint WPD/JRC workshops, to settle on optimum solutions from both radio and electricity network perspectives.

The radio network was designed to use WPD's own assets where possible, to minimise cost and support a highly available network, recognising that part of the challenge of maintaining highly available telecommunications is resilient power supplies, redundant backhaul and 24/7/365 site access for maintenance and repair.

Typical suburban distribution substation to which connectivity will be required to facilitate a more intelligent electricity network.

In terms of future modelling of the cost of a radio network providing ubiquitous reliable connectivity, it was recognised that the major investment is in the installation of the telecommunications equipment at the electricity substations. Infrastructure was therefore selected to minimise installation costs, avoid potential for lengthy planning approval delays, and provide less incentive for vandalism and damage.

WPD's network:

- Serves 7.7 million customers
- Covers 55,500 km^2
- Consists of:
  - 92,000km overhead lines
  - 129,000km underground cables
  - 185,000 transformers

The maximum data rate which could be achieved for each outstation connection was based on the practical trials at Portishead, which confirmed that data rate is dependent on the quality of the radio path rather than distance from the base station. The radio network capacity was then scaled for a utility environment where a guaranteed quality of service must be delivered.

Although the target was connectivity to all WPD's substations (approaching 200,000 in number), design analysis was not progressed further once 90% of substations were predicted to be served as the cost effectiveness of providing service to last 10% would need to be examined more closely in the light of real life experience and substation telecommunications infrastructure alternatives; noting that by the time connectivity has been rolled out to 90% of sites – which itself may take until 2030 and beyond – additional telecommunications options may have become available, to provide enhanced connectivity at lower cost to these more difficult to serve locations.

Providing connectivity in remote areas with challenging terrain in order to be able to deliver the same services to customers as in urban areas is a major challenge.

In conclusion we have shown that an LTE network can be constructed to cost effectively deliver the required connectivity. In dense urban areas, providing adequate capacity was often the dominant challenge whereas in rural areas with adverse geography, coverage was often a constraint. However, whilst the focus of this analysis was connectivity via a private LTE network, it is recognised that in reaching the most challenging paths, other telecommunications options might be available to 'fill in the gaps', avoiding excessive cost for electricity consumers and providers in remote areas, whilst still providing the same level of service as in urban areas.

An essential requirement for a wireless network is access to suitable and sufficient radio spectrum. The modelling demonstrated that not less than 2 x 3 or 1 x 5 MHz of spectrum in the 400 MHz band would be the most cost effective way in which to deliver advanced connectivity, whilst the modelling was extended to the 700 MHz band to demonstrate its capability to operate in an alternative frequency range between 100 MHz and 1000 MHz, should alternative frequency bands be made available [See Section 2].

Whilst not directly addressing 5G, the report notes that the LTE technology utilised in this study is on the roadmap for 5G and will be upgradeable to later technology releases should that be the chosen pathway.

From the conclusions of this analysis, it is recommended that further field trials are conducted to build on the current work and to:

- Assess the interference effects between overlapping base stations, especially their influence on capacity;
- Determine operational characteristics in a 'live' operational data-loaded environment including assessment of throughput;
- Examine the resilience of an LTE network where substations can connect to more than one base station; and
- Validate propagation modelling and data volume assumptions.

1. Introduction

Background

This final report from the combined Western Power Distribution (WPD) and Joint Radio Company (JRC) team presents the outcome of the Network Innovation Allowance (NIA) funded 'Next Generation Wireless Telecoms Analysis'. The Analysis builds on previous work undertaken by WPD at Portishead to assess the feasibility of LTE (Long Term Evolution) technology to support future Smart Grid electricity network functionality.

The applicable time frame considers the needs of the electricity network to address public policy objectives up to 2030 and beyond. This would encompass the RIIO2 regulatory review periods for UK electricity distribution licences. Although it is recognised that different utility companies may face differing or non-aligned regulatory review periods as well as different geographic areas, the design philosophy is sufficiently flexible to accommodate these differences.

In terms of technology, while public policy debate is focused on 5G (5th Generation) mobile technology, this technology will be insufficiently proven or stable within the time frame essential for utilities to deploy in the highly available and challenging environments required of utility operations. In terms of wide-area coverage, public 5G is unlikely to be sufficiently available and resilient to service utility requirements in that time frame. By focusing the analysis on private LTE technology, we provide the foundation for a later upgrade to 5G should the need arise since LTE is an integral part of the developing 5G ecosystem.

The primary objective of the analysis was to develop a methodology for determining an optimum telecoms network design to provide the enhanced connectivity required for the future smart grid that will be necessary to facilitate the transition from 'Distribution Network Operator' (DNO) to 'Distribution System Operator' (DSO).

The need to provide this enhanced connectivity is driven by the obligation to:

- Connect more embedded electricity generation into the distribution network whereas previously generation was usually connected into the transmission network;
- Reduce the costs associated with connecting generation to the distribution network to encourage more renewable generation which is often located in places with insufficient network capacity to carry the load;
- Facilitate demand management to enable loads to be connected flexibly to the network to avoid the costs of re-enforcing the electricity network and building expensive peak power generation plant;
- Enable new demands to be managed as we move towards a zero-carbon economy with the electrification of transport and heat, plus new innovative demands in the electricity network;
- Improve the reliability and quality of electricity supplies as we become a digital nation ever more dependent on a reliable supply of electricity;
- Ensure a sustainable and affordable supply of electricity for consumers and the economy;
- Enhance asset life and reduce maintenance costs through more intelligent monitoring of infrastructure; and
- Enable innovative new market mechanisms to flourish.

Scope

In considering WPD's future operational data communications requirements, the approach taken was to select a contiguous region within WPD's licenced areas for analysis [See Figs 1.1 & 1.2]. In order to include a representative mix of demographic and geographic challenges, the specific areas chosen included the southern half of the West Midlands area from north of Birmingham down past Gloucester and the South West region from Bristol to the tip of Cornwall [the two coloured areas in Fig 1.1]. These two areas are respectively referred to as 'West Midlands' and 'South West' in this report.

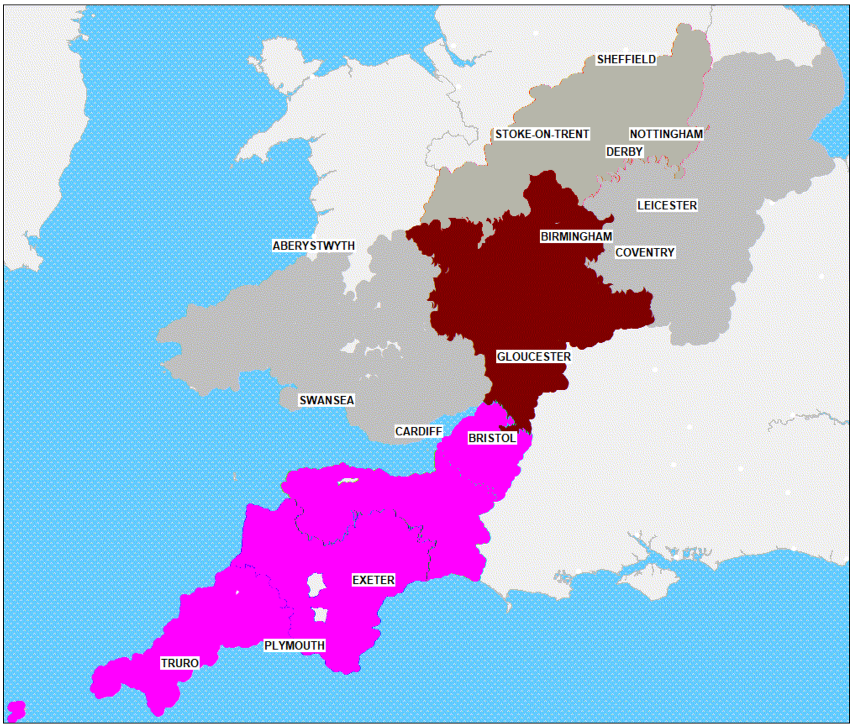


Figure 1.1 - Selected geographic region within WPD's licence areas

The outcome of JRC's analysis can be extrapolated to the whole of WPD's area using an easily calculated scale factor.

The modelling was informed by WPD's eLTE (enterprise LTE) technology trial based on their Portishead Grid substation and centred on 410-430 MHz spectrum, but was designed from the outset to be readily adaptable to other DNO areas, other technologies and any spectrum below 1 GHz where radio waves are more able to penetrate obstructions and move around physical obstructions such as hills.

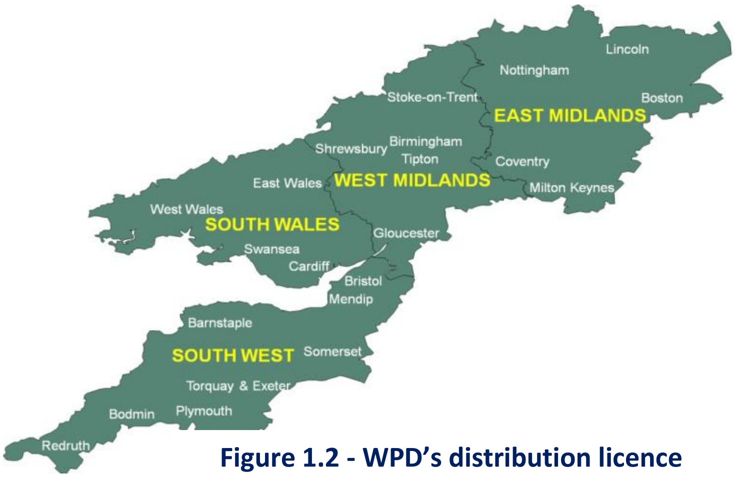


Figure 1.2 - WPD's distribution licence

The LTE radio network design therefore addressed these areas to include dense urban areas around Birmingham and the challenging Devon and Cornwall moors and coastal inlets. The objective was to leverage WPD's existing active and passive infrastructure to minimise future investment requirements, confirming the feasibility of utilising an operational network based on LTE technology to support national, next generation Smart Grid energy infrastructure. The network capacity would be designed to address WPD's future requirements for enhanced real time monitoring and control.

In designing the network, existing radio infrastructure based on the 450 MHz SCADA (Supervisory Control and Data Acquisition) network was to be used, supplemented by radio sites used for the 150 MHz VHF emergency PMR (Private Mobile Radio) mobile voice network and a similar VHF automation network designed around Digital Mobile Radio (DMR). This ensured radio sites were already designed to a high degree of resilience and could access WPD's existing fibre-optic and microwave backhaul network. After these assets had been exhausted and where further connectivity or coverage was required, then new radio sites based firstly on WPD's remaining asset base and later on third-party sites were considered whilst still maintaining similar resilience and redundancy standards.

The final element was to ensuring that telecommunications equipment at substations could be installed cost effectively and efficiently with maximum resilience against vandalism and theft along with physical security to complement sophisticated cybersecurity measures embedded in the telecommunications network to resist and detect intrusion which might escalate to hostile foreign state level.

Outcomes

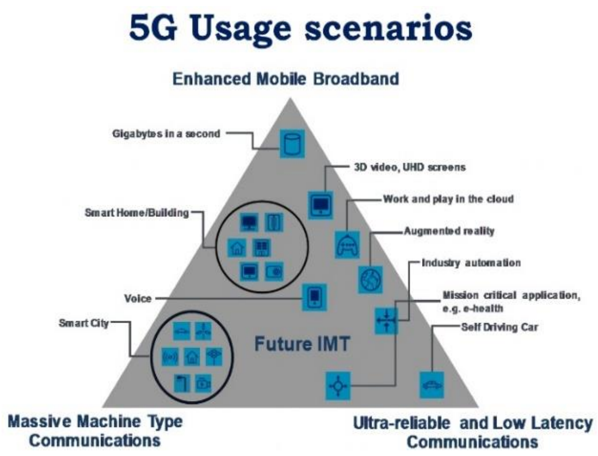
This study has established the principles for the design, co-ordination and deployment of national LTE data communications networks for all DNOs/DSOs in the UK and Ireland and even beyond. An additional objective was to clarify the radio spectrum requirements for such a deployment.

In devising the network to provide adequate outstation coverage from base stations largely located on existing WPD telecom sites, backhaul had to be added to or upgraded in some cases. A proportion of these upgrades had already been planned as part of on-going SCADA enhancements. Such a network will provide enhanced visibility of network assets in real time, allied to secure and fast switching to ensure a rapid response to changes in the energy supply dynamic, enabling supply and demand to be balanced on a minute by minute basis, a key component of the transition from Distribution Network Operator (DNO) to Distribution System Operator (DSO).

Commercial public mobile phone networks are based on the concept of providing connectivity to an area in the expectation that devices operating in that area have a defined probability of obtaining service with a data rate dependent on the quality of the radio path, the number of Resource Elements allocated by the network and the overall traffic levels. This is usually termed a 'reasonable endeavours' service. Since commercial networks are targeted principally at mobile devices, this level of service is acceptable since if a device does not have connectivity at a given point in time, it is likely to obtain connectivity when it moves. In contrast utility networks, being designed principally for fixed devices, are designed to ensure that a guaranteed minimum 'quality of service', including availability and data capacity sufficient for their intended mode of operation.

Although hosted by WPD, both the LTE trial at Portishead (Phase 1) and this analysis (Phase 2) have been designed to create a knowledge base and toolset to enable the Energy sector to plan and implement a structured approach suitable for all UK utilities. The intention has been to maintain flexibility to be able to encompass different business models for utility telecoms networks, ranging from each utility owning and operating their own private network, to shared networks and potentially up to a single national network to service electricity and gas transmission and distribution networks.

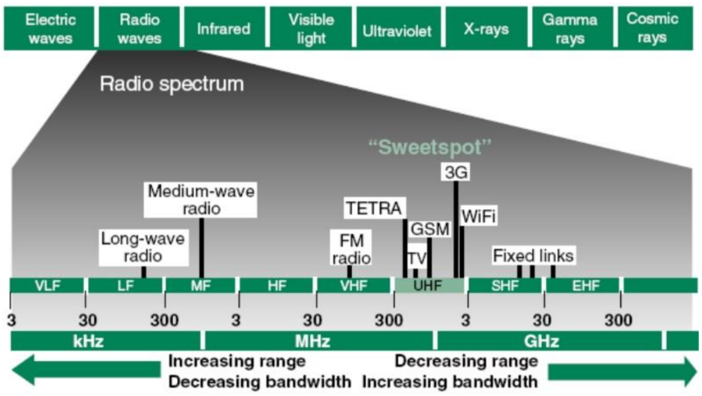
By enhancing the ability to understand the scale of system and infrastructure deployment required for single or multiple utility licence areas, this analysis along with further work recommended in this report, will allow the energy sector to develop network cost models which can be populated and customised to further develop investment and business case formulation.



In developing this model for a variety of outcomes, it is recognised that not all utility network requirements will be served by an LTE network. In particular, backhaul requirements of 100s of Mbits/sec and tele-protection circuits requiring latencies in the order of milliseconds are not envisaged as being adequately developed or sufficiently widely deployed for the start of the deployment of utility telecommunications requirements. These requirements are on the roadmap for, and thus may in future be met by, so called 5th Generation technology ('5G'). An LTE solution will be upgradeable to 5G in due course.

In considering the cost of a private LTE telecommunications network, it was observed that the dominant costs are those of the installed equipment at the outstations, which will have to be met whether the access network is 'private' or 'public'. This study did not seek to prefer either a private or public network. It is inevitable however that the design, being driven by the specific requirements of the energy sector in terms of data upload, geographic reach and network resilience, will be optimised for a private network.

Of course such a network will require access to appropriate spectrum and this analysis has been able to characterise and quantify the radio spectrum requirements assuming a UHF allocation and provide early evidence in support of discussions with government, regulator and industry representatives and stakeholders to support the case for timely spectrum access. Note that any costs associated with acquiring and maintaining access to suitable spectrum has not been considered here. Although spectrum around 400MHz is considered optimum for this application, we have also given some consideration to 700MHz spectrum as an alternative (See Appendix D).



The radio spectrum between frequencies of 300 MHz and 3 GHz (UHF) is known as the "sweet-spot" because of its suitability for a variety of applications including TV, mobile communications and broadband.

[Image source: Ofcom]

In addition to reporting on work done and outcomes achieved, we make important recommendations for further work to validate and expand on the technical outcomes, a critical precursor to using the results in the future to underpin the case for spectrum access and allow for detailed planning in advance of network build. This will form an integral part of future DSO communications capability and rollout.

Through the utilisation of LTE technology, which is well-established in service and widely supported around the world, this study has focused on the specific requirements for an upload-centric data network supporting future DSO operations and has facilitated the creation of planning rules for a comprehensive and resilient operational network to provide Smart Grid connectivity. Thus, we are confident that the desktop study we have undertaken will play a pivotal role in enabling Distribution Network Operators to transition to a smarter electricity network and ultimately a UK-wide low carbon economy.

2. Technical Analysis

Methodology

The following steps were carried out to provide an outline LTE data communications network design:

- Determine outstation quantity and density in 2km squares, thus highlighting rural & urban areas.
- Determine and agree generic data upload requirements
  [Note – Downlink requirements considered secondary].
- Agree network design assumptions
  [e.g. Outstations to have a simple non-directional antenna at 2m above ground level].
- Carry out an initial design exercise to determine the quantity of Base Station sites required to serve a high percentage of outstation sites. Calculate the range of average upload times.
- Two further tranches of sites were considered as Base Stations in the following priority order:
  (i) Other WPD sites highly suitable for development and integration into the network.
  (ii) 3rd Party and other sites with more onerous costs and timescales associated with them.
- Produce an enhanced network design, essentially by adding Base Stations as required to increase coverage (to typically >90%) and ensure the average data upload times meet the specified capacity requirement.
- Assess backhaul implications of the proposed Base Station network locations.
- Carry out an initial optimisation exercise to minimise infrastructure and maximise inherent network resilience.

Each of the above steps are described in greater detail in the sections below:

Substation Density

From a list of the Primary and Distribution substations to be monitored, the number of substations in each 2km square was counted and plotted both numerically and by numeric density band. This provided a link with a previous study commissioned by the Energy Networks Association and carried out by Telent[1], indicating the likely magnitude of data volumes, area by area. It was felt that this approach would both validate the current analysis and facilitate comparisons with the previous study.

[1] DNO – Smart Grid Communication Requirements. Telent Report: E007146-001. August 2011

An example site density for the West Midlands is shown in Figure 2.1.

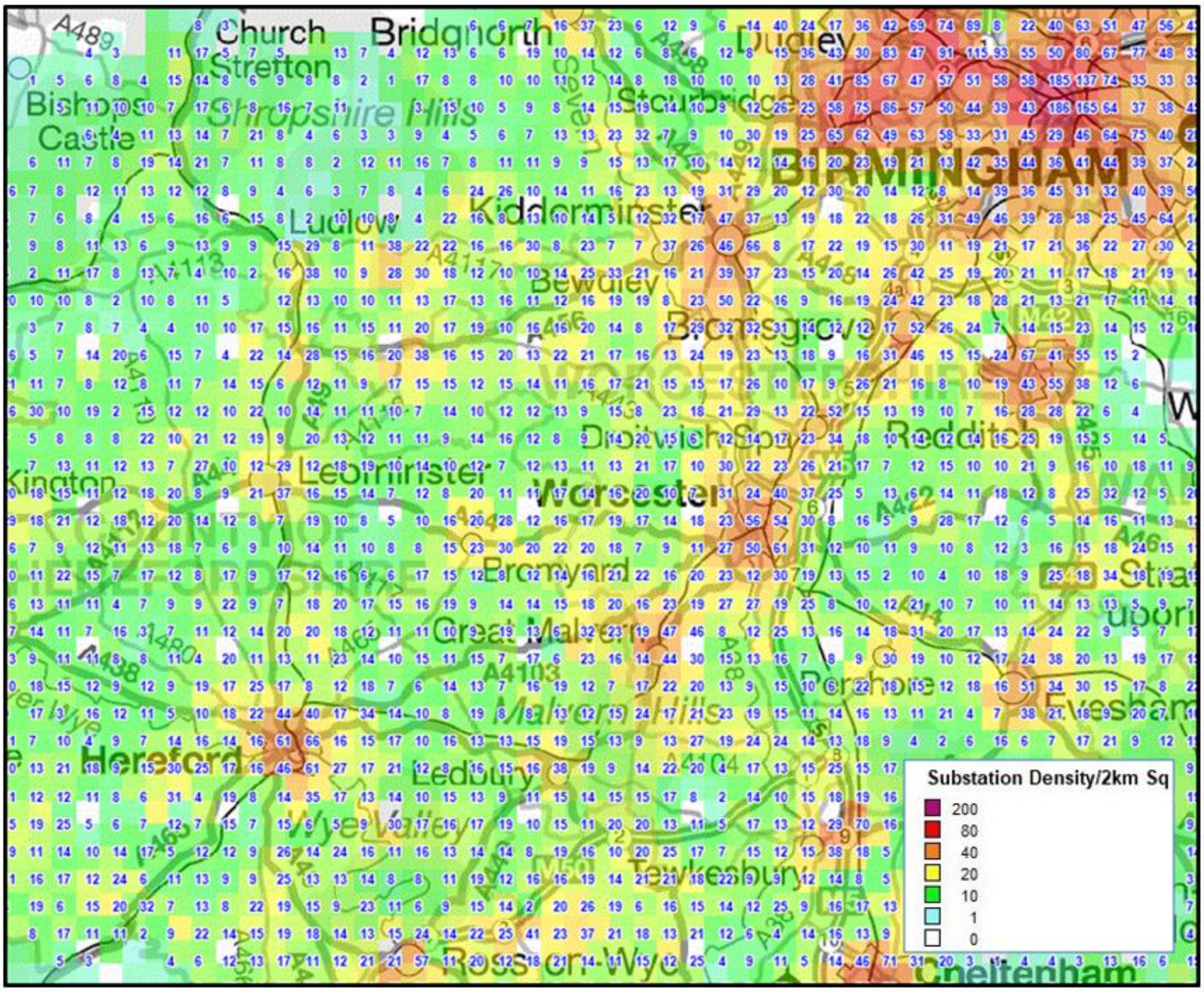


Figure 2.1 - Substation Density in the Midlands

This clearly demonstrates the extreme variation in density of substations between dense urban and rural areas, providing an early indication of the dual challenge of meeting area coverage in rural areas, whilst meeting traffic (data volume) requirements in urban areas.

At a joint workshop between WPD and JRC designed to consider the sources and volumes of monitored data, it was clear that the need to convey analogue measurement dominated the data requirement. Considering the number of distribution sites (11kV to 415V) compared to primary substations, bulk supply points, pole mounted re-closers, sectionalisers, fault passage indicators and new distributed energy resources etc., it was concluded that distribution substations dominate for data volumes.

The data supplied for the WPD licence areas under study indicated that there were around 1,600 primary substations and 193,000 distribution substations in 2018. In terms of network growth over the period under consideration, in contrast to data volumes and points of connectivity which are predicted to grow by orders of magnitude, the total number of distribution substations is unlikely to exceed 200,000; and the number of personnel in the workforce will be largely stable.

The list of Primary Substations includes bulk supply points, whilst the list of distribution sites includes pole mounted re-closers as well as both ground-based and pole-mounted transformers.

It was concluded that for the purposes of this study a distribution substation might have 25 analogue measurement points, whilst a primary substation might have 50 analogue measurement points.

An analogue measurement was assumed to be represented by 128 bytes of raw data.

128 bytes = 128 x 8 = 1024 bits

With a 2 times allowance for security overhead and a further 2 times allowance for protocol, the required volume of data would be 4096 bits. In recognition of the need to convey digital measurements (switch positions) a further 50% allowance was added.

Resulting data for a set of measurements = 4096 x 1.5 = 6144 bits.

Whilst more work would be required to optimise this volume and produce specific data volumes for different types of monitored asset, the simplicity of this assumption allows the volume of overall data to be easily scaled, when considering other scenarios. It was also recognised that by explicitly stating the data volume assumptions, changes in data volumes which are at present highly subjective can readily be made. One aspect likely to change will be the security environment in that if digital control signals are subjected to end-to-end encryption, their contribution to data traffic could increase markedly.

Initial Data Volume / Data Rate Calculations

Before considering actual base station sites and planning coverage, it was considered useful to understand the total volume of data, the possible number of base station sites, the time available to collect the data and from this calculate the data rates possible.

Table 2.1 shows the data volume calculation for all WPD areas, using the above assumptions.

Total number of bits:
(6144 bits per 'analogue' measurement)

	Number of Sites	Analogue measurements per site	Total Number of Analogue Measurements	Proportion of Total Analogue Measurements	Single Substation kBits	All Substations GBits
Primary Substations	1600	50	80000	1.6%	307.2	0.5
Distribution Substation	193000	25	4825000	98.4%	153.6	29.6
	194600		4905000			30.1
				Average data volume	**154.9**	**kbits per substation**

Table 2.1 - Volume of Data considering all WPD areas

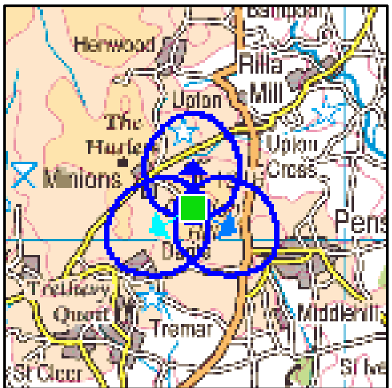


Figure 2.2
Typical 3-Sector Base Station

An LTE base station site will typically consist of three sectors, allowing the resources (data capacity) to be re-used in three specific directions (120° in angular separation) as shown in figure 2.2 and the adjacent picture.

The WPD DNO regions cover an area of around 55,524 km^2. If it is assumed for a simplistic starting point that this area is uniformly served by 3 sector base-stations, where each sector has a reach (site coverage radius) of 10km, then 530 sectors would be required.

3-Sector Base Station mast used at Portishead for Phase 1 trials

If it is assumed that all data is to be received over a period of 3 minutes (180 seconds), then each sector would need to receive data at a rate of:

30.1 Gbits/ (530 sectors x 180 seconds) = 315kbits/s

To understand the possible upper data rate, a densely populated sector in the West Midlands (Oldbury) was considered, containing around 2000 substations.

For 154.9 kbits per substation, the total volume of data would be:

154.9 kbits x 2000 substations = 310 Mbits

The required data rate, spread over 180 seconds would be:

310Mbits/180 seconds = 1.72 Mbits/s

This assumes that the task of switching between multiple eNodeBs, all receiving relatively small volumes of data, is not severely time limited by operational overheads.

For the LTE mode under consideration here (3MHz TDD 6:2:2 frame structure [Upload : Download : Subframe], the upper theoretical data rate would be around 2.8 Mbits/s [2]. This initial assessment provided an understanding of the volume of upload data and possible upload data requirements.

Prediction of Upload Data Rate

As part of the Portishead trial, measurements were undertaken by WPD of the upload and download link performance between the three eNodeB sectors at Portishead and nine outstation or CPE (Customer Premise Equipment) locations. These measurements are outlined in various test reports and supporting documentation[3].

Of prime importance is the data rate at which data may be uploaded from the remotely monitored point (CPE) to the eNodeB. During the testing, download and upload data rates were measured individually and bi-directionally for 'small' packets of data and individually for 'large' file transfers, using different equipment and antenna configurations. This was intended to simulate the type of traffic typical of a utility network which may differ from consumer i.e. commercial network traffic profiles.

The rate of data transfer is closely related to the ratio of 'wanted' received signal to 'unwanted' received noise, where received noise includes contributions from received interference, locally generated site noise and noise generated within the receiver. Link path predictions along with the associated assumptions allow both the wanted signal and the various noise factors to be modelled. From the resulting 'signal-to-noise' ratio, a value of achievable data transfer rate is determined.

The relationship between 'signal-to-noise' and transfer rate is the key assumption in ultimately calculating how long it would take to transfer all of the required data between the monitored locations (CPE's) and the allocated base station sector (eNodeB).

[2] Based on calculations referencing Tables 7.1.1.1-1 & 7.7.7.2.1-1 for Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 15).
[3] WPD eLTE3.4 Portishead Test Report [Unpublished at the time of writing]

A gas control engineer's view of the distribution network.

The time taken to transfer all the data between monitored locations allocated to a base station sector, referred to as 'upload time' herein, is a key parameter for a utility network and a fundamental differentiator of a utility network from a normal commercial public mobile phone network. Consumer networks are characterised by the peak data-rate in the download path under optimum conditions. This measurement has little relevance in a utility data network where most data traffic is in the upload direction and substations may be distant from a base station and with an obstructed radio path.

From a utility control engineer's perspective, the key parameter is the time taken to establish a comprehensive view of the network status following an incident such as an electricity network major change of state, be it power outage, instability on the network or power supply restoration. This dictates the amount of time the control engineer or network management system has to survive using the last recorded data. It is akin to the amount of time taken by windscreen wipers and washers to restore vision to a car driver when a load of mud is thrown onto the windscreen. For a few seconds, the driver may have to proceed with only a historic view of what the road ahead looked like before the incident, while the windscreen clears. This is the analogy for the control engineer as they wait for the telemetry system to re-establish the status following a major incident on the network.

A control engineer's view of the electricity transmission network. [Picture courtesy of National Grid]

The 'signal-to-noise' to upload data rate characteristic used within this study is based upon the 'bi-directional' upload measurements and reported 'signal to noise' (SINR) from the Portishead trial. This characteristic is shown in figure 2.3.

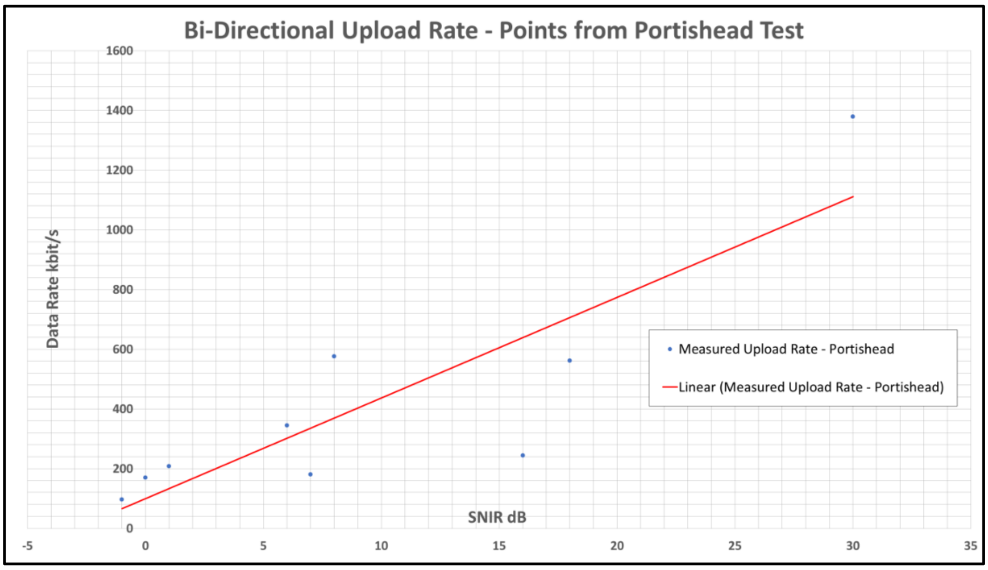


Figure 2.3 – Portishead - Data Rate vs Signal-Noise (SINR)

It is understood that the data capacity at Portishead, when these measurements were being taken, was divided between the three eNodeB sectors, rather than allocated to each sector. This will have resulted in a reduction of data rate of between one third and one half.

The simple (Portishead) linear characteristic in Fig 2.3 was used to maintain the consistency of reported results throughout iterations of the analysis, knowing that a simple up-scale (perhaps of 2.5x) may result in more realistic upload times.

Further work is needed to derive a practical, realistic characteristic, which is expected to be a scaled version of the theoretical characteristic, as outlined in Appendix A.

Link Budget

To enable predictions be performed, it is necessary to define a received signal level threshold, above which data can be successfully sent and also define the fixed elements of the noise environment (thermal noise degraded by the receiver performance and additional site noise) to enable the 'signal-to-noise' calculations to be performed.

The details of the 'Link Budget' calculations are shown in Appendix C.

Portishead Coverage Calculations

For the Portishead site (eNodeB) and outstations (CPE's), coverage calculations were performed in-line with the link budget used within the study (Outlined in Appendix C).

The resulting map of 'reference signal received power' (RSRP) is shown in figure 2.4

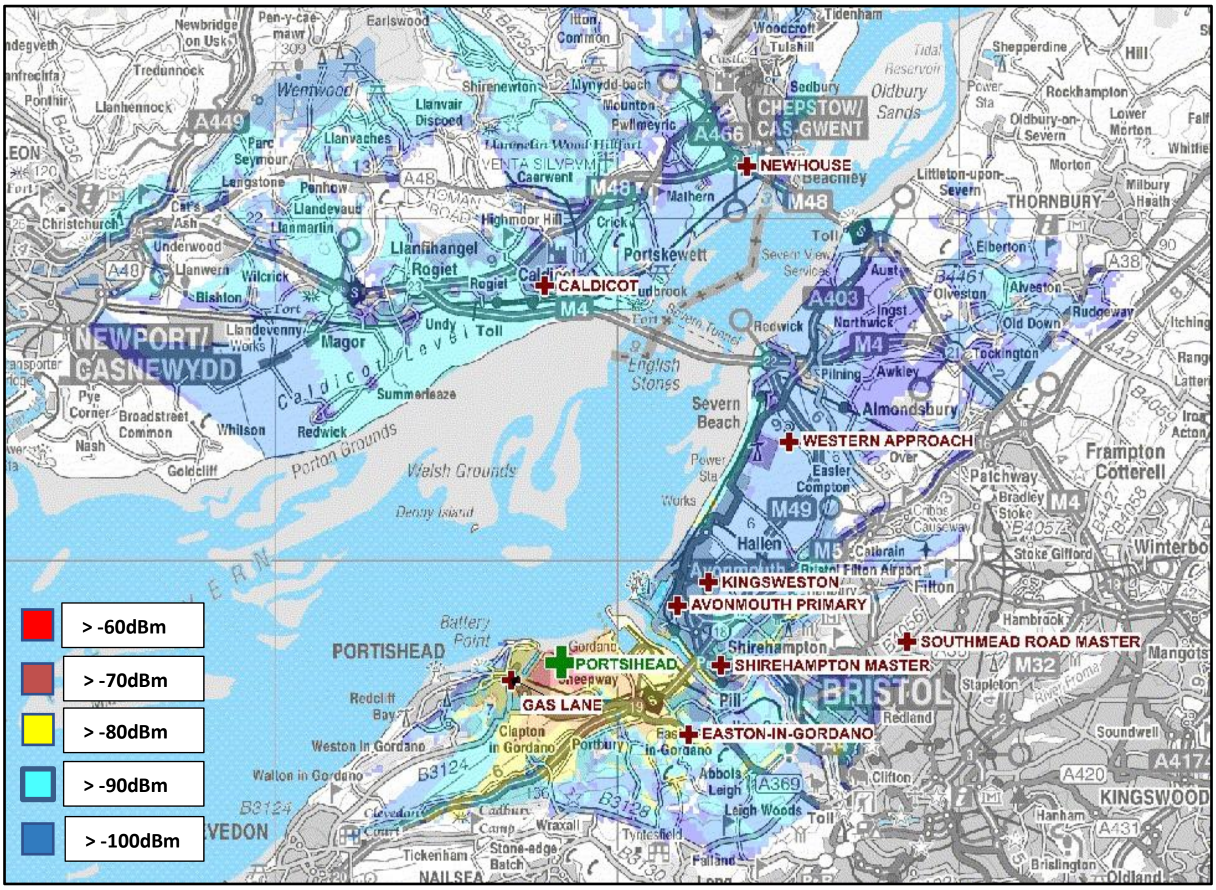


Figure 2.4 – Portishead Trial Site Locations & Predicted Received Signal (RSRP)

For each of the outstation (CPE) sites, the predicted level of received signal (RSRP) and signal-to-noise (SINR) was compared with measurements recorded by WPD, as part of the Portishead trial.

The predicted level of signal-to-noise was used with the signal-to-noise to upload data rate characteristic (figure 2.3) to calculate the predicted resulting upload data rate.

The signal level (RSRP), signal-to-noise and derived upload data rate comparisons are shown in figures 2.5 to 2.7.

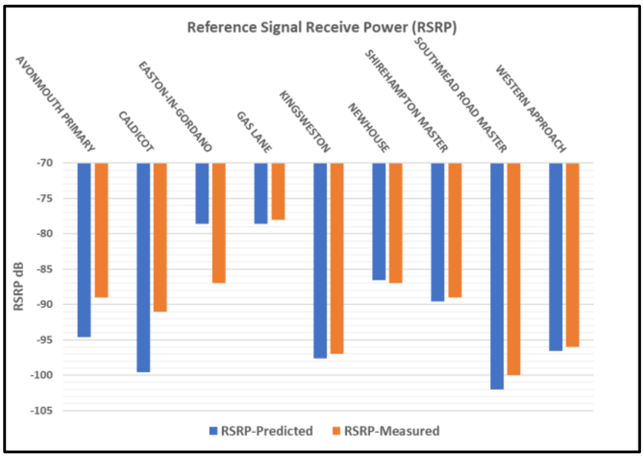


Figure 2.5 Portishead – Measured/Predicted Receive Level Comparison

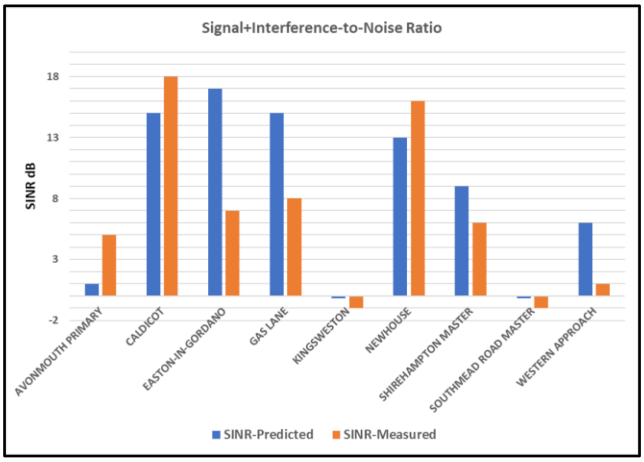


Figure 2.6 Portishead – Measured/Predicted SINR Comparison

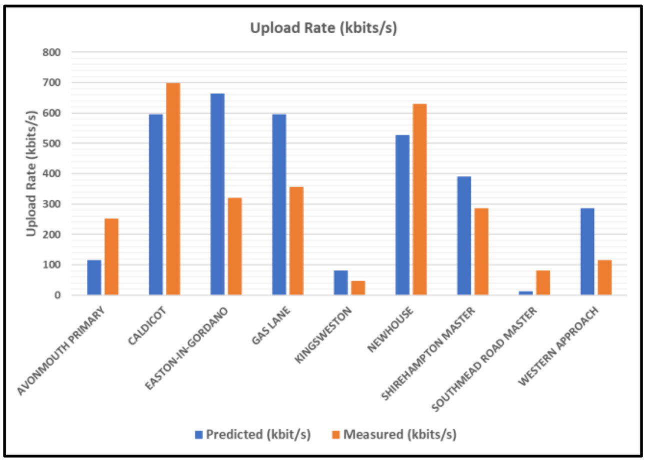


Figure 2.7 Portishead – Measured/Predicted Upload Rate Comparison

Although a simple comparison over a very few points, these outcomes provided a useful check of the approach and an early guide to some of the uncertainties.

A large wind turbine in close proximity to the Kings Weston substation may contribute to the relatively poor upload

West Midlands and South West LTE Network Planning

Initial Plan using existing WPD Communications Sites

The initial aim was to investigate the predicted performance for LTE networks in the West Midlands and the South West, utilising the existing WPD scanning telemetry and DMR (Digital Mobile Radio) base-station sites. These sites already have back-haul connectivity to the WPD data network via microwave or fibre-optic links. Further sites added to these networks would incur additional cost, for example requiring new structures and connectivity back to the existing data network(microwave or fibre).

Within the two areas, the number and type of sites[4] considered are shown in Table 2.2.

	Scanning Telemetry	Digital Mobile Radio
West Midland	28	15
South West	38	6

Table 2.2: Initial sites in the West Midlands and South West

As the West Midlands is surrounded by areas not considered within this study, scanning telemetry sites from other areas (some belonging to other DNO's) were included, in boundary areas, to ensure coverage to the boundary.

For each site, three antenna sectors were assumed to be at the height of the existing ST or DMR infrastructure and existing values of feeder loss were used.

Coverage predictions principally result in a value of download signal level, signal-to-noise (SINR) and the site/sector providing the best quality signal (combination of signal level and SINR). The inferred uplink performance is calculated from these values. Link budget calculation details are shown in Appendix C.

The prediction delivers two key metrics:

- From the values of signal level, signal-to-noise and receive threshold, a decision is made of whether the outstation (CPE) is served; and
- From the signal-to-noise, a value of upload data rate (as previously described) is calculated and this is used along with the information regarding the best serving sector and corresponding data from other outstations (CPE's) allocated to the same sector, to calculate the time required to upload all data from all allocated sites, to each sector.

The resulting coverage maps for the West Midlands and South West, assuming that the outstations (CPEs) have a simple non-directional antenna at 2m (above ground level), are shown in figures 2.8 and 2.9.

[4] Some scanning telemetry sites have DMR. The sites counted as DMR sites are those only used for DMR.

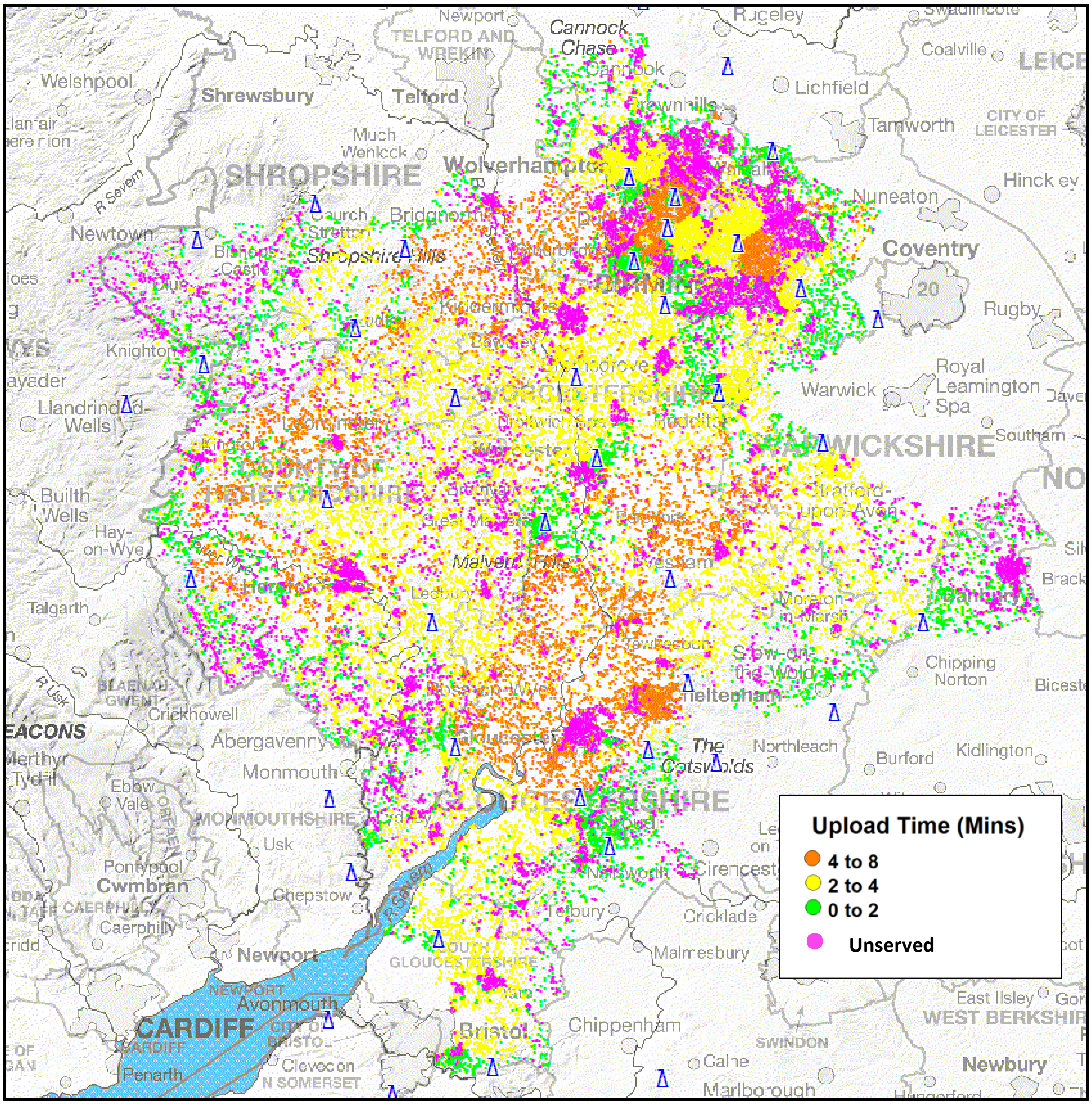


Figure 2.8 West Midlands Coverage: Scanning Telemetry and Digital Mobile Radio Sites Only

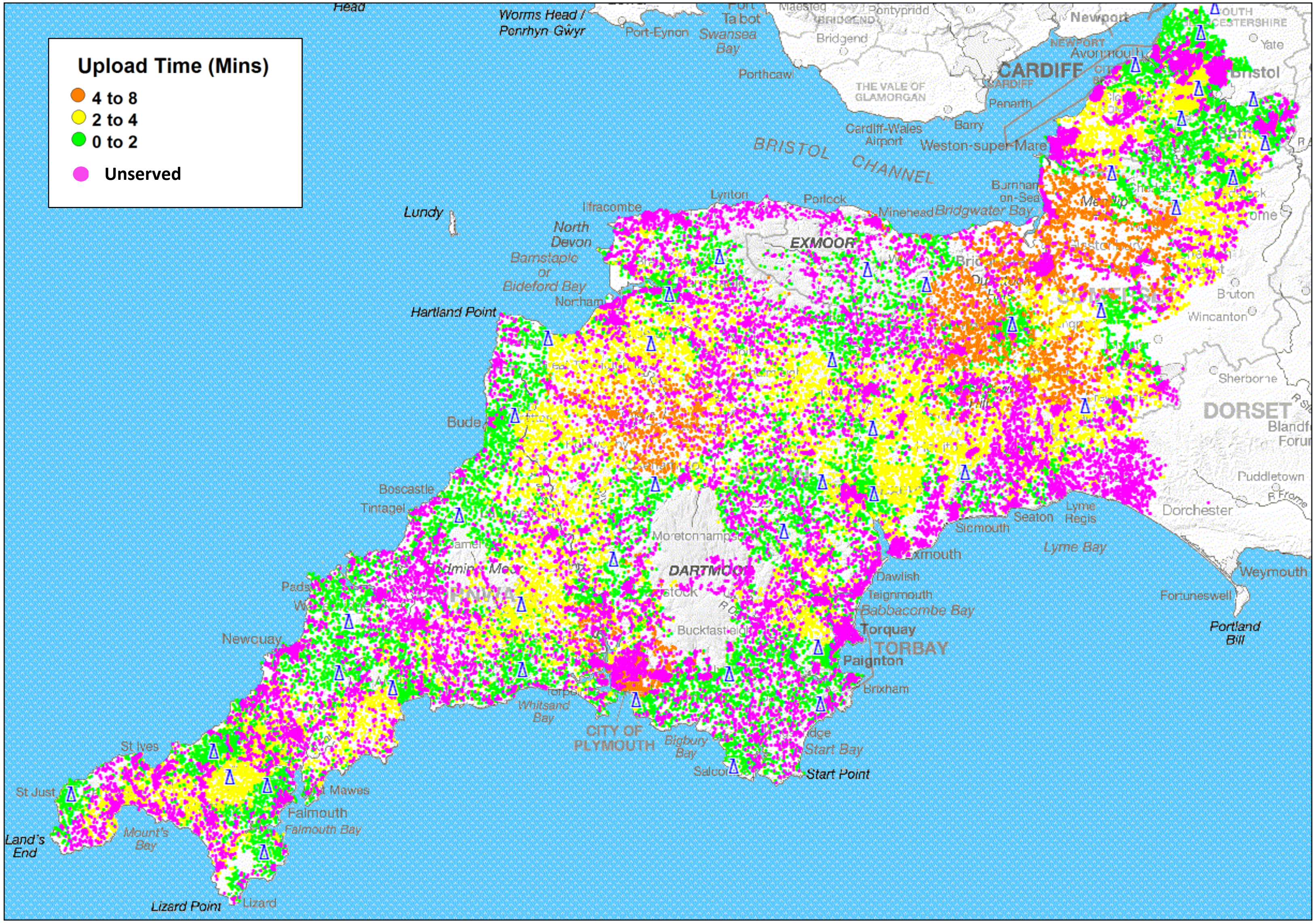


Figure 2.9 South West Coverage: Scanning Telemetry and Digital Mobile Radio Sites Only

The corresponding served / unserved statistics using only ST and DMR sites are shown in Tables 2.3 and 2.4

West Midlands	Primary	Distribution	Total
No. of Substations	198	40863	41061
Served: Antenna at 2m agl			
111 Sectors	Primary	Distribution	Total
	156	30288	30444
	78.8 %	74.1 %	74.1 %

Table 2.3: West Midlands Coverage Statistics: ST and DMR Sites

South West	Primary	Distribution	Total
No. of Substations	545	53036	53581
Served: Antenna at 2m agl			
131 Sectors	Primary	Distribution	Total
	384	33855	34239
	70.5 %	63.8 %	63.9 %

Table 2.4: South West Coverage Statistics: ST and DMR Sites

The distributions of the number of sectors against time to upload all data from sites allocated to a sector are shown in figures 2.10 and 2.11.
These show upload times are constrained in relatively few locations.

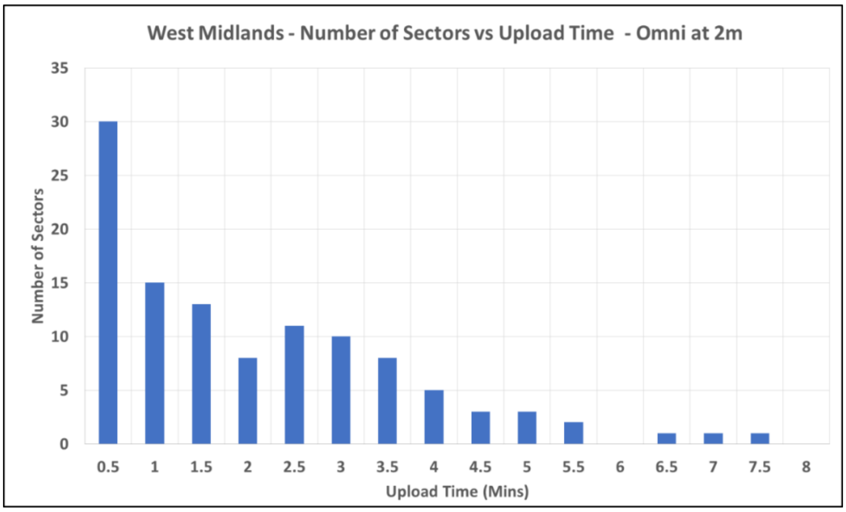


Figure 2.10 West Midlands - Upload Time Distribution

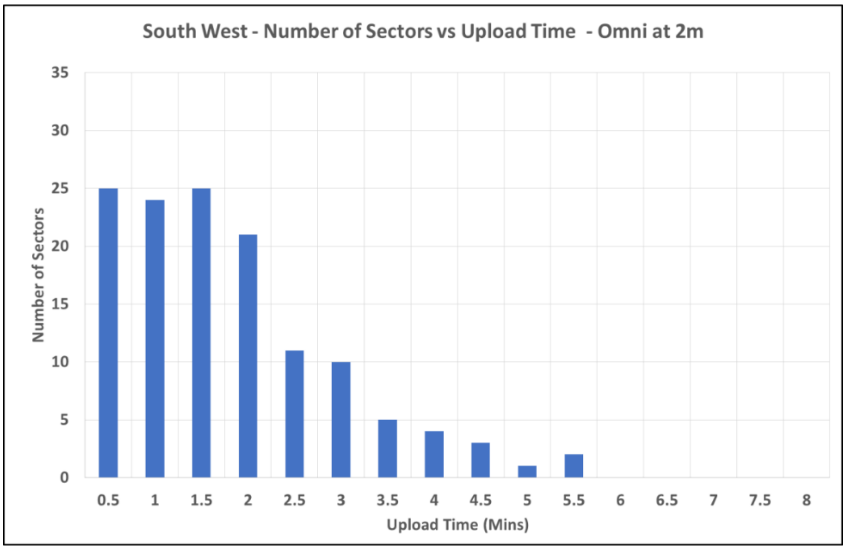


Figure 2.11 South West - Upload Time Distribution

Enhanced Plan using Additional Sites

Base-station sites were added to enhance coverage and performance; beyond 74% and data upload time up to 7.3 mins for West Midlands; and correspondingly, 64% and 5.5 minutes for the South West.

The aim was to add sites at WPD owned locations and where possible at locations with microwave or fibre-optic connectivity to the WPD data network. The prime candidate locations were the bulk supply points and the larger primary substations. In areas where a suitable WPD owned site could not be found, third-party structures have been be used. In some areas it might be possible to use two or more WPD owned sites in place of a third-party structure or WPD could establish a new base-station structure with possible scope to add third-party users.

St Tudy in Cornwall is a typical primary substation site with existing fibre connectivity, power back-up facilities and adequate space to install a new LTE base station.

At new sites, it had been assumed that a structure could be built to place the antenna systems between 15m and 18m above ground level (a.g.l.) and the site located near to the substation main entrance, sufficiently clear of HV infrastructure. On third party structures, a judgment has been made on an achievable height for the LTE antenna system.

Sites were added primarily to increase the number of outstations served but noting that this would improve resilience against site failure and share traffic load, thereby reducing upload times. Network performance was predicted at various stages, so it was possible to judge progress and where necessary add sites to share traffic load / add resilience in the areas where sectors were seen to be most heavily loaded.

For the data capacity assumptions made and number of sites thought practical, it appeared that the maximum upload time for all data to a sector was around 4 to 5 minutes. As outlined in Figure 2.3 (Upload Data Section) the practical data rate might be twice that assumed, allowing the maximum data upload time to approach 2 minutes. More work is needed to confirm data requirements and LTE data transfer performance with typical telemetry data.

In line with many networks, adding base-station sites eventually results in a situation of diminishing returns, whereby the cost per increase in coverage reaches a threshold. This is illustrated in figure 2.12 for coverage in the West Midlands area.

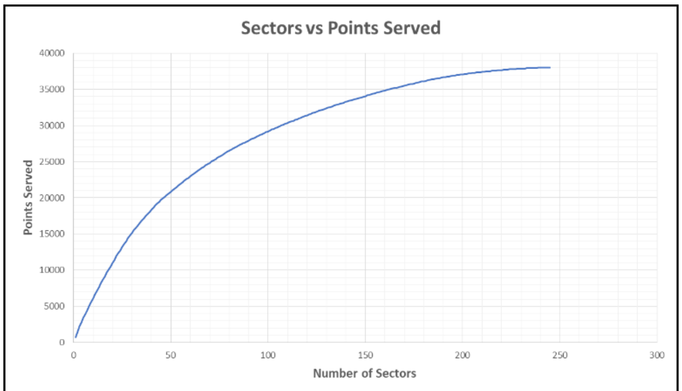


Figure 2.12 – Diminishing Return Sites – Sectors in the West Midlands

The networks for the West Midlands and South West have been developed to a point near to the threshold where further work on checking the prediction accuracy, system performance and data requirements is necessary, in order to guide further development.

3. Outcomes of the Analysis

Within the two areas, the total number of Base Stations in the enhanced design was 229. The total number and breakdown by type of site[5] are shown in Table 3.1.

	Scanning Telemetry	DMR	Primary Substation	WPD Depot	Microwave Radio	New/Third Party	Total
West Midlands	28	15	40	1	2	4	**90**
South West	38	6	69	1	0	25	**139**

Table 3.1: Sites in the West Midlands and South West

The coverage maps for the enhanced West Midlands and South West networks, assuming outstations have a simple non-directional antenna at 2m (above ground level), are shown in figures 3.1 and 3.2.

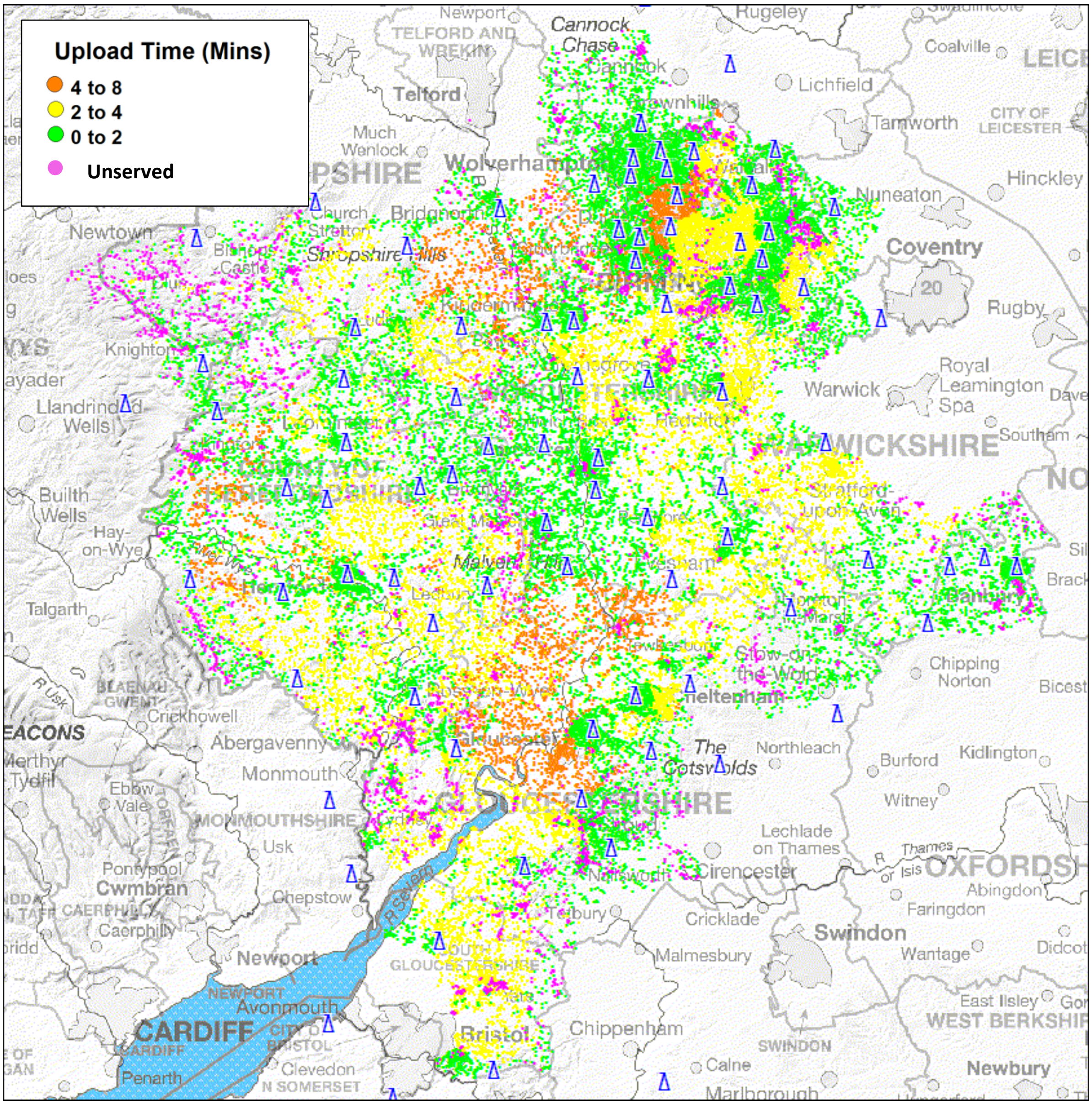


Figure 3.1 West Midlands Coverage: All Sites

[5] Some scanning telemetry sites have DMR. The sites counted as DMR sites are only used for DMR

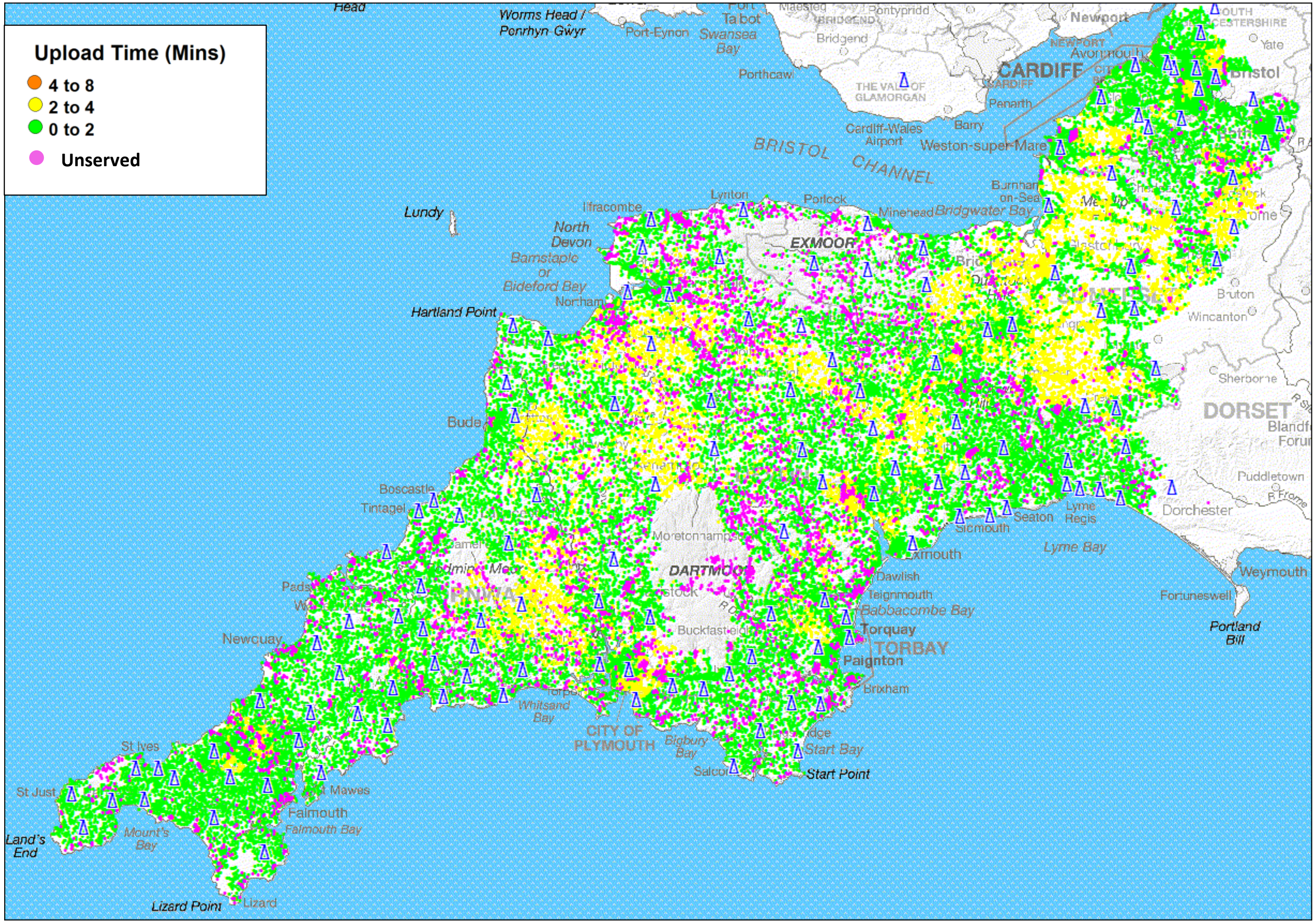


Figure 3.2 South West Coverage: All Sites

The coverage statistics using all planned base-station sites are shown in Tables 3.2 and 3.3.

West Midlands	Primary	Distribution	Total
No. of Substations	198	40863	41061
Served: Antenna 2m agl			
249 Sectors	Primary	Distribution	Total
	183	37232	37415
	92.4 %	91.1 %	91.1 %

Table 3.2: West Midlands Coverage Statistics: All Sites

South West	Primary	Distribution	Total
No. of Substations	545	53036	53581
Served: Antenna 2m agl antenna			
403 Sectors	Primary	Distribution	Total
	510	47123	47633
	93.6 %	88.9 %	88.9 %

Table 3.3: South West Coverage Statistics: All Sites

The distributions of the number of sectors against time to upload all data from sites allocated to a sector are shown in figures 3.3 and 3.4.

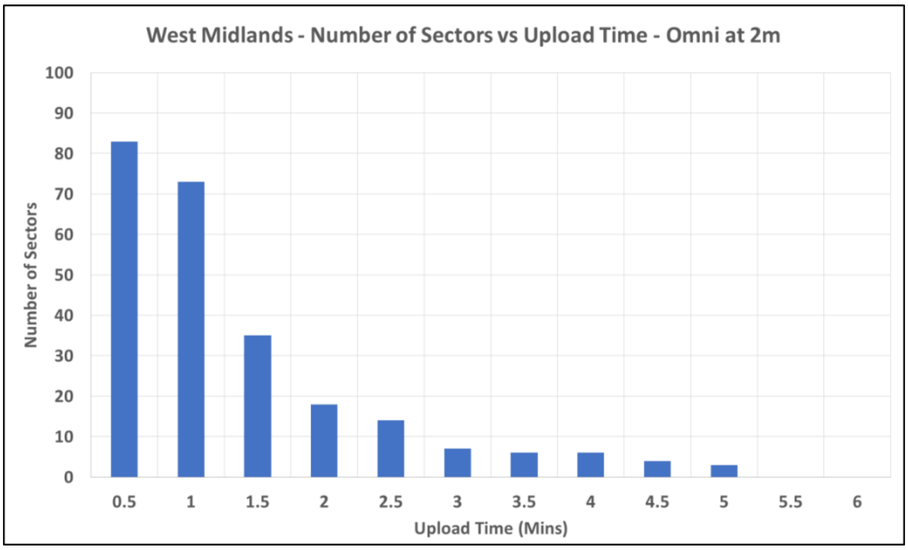


Figure 3.3 West Midlands - Upload Time Distribution: All Sites

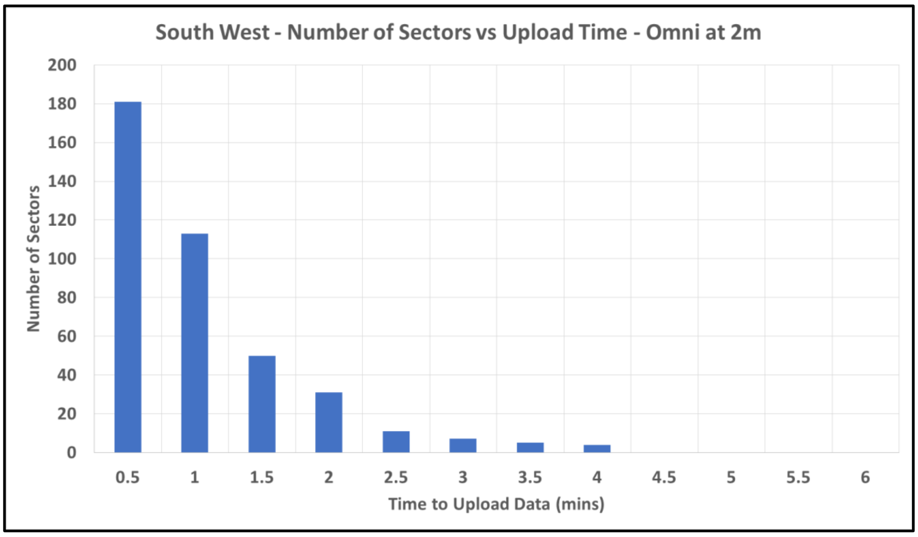


Figure 3.4 South West - Upload Time Distribution: All Sites

Base-Station Connectivity (Backhaul)

Where possible, additional base-station sites have been added with either existing fibre-optic or microwave connectivity to the WPD data network. When adding sites with no existing connectivity, a check has been made to see if a ‘single hop’ microwave path might be possible.

In some instances, an obvious solution was not apparent and further work would be required. Within the two areas, the status of the backhaul feed planning is shown in Table 3.4.

	Existing Fibre Link	Existing Microwave Link	New ‘Single Hop’ Microwave Link Thought Possible	Link Solution Required
West Midlands	7	50	29	4
South West	14	50	48	27

Table 3.4: Backhaul Feed Status within the West Midlands and South West

The status of backhaul feeds to the planned base-stations (ENodeBs) are mapped in Figures 3.5 and 3.6.

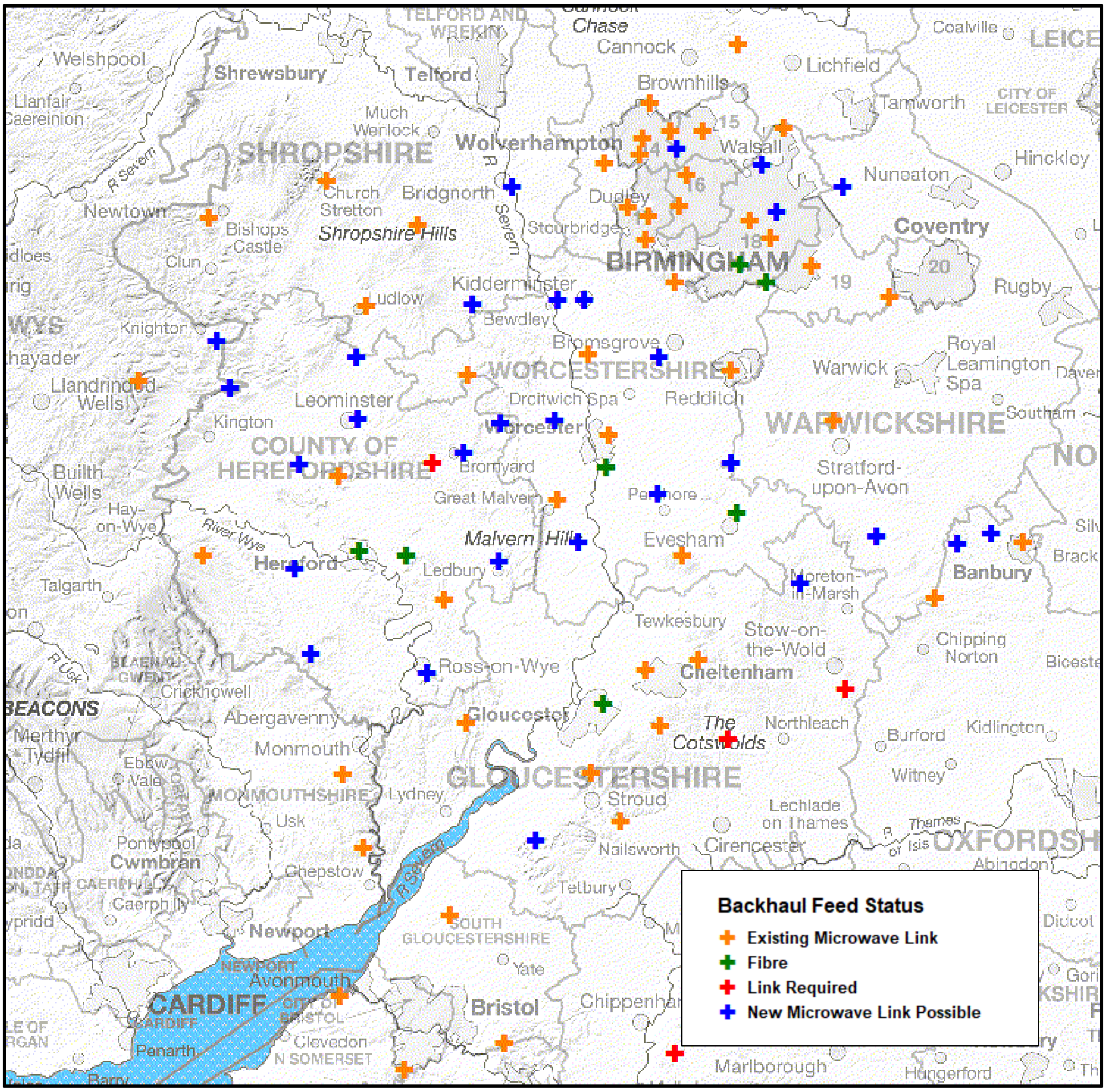


Figure 3.5: West Midlands – Backhaul Feed Status

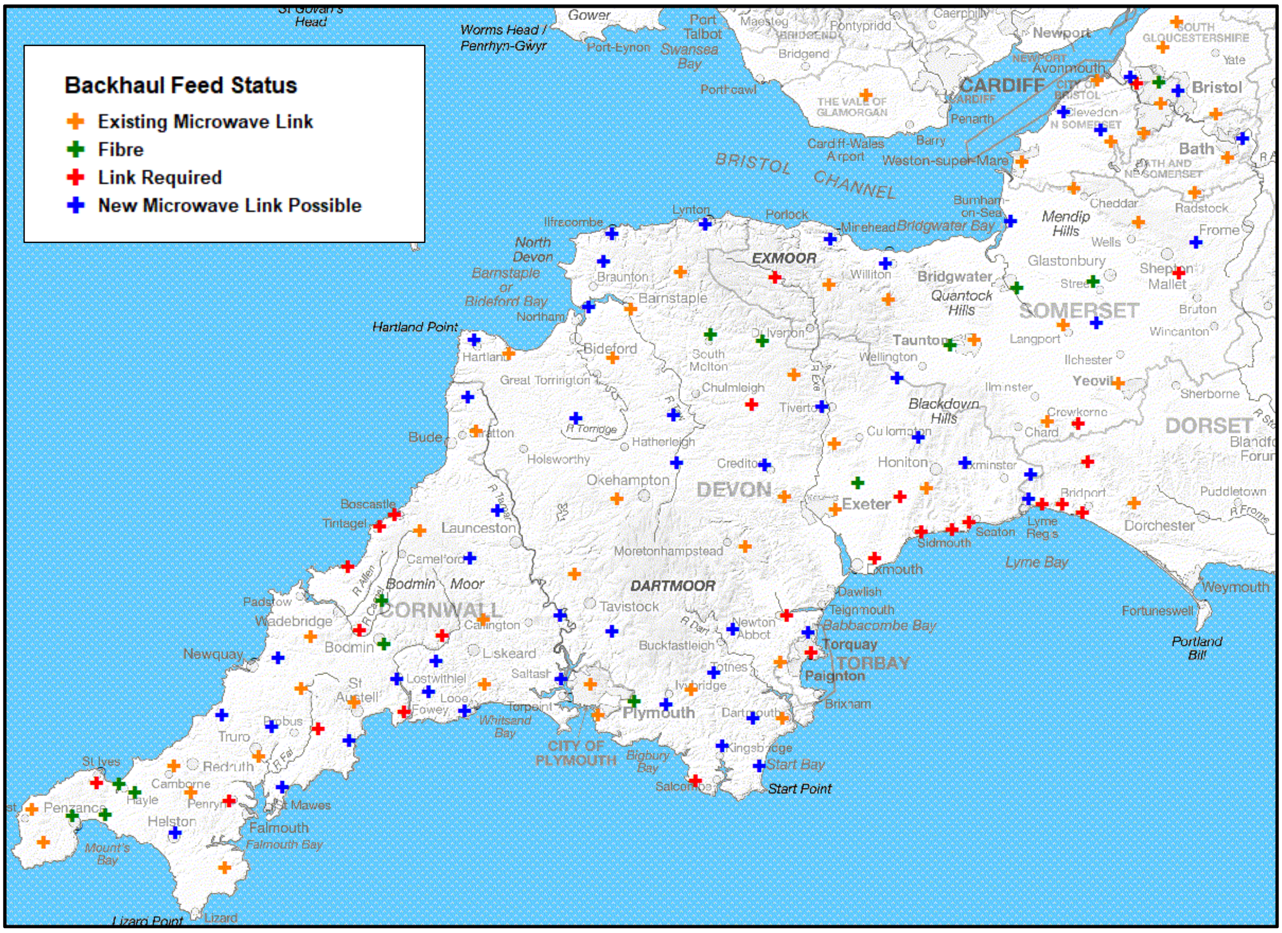


Figure 3.6: South West – Backhaul Feed Status

It is anticipated that it would be possible to extend backhaul to a group of otherwise unconnected base-stations by the addition of dedicated link sites. As indicated in Figure 3.6, the group of sites serving isolated areas around Lyme Bay do not have the possibility of a 'single hop' microwave backhaul feed, so it is likely that two or more specific link sites will be required to extend connectivity.

To provide resilience to the backhaul network, additional connectivity would be necessary. This planning would require further work beyond the scope of this initial study.

Sensitivity to increased outstation transmitted power & antenna height

Predictions have been performed with an outstation radiated power of +24.3dBm EIRP (270mW), given a user equipment (UE) power limit of 23dBm (3GPP Cat 4), 2dBi antenna gain and 0.7dB feeder loss.

UEs may become available that will operate at higher maximum power, and thus it is useful to understand how coverage might increase in the event that an enhanced link budget is possible. This has been investigated by considering a UE power increase of 4dB.

The LTE network has been modelled assuming an outstation antenna height of 2m, corresponding to the majority of monitored assets being distribution substation housed in GRP cabins. Primary substations with more substantial buildings and protective fences may readily utilise an antenna at an increased height, thus also addressing the need to ensure good communications to primary substations. Pole-mounted transformers are also likely to have antennas approximately 4m above ground level improving their performance beyond that modelled.

To understand the sensitivity of the results to antenna height and to more accurately assess the coverage to primary substations, the network has been modelled assuming an outstation antenna height of 6m above ground level.

The coverage statistics for these scenarios of increased UE power (+4dB) and increased UE antenna height (2m to 6m) are shown in Table 3.5 & 3.6.

West Midlands				
UE Power	**UE Antenna Height**	**Primary Substations**	**Distribution Substations**	**Total**
Nominal	2m	92.4%	91.1%	91.1%
Nominal + 4dB	2m	97%	96.3%	96.3%
Nominal	6m	97.5%	96.1%	96.1%
Nominal + 4dB	6m	98.5%	97.8%	97.8%

Table 3.5 West Midlands: Coverage for Increased UE Power and UE Antenna Height

South West				
UE Power	**UE Antenna Height**	**Primary Substations**	**Distribution Substations**	**Total**
Nominal	2m	93.6%	88.9%	88.9%
Nominal + 4dB	2m	97.4%	94.8%	94.8%
Nominal	6m	96.7%	93.4%	93.4%
Nominal + 4dB	6m	98.7%	96.9%	96.9%

Table 3.6 South West: Coverage for Increased UE Power and UE Antenna Height

Network Design Resilience

Coverage calculations assess if each outstation or asset is served by at least one base-station sector. Data transfer capacity calculations take into account which site/sector provides this coverage.
It is noted that many assets are served by multiple sites / sectors and this provides resilience should communications fail within a particular site or sector.

An assessment has been made of how many monitored assets have no alternative source, how many can use a different sector at the preferred base-station site and how many are served by an alternative base-station. In practice, many monitored assets will move seamlessly between sites / sectors as alternative link paths are continuously measured by the system and assets transferred to the most favourable route.

The resilience results for various configurations (Nominal Power, + 4dB above nominal power, 2m and 6m antenna height) are most easily shown graphically, as this allows easy comparison.

Distribution substations (assets) are most likely to be limited to an antenna height of 2m, whilst primary substation (assets) may more readily have an antenna at 6m. This is reflected in the results displayed in figures 3.7 – 3.10.

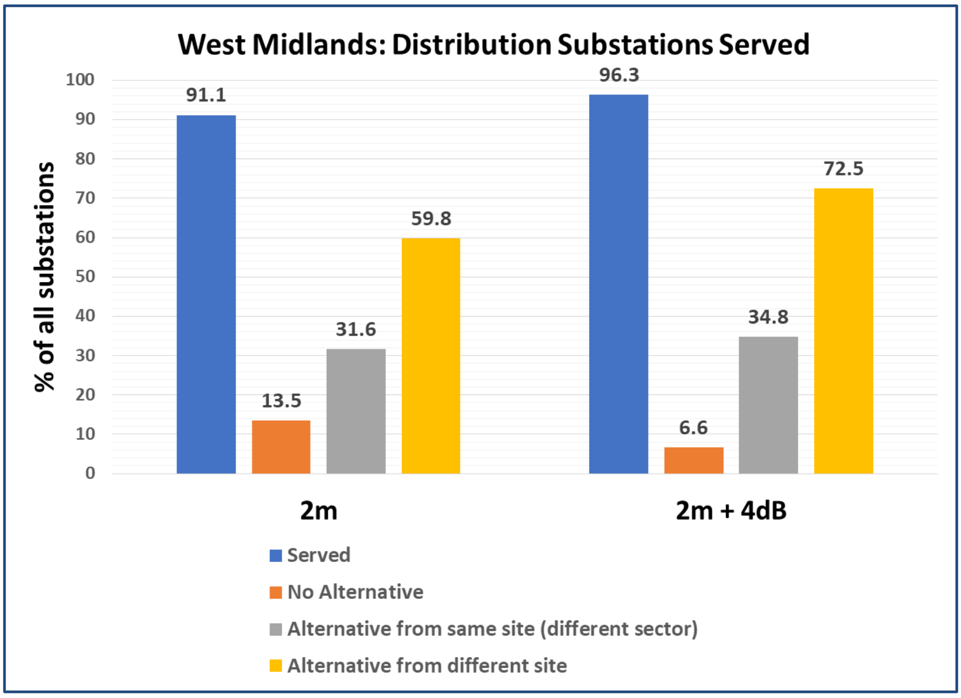


Figure 3.7: Resilience: West Midlands Distribution Substations

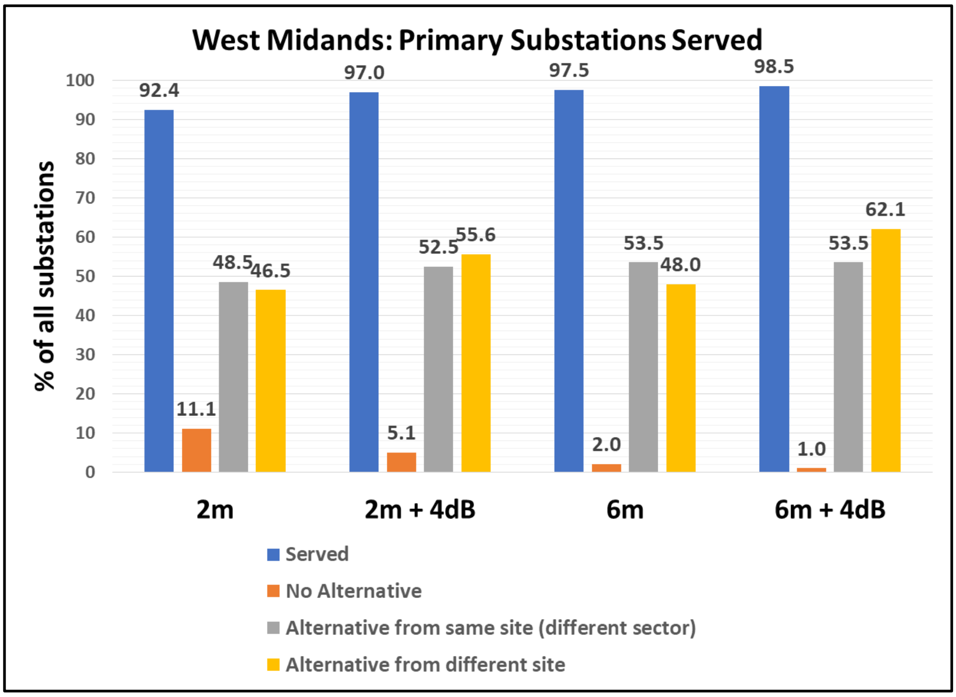


Figure 3.8: Resilience: West Midlands Primary Substations

In the West Midlands, with a 2m antenna height, 13.5% of distribution substations and 11.1% of primary substations are predicted as being served by only one base station / sector. The network resilience would be improved by increased UE nominal power (if equipment or regulations allow this) and / or antenna height.

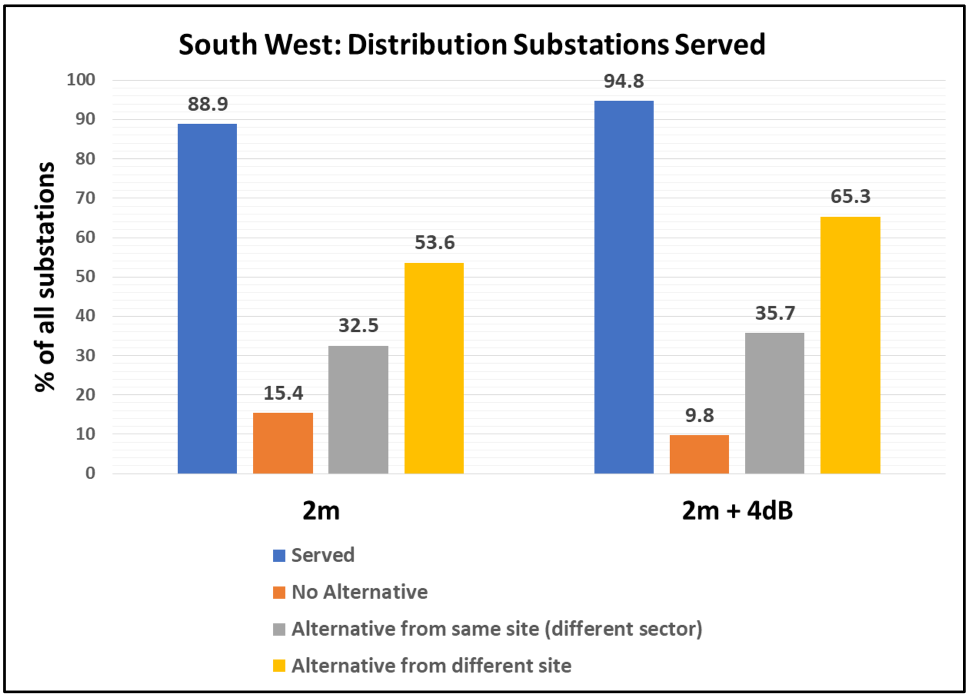


Figure 3.9: Resilience: South West Distribution Substations

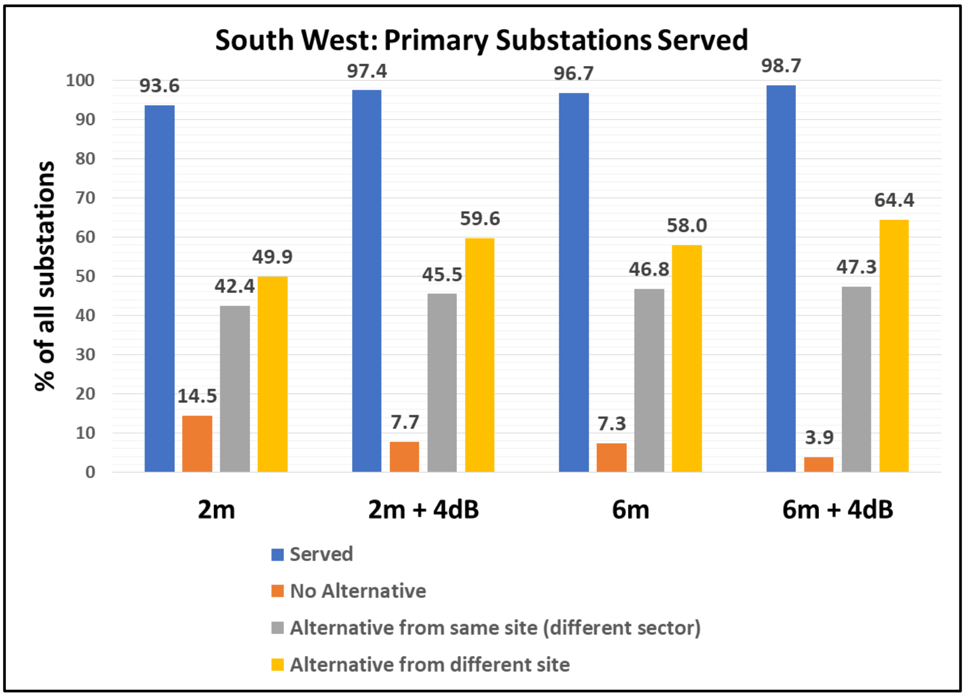


Figure 3.10: Resilience: South West Primary Substations

In the South West, with a 2m antenna height, 15.4% of distribution substations and 14.5% of primary substations are predicted as being served by only one base station / sector. The network resilience would be improved by increased UE nominal power and/or antenna height.

4. Network Costs

Although it was not within the Scope of the project to estimate the cost of the whole network, cost issues were considered as part of the network element design. From this analysis, a number of principles were noted:

- The majority of the cost of the telecommunications hardware arises from the CPE (Customer Premise Equipment) which therefore dominate network costs. The cost of the radio base station hardware is relatively minor;
- Outstation roll-out and installation costs will be aligned with other network investments, e.g. active network management and will form a small element of that investment;
- If LTE is the chosen technology, outstation costs will be similar even if a commercial public network is used instead of a private network;
- Outstation investment will be more beneficial and justified if served by a highly available private network rather than a potentially lower availability and less resilient public network;
- There may be further opportunities to leverage a private LTE telecoms network solution to facilitate local network monitoring & control i.e. switching via tablets and to provide wide area emergency voice communications;
- Subject to robust security provisions, a private LTE network could provide Wi-Fi coverage at substations for operational staff to enhance their efficiency when working in remote areas with no public network provision;
- LTE has the capability to provide CCTV security images [e.g. if an intrusion has been detected] and other augmented applications if sufficient capacity is available;
- Rollout of the private LTE network can be prioritised on constrained areas (Bulk Supply Points) if required;

With the anticipated investment in Smart Grids by the UK Energy sector estimated to be £40 billion up to 2040[6], the level of investment required to construct a resilient and highly available telecommunications network to monitor and control that infrastructure is insignificant in comparison and indeed may reduce overall spend due to 'SMART' features and optimisation.

Ruggedised LTE telemetry outstation suitable for external locations.

The key conclusions from the study show that by taking advantage of a utilities' portfolio of existing sites and infrastructure, costs can be minimised and delivery timescales made more certain. Key findings include:

- Sites can be largely sourced from within the utility's own asset base, hence site acquisition costs are not significant;
- Operating costs can be controlled through limited use of third-party sites based on individual business case and benefit analysis;
- Using existing sites, infrastructure, facilities and maintenance resource minimises cost as site access does not inhibit the time required to bring sites back to operation after an out-of-hours fault; and
- Because LTE is a commercial consumer market product highly dependent on software, network costs are based on a licensing model influenced more by features and number of connected devices than hardware costs (as was the case for previous generations of utility telecoms networks).

[6] https://www.carbonbrief.org/in-depth-how-smart-flexible-grid-could-save-uk-40-billion

5. Lessons Learnt

LEARNING – NETWORK DESIGN

- A utility LTE network differs substantially in its design and operations from a commercial public mobile phone network;
- Existing UHF SCADA base station sites alone proved insufficient for ubiquitous coverage and thus additional base station sites were added and optimised;
- That said, a utility has a wealth of assets than can be leveraged to develop a radio telecommunications network tailored precisely to meet it's needs;
- Adding sites and backhaul carries additional benefits as WPD may need these sites for SCADA. Some additional sites considered for coverage may also address capacity requirements;
- An economic solution will lead to a cap on the number of base station sites and limit outstation coverage to approx. 90% using the parameters agreed for in this study;
- Options remain available for connecting those outstations not reachable with the current design of LTE network should there be a business requirement to extend connectivity;

Utility UHF SCADA telemetry and microwave tower

- Increasing antenna height, directivity and / or power can provide improvements, possibly up to 97% of sites connected, but difficult terrain cannot be overcome simply by increasing power and / or antenna height;
- Since it was noted that TV coverage in a similar frequency band uses very high masts (up to 150m in the areas under examination), the model was run using very high antenna locations to investigate whether this might be the solution for challenging coverage areas. However, with a single frequency block used for utility networks, co-channel interference meant as many outstations were being lost through interference as were being gained by improved coverage;
- There is also a trade-off between coverage and interference issues, hence adding more sites beyond the optimum can result in diminished performance (an issue mobile networks encounter in congested areas);

Classic 330m UHF TV mast

- The study has quantified the number of base station sites required and thus the number of existing telecom sites and sites with existing backhaul connections. As expected, network coverage is more of an issue in rural areas with capacity more of an issue in urban areas;
- At the edge of a DNO area, there may be gains from using sites in an adjacent DNOs area. Thus, a collaborative approach by DNOs would be beneficial;
- Outstation antenna format and height have a significant influence on telecoms network design. The current study has typically assumed for example a compact, low profile antenna on the roof of a distribution sub-station cabinet. In a more detailed planning phase, it may be possible at certain sites to accommodate either antennas at a greater height or in some cases directional antennas albeit at the possible cost of compromising service resilience; and
- More detailed planning is also likely to offer scope for rotating sectors as a given base station site to further enhance connectivity, and possibly increasing the number of sectors to six per base station to enhance capacity in congested areas.

Pole mounted transformer with directional UHF SCADA antenna.

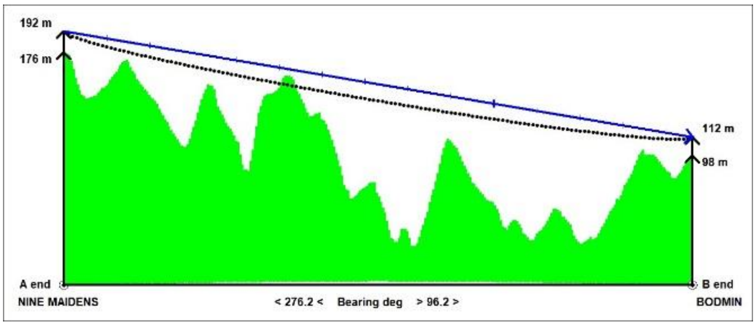
LEARNING – NETWORK PLANNING

- Traditional methods of planning a mobile network based on maximum download data speed are not applicable to a utility environment;
- The methodology developed is optimised for the specific data requirements as set out at the outset and developed during the study. This requirement, including transactional data and low-latency monitoring applications, is dominated by the need to upload analogue values and the timeliness of data transmission;
- Analysis timescales were minimised by using an efficient propagation model for the early stages of the work with a more accurate model being used at the later stages;
- Work has been done to optimise the network given base station and outstation distribution to ensure a robust and resilient network both in terms of backhaul diversity and base station failure;
- The number of outstations able to connect to two or more base stations or sectors and hence increase service resilience was greater than expected, supporting the case for installing omnidirectional aerials at outstations wherever possible;
- The use of MIMO (Multiple Input / Multiple Output) technology has limited potential to enhance performance at these frequencies, especially in the Uplink unless the newer CAT of UE is deployed;
- Further work is required to confirm data overhead requirements for cyber security, encryption and authentication; and
- The network may have spare capacity in some areas for non-critical data uses.

LEARNING – BACK-HAUL

- Where a base station site has existing backhaul, the available capacity will need to be reviewed to ensure that it is adequate;
- Where a fibre route appears to pass near a potential new radio site, it isn't always possible to access it for backhaul as there may be physical obstructions to the access route (roads, railways, rivers); [The map to the right shows a fibre route (in blue) which in this case can be accessed at St Tudy to facilitate construction of a base station there.]

- If a microwave link passes overhead, it cannot be assumed that the path can be intercepted to provide dual routed backhaul. Two-dimensional analysis of an area can be misleading. In the example illustrated above, it at first appears as if the unserved areas of Wadebridge and Bodmin (purple dots) could be addressed by intercepting the microwave links passing overhead (purple lines) and building an LTE base station in the valley between Wadebridge and Bodmin. However, the cross-section analysis (shown below) illustrates that the microwave path is almost 100m above the valley with steep sides, preventing a base station in the valley seeing either end of the link, meaning that an alternative solution has to be devised to serve important areas around Wadebridge and Bodmin.



Project Team at St Tudy Bulk Supply Point Primary Substation.

6. Recommendations for Further Work

While there is no immediate planned implementation following directly from this study, the outcomes are an important step in a process which could lead to the detailed planning & deployment of an operational telecommunications network supporting an effective, efficient and sustainable future smart grid system.

However, further work is necessary to fully establish the technical characteristics of a multi-site network capable of real-time operational control of DSO assets, integrating with and eventually replacing legacy communications networks. It is therefore recommended that further tests and measurements be undertaken on a multiple base station network with multiple vendor equipment to validate the network assumptions and design methodology from this study, under more realistic 'loaded network' conditions using simulated data and in the presence of both inter and intra-cell interference. It will also be an opportunity to consider communications requirement for operational voice and non-critical data.

Building on WPD's single vendor, single base station LTE evaluation trial at Portishead [Phase One], this Next Generation Wireless Telecoms analysis [Phase Two] has established provisional technical characteristics, radio network planning methodology and recommended further work that should be considered in Phase Three.

Sites have been identified in the Taunton area which would support a 'Phase Three' trial using three base station sites, having the added advantage of being in an area subject to network constraints. It is an essential pre-requisite of this further work that Ofcom make suitable radio spectrum available.

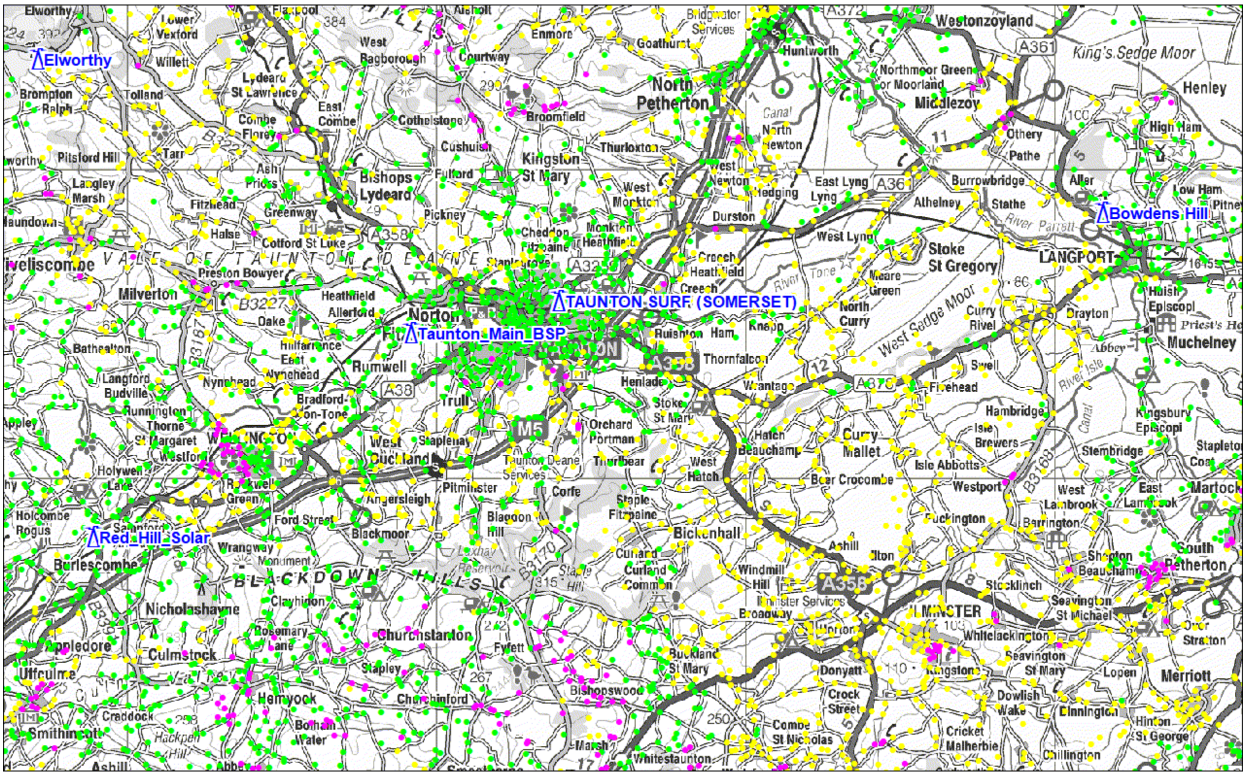


Figure 2.23: Resilience: South West Primary Substations

In summary, we recommend further work in order to:

- Validate propagation modelling, data volume assumptions and upload times, particularly in challenging geographic locations;
- Investigate and assess uplink interference effects and mitigation from overlapping coverage, and especially the influence on data capacity;
- Examine the resilience of an LTE network where substations can connect to more than one base station. Simulate base station and sector failures to confirm resilience hand-over;
- Compare data requirements with other DNO analyses;
- Further investigate network design optimisation;
- Specific testing will be carried out to determine operational characteristics in a 'live' operational environment and when loaded with real or simulated data, including an assessment of throughput in interference and non-interference environments;
- Analyse single and multiple antenna configurations and investigate potential MIMO gains;
- Assess potential for mobile data & wide-area emergency voice capability;
- Engage with Ofcom, Government & other utilities to facilitate spectrum access;
- Develop the security model required for live operations;
- Trial multi-vendor interworking; and
- Investigate whether when cybersecurity measures are deployed to protect digital values and statuses, their data volumes become significant compared to the analogue parameters considered dominant in this study

Glossary

Abbreviation	Term
a.g.l.	Above ground level e.g. antenna heights
base station	A site equipped with a number of (typically 3) eNodeB sectors & equipment
Bit	A single element of digital data, either '1' or '0'
Bulk Supply Point	Also known as Grid Substation. Transforms from 132kV to 66/33/11kV
Byte	8 bits of digital data
Cat 4	3GPP definition of versions LTE capability and interoperability, most significantly in Cat 4, upload limited to 16-QAM
CPE	CPE (Customer Premise Equipment), also referred to as UE (User Equipment)
dB	Decibel, a unit of measurement used to express the ratio of one value of a power or field quantity to another on a logarithmic scale
Distribution Substation	A substation transforming voltage from 11kV to 400/230V
DMR	Digital Mobile Radio, a digital successor to PMR with greater capability to carry digital traffic
DNO	Distribution Network Operator
DSO	Distribution System Operator
eLTE	Enterprise LTE – Fully 3GPP compliant specification derived from an Enterprise rather than Carrier scale use case and with a telemetry bias
eNodeB (eNB)	Evolved Node B (Equipment for one base station sector)
GRP	Glass Re-enforced Plastic – a common material from which electricity substation housings are constructed
LTE	Long Term Evolution - 4th Generation mobile phone technology (4G) specifically designed to carry data traffic
MIMO	Multiple Input - Multiple Output, a technology using multiple aerials for transmit and receive to increase the capacity and resilience of a radio channel
NIA	Network Innovation Allowance, a government sponsored scheme to encourage innovation in energy networks and services
Outstation	Any network node requiring an LTE data connection to a base station. In the case of an electricity network, these are mostly substations [Primary or Distribution]
PMR	Private Mobile Radio, conventionally a two-way analogue voice radio, but also capable of carrying digital data traffic
Primary Substation	A substation transforming voltage from 66/33kV to 11kV
Resource Element (RE)	A Resource Element (RE) is one 15 kHz subcarrier of one symbol. Resource Elements aggregate into Resource Blocks. A Resource Block has dimensions of subcarriers by symbols. Twelve consecutive subcarriers in the frequency domain and six or seven symbols in the time domain form each Resource Block
RSRP	Reference Signal Receive Power: the average power of Resource Elements (RE) that carry cell specific Reference Signals (RS). RSRP is the average received power of a single RS resource element
RIIO	Regulatory formula of Revenue = Incentives + Innovation + Output
Rural	Areas where coverage is the predominant factor in optimising LTE network design

SCADA	Supervisory Control and Data Acquisition
SI	The International System of Units
SINR	Signal to Interference plus Noise Ratio
Substation	A substation is a part of an electrical generation, transmission, and distribution system whose primary function is to transform voltage from high to low
TDD	Time Division Duplex, a method of radio communication using a single radio channel for two-way communications
UE	User Equipment, also referred to as CPE (see above)
UHF	Ultra-High Frequency, refers to the radio frequency range 300 MHz to 3000 MHz (or 3 GHz)
Upload time	The time is would take to transfer all of the data from all monitored outstations allocated to a single base station (eNodeB) sector or cell
Urban	Areas where capacity is the predominant factor in optimising LTE network design
VHF	Very High Frequency, referring to the radio frequency range 30 MHz to 300 MHz

Appendix A - Signal to Noise vs Upload Data Rate

The 'signal-to-interference plus noise (SINR)' to upload data rate characteristic used within this study is based upon the 'bi-directional' upload rates and 'signal to interference + noise' (SINR) reported by WPD from the Portishead trial. This characteristic is shown in Figure A1.

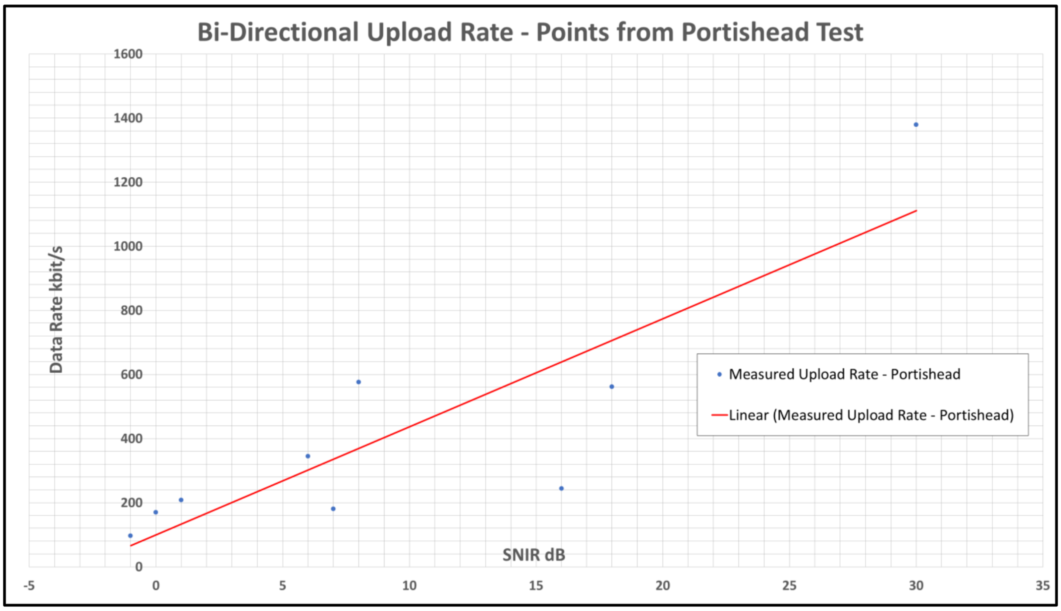


Figure A1 – Portishead - Data Rate vs Signal to Interference plus Noise (SINR)

This characteristic 'falls short' of what might be expected from the theoretical performance of LTE. A theoretical upload data rate characteristic is shown in Figure A2. This is based on Shannon's law, scaled, with limits of minimum SINR and upper theoretical data rate (2.8 Mbits/s).

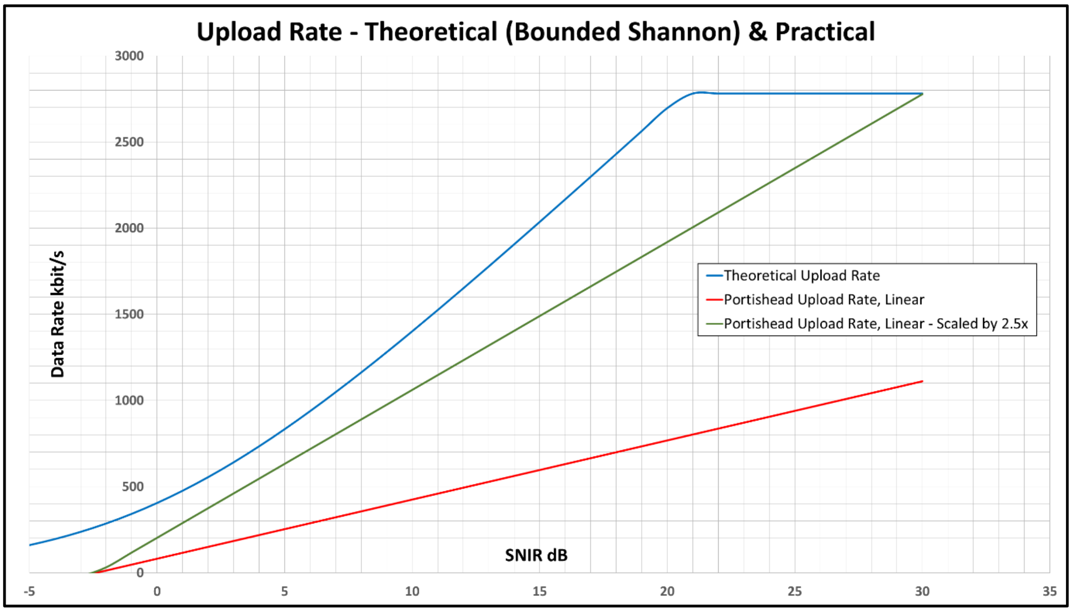


Figure A2 – Theoretical/Practical Data Rate vs Signal to Interference plus Noise (SINR)

Further work is required to base this characteristic on measured results (See Section 6).

The 'Portishead' linear characteristic was used to maintain the consistency of reported results throughout the study, knowing that a simple up-scale (perhaps of 2.5x) may result in more realistic upload times, nearer to the theoretical values.

Appendix B - Uncertainty and Related Further Work

Ultimately, there will always be issues if a steel-framed building is erected in front of an antenna without prior knowledge.

Whilst every effort has been made to select appropriate parameters in the link budget relating to noise levels, receiver sensitivity, receiver performance and signal availability, these factors are all subject to a level of uncertainty.

In addition, predicted signal levels are subject to a level of uncertainty. There is a level of confidence in predictions over many points that the mean prediction accuracy would not be an overriding uncertainty; however, there is a distribution associated with the uncertainty relating to individual points, all in differing settings, due to local clutter (Trees, buildings etc).

The coverage results presented for the UE power increase of 4dB above nominal gives a guide to the relationship of this possible uncertainty to overall coverage.

This is slightly expanded upon by the graph of figure B1, showing how overall predicted coverage changes for up to a 6dB increase from the net effects of threshold calculation, UE power change and mean prediction error.

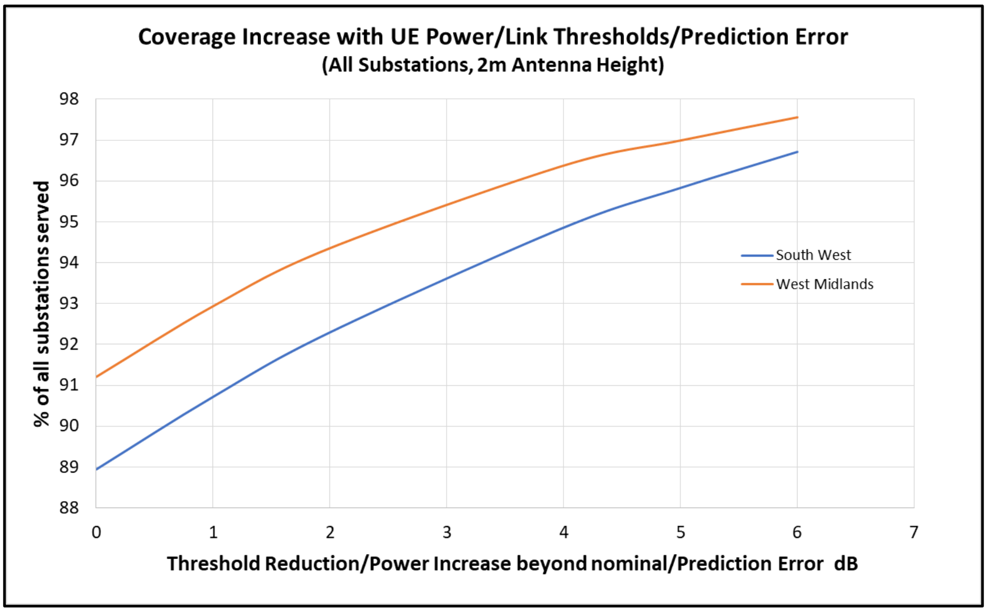


Figure B1 – Coverage vs Link Budget Characteristics

Further work is required to investigate these factors, to reduce these uncertainties and enable the individual mean and distribution of remaining uncertainties to be appropriately understood, allowing an estimate of overall compounded uncertainty to be calculated.

A trial of a more realistic network is perhaps the most direct and clearest way to have confidence in the performance to be achieved by a full LTE network.

Appendix C – Link Budget Calculations

The following parameters and calculations were used to derive the level of noise and received signal thresholds. Within the network, base station (eNodeB) sites will each have varying amounts of antenna gain and feeder loss taken into account during the prediction calculations.

Link Budget - Threshold and Noise Level Calculations

Noise Figure	6 dB	
Environment	7 dB	
For FDD (Frequency Division Duplex) - Down Link		
BW (B)	2700 kHz	*(k) Boltzmann Constant 1.38 * 10^{-23} joules/kelvin* *(T) Temperature 290k*
kTB	-109.67 dBm	*kTB Watts*
kTBF	-96.67 dBm	*Noise Factor: Noise increased by Receiver Noise Figure & Environment*
Fade Allowance	10 dB	
Required SINR	-1 dB	
Required Receive Threshold	-87.7 dBm	

For the TDD (Time Division Duplex) system the block bandwidth is share between Downlink and Uplink according to TDD DL-UL Configuration and Special Subframe Type Frame Structure 0 (6:2:2) (UL/DL/Subframe) and Special Frame Structure 1 (1:9:4) (UL/DL/Guard)

Receive Threshold Dowlink	-92.4 dBm	*These Values Calculated using ICS Telecom EV (V15.4) LTE Threshold Calculator*
Receive Threshold Uplink	-99.8 dBm	
Outstation (UE)		
Antenna Gain	2 dBi	
Feeder Loss	0.7 dB	*Feeder typically (On small Distribution Cabin) 2m of RG214 (0.145dB/m + 2x 0.2dB Connector Loss*
UE Block Power	23 dBm	
Base Station Sector (eNodeB)		
Antenna Gain (per sector/plane)	10 dBi	*Typically 3 sectors (Kathrein 74157)*
Feeder Loss	3 dB	*Typically on ST Site 30m of LDF4/50 (0.045dB/m + 1.7dB tail and connector loss)*
Sector Block Power	43 dBm	

The same signal path is used for Downlink and Uplink (Transmit/Receive Antenna Gains and Feeder Losses are identical), however the transmit powers are different

Block Power Difference	20 dB	*ENodeB Power 43dBm, UE Power 23dBm*

We are inferring the Uplink performance from Downlink predictions

Modified Downlink Threshold	-79.8 dBm	*Receive Threshold Uplink + Block Power Difference* *Round by ICS Telecom EV to -80dBm*
Corresponding RSPS Threshold	-102 dBm	*Subcarrier Bandwidth 15kHz vs Full Block BW 2.7MHz* *10*LOG(15/2700) = -22.5dB*

The predictions presented within this report all use the ITU P-1812-4 propagation model.

Appendix D – 700MHz

The 400 MHz (UHF) frequency range is commonly termed the ‘Sweet-Spot’ for critical communications networks as it combines long range, reasonable data payload and compact antennas with penetration through man-made and natural objects such as vegetation, immunity to most weather-related effects.

However, partly as a result of the uncertainty surrounding the availability of 400MHz in the UK, the prospect of using 700MHz, an alternative higher frequency band, has been briefly investigated. Much of this spectrum, currently used for Digital Terrestrial Television (DTT) and radio microphones by the entertainment industry. is due to be released from around mid-2020 to improve the level of mobile coverage across the UK and is to be auctioned by OFCOM for this application.

Due to increased propagation loss, higher frequency spectrum would require more base stations and because each base station would tend to be able to connect to a smaller group of outstations, there would be a reduction in service resilience , should a base station site fail.

Within this spectrum there are ‘guard bands’ that could be used for utility smart telemetry applications. The spectrum is shown in Figure E1, taken from the OFCOM consultation of December 2018.[7]

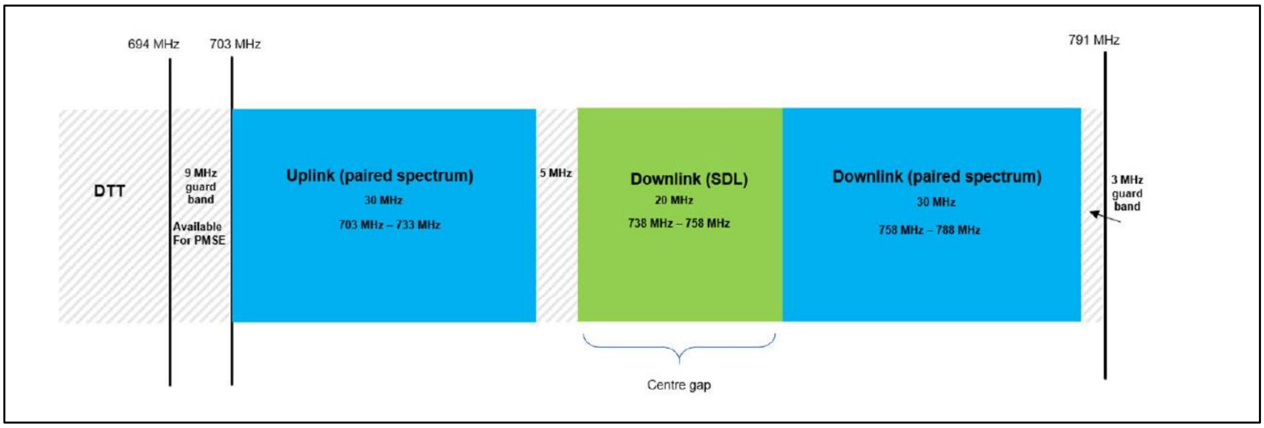


Figure E1. 700 MHz Spectrum – OFCOM Consultation December 2018

The three possible guard bands can be seen at 694MHz, 733MHz and 788MHz. There may be adjacent channel issues, particularly with the upper band at 788MHz, however it may be possible to make use of blocks of spectrum within the two lower guard bands. In particular, the band plan illustrated below identifies 2 x 3 MHz (733-736 MHz paired with 788-791 MHz) as suitable for ‘machine-to-machine’ communications, essentially a similar application to utility Smart Grid.

Bands	694-698	698-703	703-733	733-736	736-738	738-743	743-748	748-753	753-758	758-788	788-791	791-821
PPDR 2x3 MHz				UL PPDR							DL PPDR	
PPDR 2x5 MHz		UL PPDR							DL PPDR			
PPDR 2x10 MHz				UL PPDR				DL PPDR				
M2M 2x3 MHz			UL MFCN Band 20	UL M2M						DL MFCN Band 20	DL M2M	DL MFCN Band 28
SDL 4x5 MHz						DL MFCN SDL						
PMSE	PMSE			PMSE								
Block Size [MHz]	4	5	30	3	2	5	5	5	5	30	3	30

[7] Award of the 700 MHz and 3.6-3.8 GHz Spectrum Bands, OFCOM, December 2018

To gain a rough insight into the possibility of using 700MHz spectrum, the West Midlands plan has been considered at 700MHz. The coverage that might be achieved, by retaining all parameters except the frequency, is shown in figure E2. The served statistics are shown in table E1.

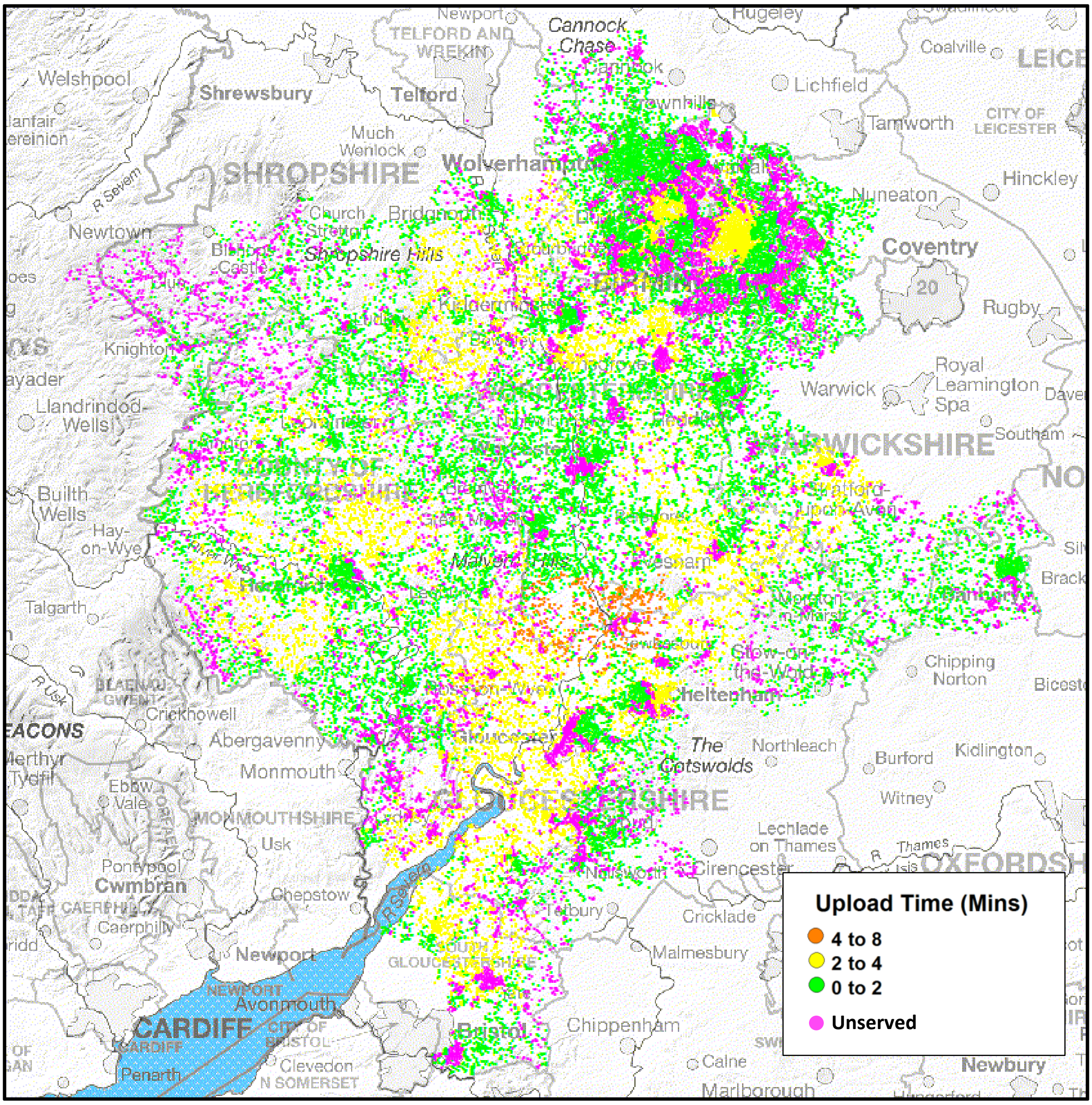


Figure E2. Possible West Midlands Coverage at 700MHz

No. Served: 2m agl antenna			
249 Sectors	**Primary**	**Distribution**	**Total**
(700 MHz: 10dBi Base Stn Ant Gain)	158	30760	30918
	79.8 %	75.3 %	75.3 %

Table E1. West Midlands Substation Served at 700 MHz

The change in frequency has caused a reduction in substations served by almost 16%. It is estimated that, to restore the previous level of served substations, the number of base station sites required would at least double (~ 180 sites).

At the higher frequency it becomes quite practical to employ antenna systems at the base stations with more gain. A 3dB increase in base station antenna gain is considered quite practical and may result in an increase in substations served by 9%. For this situation, to retain the level of 400MHz coverage, 50% more base station sites are thought to be required (~135 sites). If a further 3dB were gained at the outstation through increased antenna gain and / or increased RF power, then perhaps only 20% more sites (~110 sites) would be required.

It is noted that these findings are roughly in line with those reported in a study conducted by Simon Forge Associates for the European Commission in 2014[8], generating confidence in these predictions. The question of the availability of alternative, higher frequency spectrum has only been posed after completion of the main work and consequently further work would be required to optimise the plan for this higher frequency range, taking into account possible changes in parameters and prediction model.

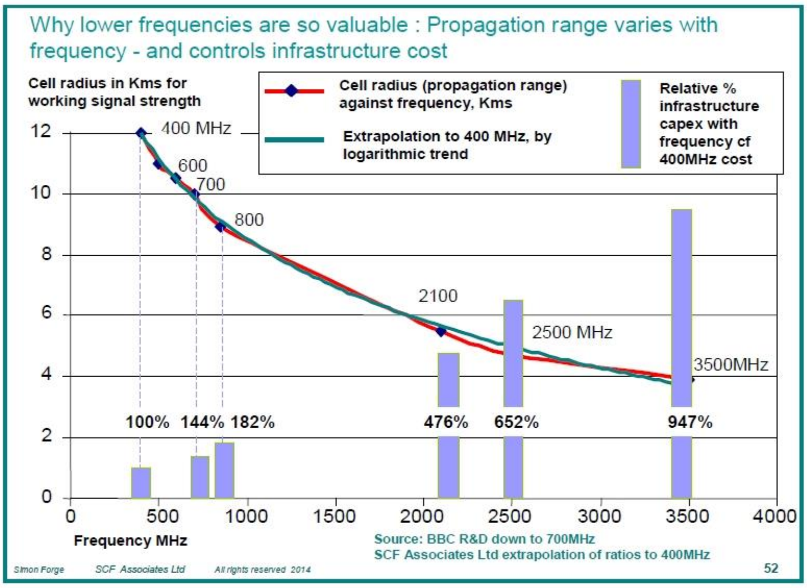


Chart taken from Report prepared for European Commission in 2014 by SCF Associates Ltd “Is Commercial Cellular Suitable for Mission Critical Broadband?”

However, if it were not possible to release spectrum in the same band across the UK for utilities applications, there still might be a possibility of identifying different spectrum in different parts of the country, still ensuring that utilities throughout the UK had access to at least 2 x 3 MHz of spectrum, even if in different frequency ranges. Although the infrastructure costs would be higher than if a single band could be released at 400 MHz across the whole of the UK, it would still be a viable cost-effective solution provided the bands were all subject to harmonisation within 3GPP for use globally. This composite option could be developed further if the regulatory framework were open to it.

8 https://www.researchgate.net/publication/289540175_Is_Commercial_Cellular_Suitable_for_Mission_Critical_Broadband_Final_Report_to_the_European_Commission