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INNOVATION

NEXT GENERATION NETWORKS

Next Generation Wireless Telecoms Analysis

CLOSEDOWN REPORT

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Contents

Executive Summary

The Network Innovation Allowance (NIA) funded 'Next Generation Wireless Project', undertaken jointly by Western Power Distribution (WPD) and Joint Radio Company (JRC) has concluded, having met all of its Objectives and Success Criteria.

The challenge was to develop a desktop model capable of predicting a telecommunications network architecture that would enable the advanced connectivity considered necessary to support an intelligent electricity distribution network, essential to match the changing environment for the future. The solution had to be capable of meeting the migration of energy networks to dynamic two-way infrastructures with sufficient flexibility to accommodate new market structures currently being developed. The study focused on the forecasted needs of a Distribution System Operator in the time frame up to 2030.

Since the precise nature of the electricity distribution networks of the future is still emerging, the approach taken was to focus on the provision of a resilient telecommunication connection to every existing substation, each of which could then act as a telecommunications hub for further connectivity into the electricity network.

Important parameters such as data volumes, uplink prioritisation, antenna heights/types, etc. were developed in joint WPD/JRC workshops to scale the Long Term Evolution (LTE) network for a private utility environment, substantially different from that of the public commercial mobile phone networks.

The radio network was designed to use a Distribution Network Operator's (DNO) own assets where possible to minimise cost and provide a high availability network, recognising that maintaining such networks requires resilient power supplies, redundant backhaul and site access at all times.

The conclusion of the project is that a telecommunications network based on LTE technology utilising two x 3 MHz spectrum blocks in a Frequency Division Duplex (FDD) configuration in the 400 MHz band would provide a cost effective solution to facilitate multiple connectivity for the future smart grid network. A similar telecommunications network derived from alternative technologies may require a greater amount of spectrum and offer less resilience and less flexibility for expansion. Whilst modelled on LTE, the planning model developed during the study provides flexibility in accommodating alternative radio spectrum bands and physical parameters both in terms of radio base stations and the terminal equipment which could be deployed.

This assessment has been based on a number of assumptions and simulated calculation models utilising radio propagation tools. Whilst these tools are relatively accurate, there is a risk of invalidity if assumptions have been made incorrectly. As with all prediction models, a sample of the model should be ratified and proven accordingly. It is thus recommended that further field trials are conducted to assess planning parameters. Equipment performance and the connectivity requirements for existing and future WPD services, such as Supervisory Control and Data Acquisition (SCADA), Voice and Tele-Protection; which would traverse over an LTE network.

1 Project Background

Electricity networks and other utilities face unprecedented challenges and opportunities as we head towards a net zero carbon world. For electricity networks, more and more distributed generation and low carbon technologies, such as electric vehicles and heat pumps, will be embedded, much of it intermittent and at the network edge. This will involve significant changes in the time variability and geographic distribution of network loading, driven partly by the electrification of transport and heat as the UK seeks to reduce greenhouse gas emissions.

Telecommunications has always been a vital part of energy network operations with the use of private radio scanning telemetry and other wireless systems being critical in providing connectivity to all parts of the energy network infrastructure. Utilities already have extensive and varied radio networks connecting thousands of monitoring and control points. However, with a huge increase in the anticipated number of connected points being required, these radio systems need to be greatly expanded and enhanced to manage the increasingly diverse and dynamic electricity networks with an anticipated replacement of legacy systems in the process.

This Next Generation Wireless Telecoms study was carried out as part of WPD's Innovation Strategy, following an earlier WPD funded technology evaluation of LTE at Portishead. Whilst the Portishead trial assessed the technical capability of the technology in a challenging physical environment, this project accessed NIA funding as it enables the scalability of such network(s) across DNO licence areas with the objective of developing an innovative network design toolkit that would be utilised by any DNO or utility with ambitions of deploying such networks. In addition, NIA funding helps to identify the risks and benefits which inform future telecommunication needs including costs, installation, commissioning, testing, and documentation and training requirements.

The study considered a demographic and geographical representation of two of WPD's four license area's for the future operational data communications requirements. WPD's West Midlands and South West areas were chosen as representative of this mix which comprised a contiguous area encompassing the southern half of the West Midlands from north of Birmingham down past Gloucester and the South West region from Bristol to the tip of Cornwall (two coloured areas on map). These are respectively referred to as 'West Midlands' and 'South West' in this report.

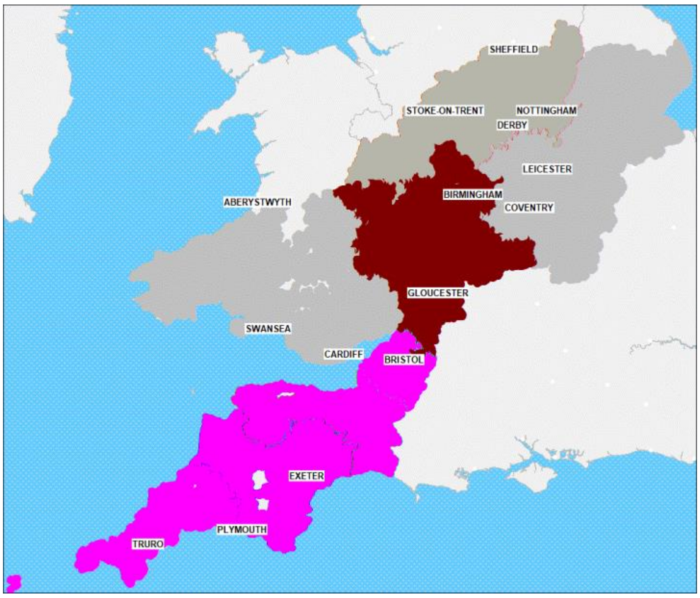

Figure 1: Selected geographic areas within WPD's licence areas

Note - The outcome of the analysis can be extrapolated to the whole of WPD's area using a scaling up factor that can be readily calculated.

The use of advanced telecommunications and embedding more intelligence within electricity networks will make it possible to prevent some outages. Alternatively, when such events occur, it will help restore supplies more quickly. This will also help to avoid or delay more costly reinforcement investments which might otherwise be necessary.

In order to better understand the potential for new wireless technologies such as LTE, a precursor to 5G, we undertook a single site technology trial and performance evaluation in the Portishead, Bristol area. This afforded insight into LTE performance characteristics and allows DNOs to understand the potential of robust and resilient data telecommunications to support future Smart Grid electricity networks.

The deployment of Next Generation Wireless Telecoms will allow greater visibility, control and protection of network assets, with enhanced centralised control functions as well as autonomous de-centralised functions. Active and pro-active network management will be essential to optimise the installed assets, whilst meeting the challenges associated with more distributed generation and storage as well as dealing with consumers changing energy demands.

3 Scope and Objectives

The purpose of this desktop study was to establish an outline design for an LTE network serving our future operational data communications requirements in the West Midlands and South West licence areas. Data volumes were developed in joint WPD/JRC workshops to scale the radio network for a private utility environment, which is substantially different from that of the public commercial mobile phone networks.

By better understanding the likely design of the required telecommunications network, the aim was to highlight the likely scale and characteristics of the network and thus enable DNOs in the UK and Ireland Great Britain to make informed decisions regarding detailed planning and deployment to develop an effective, efficient and sustainable future smart grid system by integrating with and eventually replacing legacy communications networks. One important part of this was to provide evidence to support the allocation of appropriate spectrum.

An obvious objective to minimise future telecommunications network costs, both capital and recurring, was to design it as far as possible to reuse our existing assets and infrastructure such as sites, structures, power supplies and backhaul. The priority in this regard was the choice of base stations as follows:

- Sites already used for wide-area wireless communications and with existing 'backhaul' connections;
- Other sites highly suitable for development and integration;
- Third-party and other sites, often with more onerous costs and timescales.

Below we detail each of the objectives for the project.

Objective	Performance
Define the scale of equipment and infrastructure deployment necessary	✓
Determine the performance characteristics that can be sustained in a robust and resilient manner	✓
Characterise the functionality available to enable 'Smart Grid' operations	✓
Identify the amount and characteristics of radio spectrum needed	✓
Network Design Learning can be leveraged across other use cases and DNO areas	✓
Inform the investment requirements for future communications capability	✓
Facilitate awareness raising with Government & Ofcom	✓
Inform the business case for system roll-out that will be a key enabler of the DNO to DSO transition.	✓

Table 1: Objectives

4 Success Criteria

Success Criteria	Status
Ability to define the scale of equipment and infrastructure deployment necessary	✓
Understanding of the performance characteristics that can be sustained in a robust and resilient manner	✓
Ability to characterise the functionality available to enable 'Smart Grid' operations	✓
Understanding of the amount and characteristics of radio spectrum needed	✓
A toolkit for radio network design and deployment that can be leveraged across other use cases and DNO areas	✓
Define the investment requirements for future communications capability	✓
Case for spectrum access established to facilitate negotiating with Government & Ofcom	✓
The development of network design planning rules for operational telecommunications to facilitate Smart Grid functionality	✓

Table 2: Success Criteria

6 Details of Work Carried Out

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

Substation Density

From a list of 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 the initial work in 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.

Data Upload Requirements

Considering the sources of and volumes of monitored data, it became clear that the data requirement would be dominated by the need to convey analogue measurement. Considering the number of distribution sites (11kV to 415V) compared to primary substations and other assets, it was concluded that distribution substations dominate data volumes. For primary and distribution substations, notional data volumes were established (no. measurement x data size per measurement).

Coverage predictions result in the number of substations served by each base station (sector) and the quality of path, hence data rate supported. From this it is possible to calculate the time taken to upload the data form all monitored sites to each base station (sector). This is referred to in the output as ‘upload time’.

Using a fixed data upload requirement enabled continuous assessment of LTE coverage and capacity through the process of design and optimisation. (Note - Further work required to validate theoretical assumptions).

Agree Network Assumptions

Based on results from Portishead and assuming spectrum in the 400MHz band, a set of global network assumptions such as antenna types & heights, equipment performance, RF noise and propagation factors evolved during project meetings and were agreed between JRC and us. One key assumption was the use of a compact, low profile antenna at 2m above ground level (a.g.l.) at Distribution Substations to minimise costs, visual impact and the risk of vandalism. In the rollout of a final network, some of these assumptions might be adjusted during an optimisation process.

Initial Base Station network design

Utilising existing ‘connected’ WPD scanning telemetry and DMR (Digital Mobile Radio) base-station sites, coverage plans for the West Midlands and South West were developed and analysed using coverage prediction software (ICS Telecom), Geographic Information System

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

(GIS) mapping software (MapInfo) and JRC bespoke data manipulation software. For each base station site, three antenna sectors were assumed, being at the height of the existing Scanning Telemetry (ST) or DMR infrastructure. The number of sub-stations served/unserved and sectors upload times was reported numerically and plotted graphically.

Enhanced network design

Additional base-station sites were added to improve coverage and performance, starting with WPD owned locations, where possible with existing fibre optic connectivity (e.g. Bulk Supply Points (BSP) and primary substations). In areas where a suitable site could not be found, third-party sites have been used. In some areas it might be possible later to specify multiple sites in place of a third-party site, in some cases establishing a new structure at a WPD site.

At new sites, it was assumed that a structure, located near the substation main entrance and sufficiently clear of High Voltage (HV) infrastructure, could be built to place antenna systems at between 15m and 18m above ground level. This height is considered a compromise between the requirement to provide adequate radio coverage against the necessity in meeting prospective planning regulation and the availability of suitable structures on which to mount the antenna systems. On third party structures, a judgment has been made on an achievable height.

Sites were added primarily to increase the number of outstations served, but with the understanding that extra sites would improve resilience against site failure and share traffic load, thereby reducing upload times. Performance predictions were updated to assess progress and highlight where additional coverage, capacity or resilience were required.

Adding base-station sites eventually results in a situation of diminishing returns, whereby the cost per increase in coverage reaches a threshold. In many cases further sites would then incur substantial additional costs, for example adding a new structure, in return for a moderate increase in served substations.

Backhaul Implications

In parallel with the enhanced network design work, a continuous assessment of backhaul requirements was undertaken and in particular each added site was initially assessed in terms of ease of upgrade, for example distance from existing backhaul hub.

Network Resilience

The predicted number of connected sites and the times to upload all data for each sector was compared for substation antenna heights of 2m and 6m and for a possible (4dB) improvement in link performance. For these options, the ability to connect to alternative base stations (sector) was investigated and reported.

Alternative Spectrum

In the light of uncertainty regarding the availability of the preferred 400MHz spectrum in the UK, the modelling was briefly extended to demonstrate our ability to consider an alternative band, namely 700MHz.

7 Performance Compared to Original Aims, Objectives and Success Criteria

Objective	Performance
Define the scale of equipment and infrastructure deployment necessary	Using the method detailed in Section 6, it was determined that 229 base stations would connect >90% of the 95,000 substations.
Determine the performance characteristics that can be sustained in a robust and resilient manner	For a total system restart, the time to upload all analogue values to the control room is typically within 2mins. 60% of outstations are resilient in the case of a single base station site failure.
Characterise the functionality available to enable 'Smart Grid' operations	Data volumes assumptions were developed at a joint WPD/JRC workshop. This included 25 analogue measurements at Distribution substations and 50 at Primary substations. An allowance was then added for digital indications, coding and security encryption.
Identify the amount and characteristics of radio spectrum needed	The study has determined that a telecommunications network based on LTE technology utilising a minimum of two x 3 MHz spectrum blocks in a Frequency Division Duplex (FDD) configuration in the 400 MHz band would provide a cost effective solution to facilitate multiple connectivity for the future smart grid network. A similar telecommunications network derived from alternative technologies may require a greater amount of spectrum and offer less resilience and less flexibility for expansion.
Network Design Learning can be leveraged across other use cases and DNO areas	The network design toolkit generated by this study would allow radio network design for all DNOs optimised across a diverse range of topographies, communities, energy network configurations and demand profiles.
Inform the investment requirements for future communications capability	The study has determined the volume of base station sites and equipment required broken down by category. Indicative costs were discussed but vendor pricing is required to generate a more accurate investment model.
Facilitate awareness raising with Government & Ofcom	The study outcomes detail the nature of the requirement, the scale of the network solution and the implications for the spectrum requirement. The project report will be shared with Ofcom, who recently set up a task force to consider Utility Smart Grid spectrum requirements, in addition to others.
Inform the business case for system roll-out that will be a key enabler of the DNO to DSO transition.	The study has shown that an LTE or similar network will provide connectivity to existing substations while having inherent capacity for additional substations to be added.

Table 3: Performance Compared to Original Aims, Objectives and Success Criteria

8 Required Modifications to the Planned Approach during the Course of the Project

Throughout the lifecycle of the Next Generation Wireless project, no modifications to the planned project approach were raised and therefore no change requests were issued for the project.

9 Project Costs

Activity	Budget (£)	Actual (£)	Variance (%)	Comment
WPD Project Management	38,519	31,322	19	As analysis did not require any extension no additional or further resources were required from WPD. The project management costs remained within budget.
JRC Contract	120,000	126,282	5	JRC were requested to carry out additional analysis on the project. They were asked to look at the use of 700MHz as an alternative to the 400MHz spectrum. In addition, they also spent some time on the production of the project video.
Telecoms costs	79,069	0	100	No costs or payments were received or incurred in Telecoms.
Dissemination costs	8,200	8,200	0	
Total	245,788	165,804	33	Project cost was below the budget by 33%.

Table 4: Project Costs

10 Lessons Learnt for Future Projects

10.1 Network Design

We believe that, given the assumptions made in regard to antenna type/height etc., an economic cap on the number of LTE base station sites will limit substation coverage to ~90%. This would reach 100% using a combination of increased gain & height and alternative wired and wireless telecommunications solutions.

The study has quantified the number of base station sites required and the proportion of these which are 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.

Some additional sites considered for coverage may also be needed for capacity. There will be a trade-off between coverage and interference mitigation as additional base station sites increase both coverage and potential inter and intra-cell interference.

Additional infrastructure may provide additional benefits which we can exploit for other operational services such as network enhancements, site sharing etc.

Substation antenna format and height have a significant influence on telecoms network design. As detailed in Section 6, a set of global assumptions were agreed for this analysis but might be varied in the optimisation of a final network rollout to maximise the number of outstations connected. Some sites for example may be able to accommodate antennas at a greater height than the standard height assumed for the analysis.

10.2 Network Planning

A methodology has been developed which is optimised for the specific data requirements as set out and developed during the project. 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.

Part of this work has involved using an efficient propagation model for the early stages of the work with a more accurate model (increased calculation time) being used at the later stages.

Work has been done to optimise the network given base station and substation distribution to ensure a robust and resilient network in the case of base station failure. This is radically different to the lack of base station resilience at the site level in the existing scanning telemetry network.

Further work is required to confirm data overhead requirements for cyber security, encryption and authentication.

12 The Outcomes of the Project

The study confirmed that LTE or similar broadband wireless data technologies operating in Ultra High Frequency (UHF) spectrum will facilitate robust, reliable and highly resilient upload-centric data telecommunications across an entire DNO licence area(s) to deliver the complex landscape of Smart Grid services central to the effective operation of a DSO.

12.1 Summary

The principle outcomes from the project are:

By achieving overall coverage of >90% of outstations using a total of 229 base stations to provide coverage for the West Midlands and South West, the study confirms the feasibility of using a private network based on LTE or similar technologies, operating in UHF spectrum to provide upload-centric Smart Grid connectivity for single or multiple DNO areas.

In dense urban areas, providing adequate capacity was the major challenge using radio spectrum around 400 MHz whereas in rural areas with adverse geography, coverage was the major constraint. However, although the focus of this project was connectivity through 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’ to avoid excessive costs for electricity consumers and providers in remote areas whilst still providing the same level of service as in urban areas.

The detailed breakdown of sites by category along with extensive background data gathered and generated during the study will allow WPD and others to scale the necessary system and infrastructure deployment, inform the investment requirements for future DSO communications capability and assist business case formulation.

Adequate outstation coverage has been achieved with 38% of base stations located on existing WPD radio sites. A further 49% of base stations are located on WPD assets highly suitable for development and upgrade of infrastructure [Note - some of these will already be planned for upgrade as part of SCADA development].

The study was used to evaluate the spectrum necessary to efficiently manage the Smart Grid’s contribution to a net zero carbon world. The starting point for this was a 3 MHz channel in the 400 MHz region as this is typically deployed by some Utilities in other countries. The modelling demonstrated that either 2 x 3MHz FDD blocks or 1 x 5MHz TDD block of spectrum in the 400 MHz band would be the most cost-effective way in which to deliver the required advanced connectivity. In addition, we successfully demonstrated the capability of the model to operate in the 700 MHz band if required. This outcome, along with the network design parameters and assumptions, provides evidence in support of discussions with government, regulator, industry representatives and stakeholders.

12.2 Detailed Report

The network designs for the West Midlands and South West areas have been developed as far as possible subject to the recommendations made for further work, to validate and expand on the technical outcomes of this study – see Section 12. Within the two areas, the number and type of sites[2] considered are shown in Table 5.

Licence area	Scanning Telemetry	DMR	Primary substation	WPD depot	Microwave link	New/Third Party	Total
West Midlands	28	15	40	1	2	4	90
South West	38	6	69	1	0	25	139

Table 5: Sites in the West Midlands and South West

The coverage achieved was ~91% in the case of the West Midlands and ~89% in the case of the South West. Detailed statistics are shown in Tables 6 and 7.

West Midlands No of substations	**Primary 198**	**Distribution 40863**	**Total 41061**
Served: Antenna 2m agl (above ground level), 249 sectors	Primary 183 92.4%	Distribution 37232 91.1%	Total 37415 91.1%

Table 6: West Midlands Coverage Statistics - All Sites

South West No of substations	**Primary 545**	**Distribution 53036**	**Total 53581**
Served: Antenna 2m agl (above ground level), 403 sectors	Primary 510 93.6%	Distribution 47123 88.9%	Total 47633 88.9%

Table 7: South West Coverage Statistics - All Sites

In modelling a radio network providing ubiquitous reliable connectivity, it was recognised that the largest element of the necessary network investment would be installation of the telecommunications equipment at the outstation (i.e. electricity substation) rather than at the base station. This is because there is an order of magnitude. Parameters were therefore selected to minimise installation costs, avoid potential for lengthy planning approval delays, and provide less incentive for vandalism and damage.

The analysis further concluded that a design connecting >90% of WPD's ~200,000 substations was an optimal result at this stage. Further work, beyond the scope of this study, will be required to specify options for connection to the remaining and most challenging locations.

By the time connectivity has been rolled out to 90% of sites, which itself may take until 2030, additional telecommunications options are likely to become available to 'fill in the

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

gaps', avoiding excessive costs for electricity consumers and providers in remote areas whilst still providing the same enhanced connectivity and level of service as in urban areas.

Coverage maps for these West Midlands and South West networks are shown below in figures 3 and 4.

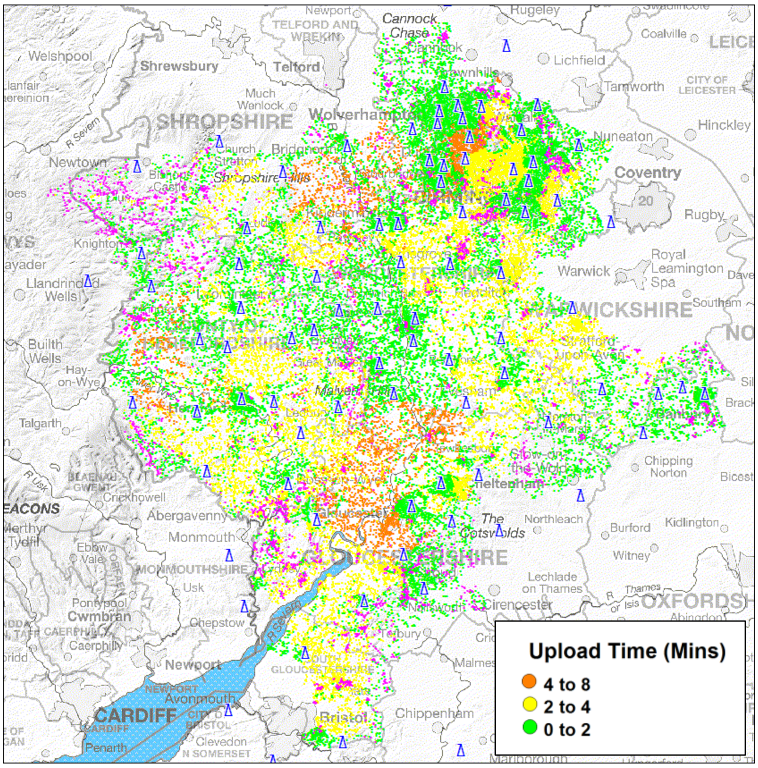

Figure 3: West Midlands Coverage - All Sites

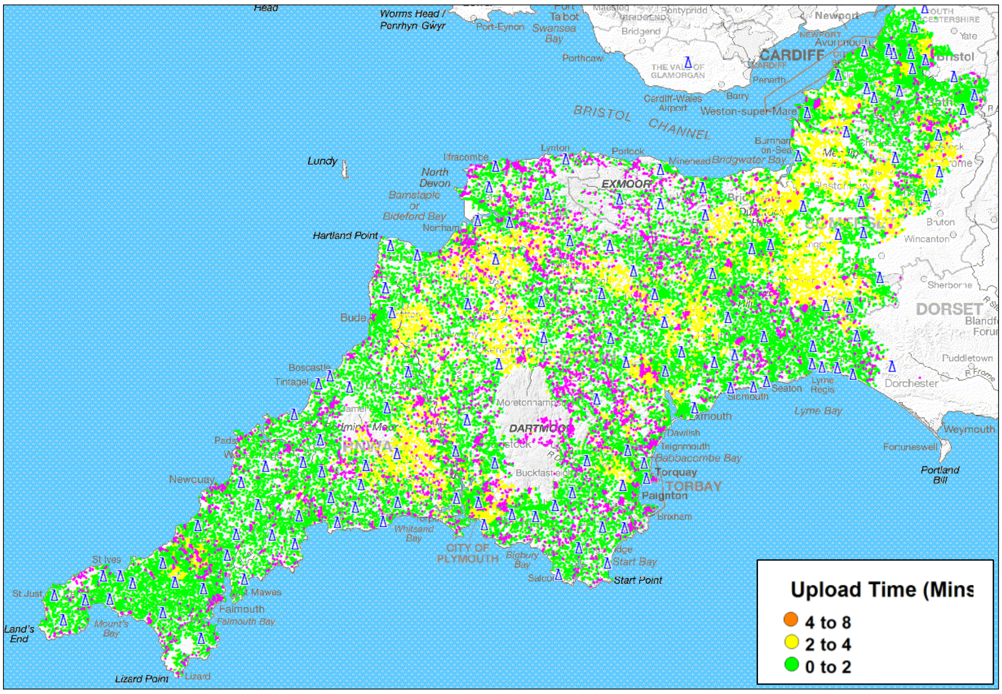

Figure 4: South West Coverage - All Sites

13 Data Access Details

The full project report from JRC has been compiled and will be available on WPD's website. Any data produced during the course of the project will be available to share in accordance with WPD's data sharing policy:

www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx)

14 Foreground IPR

No IPR was created for the project.

15 Planned Implementation

The desktop study and outcomes in this report have established technical characteristics and a radio network planning methodology for an LTE network deployment across single or multiple DNO Area(s). The outcomes detailed herein are an important step in a process which could lead to the detailed planning and deployment of an operational telecommunications network supporting an effective, efficient and sustainable future smart grid system. In that sense the Next Generation Wireless Telecoms study can be considered as Phase Two and our own LTE trial at Portishead represented Phase One.

However, it is recommended that further work, including tests and measurements as set out below, be undertaken to validate the network assumptions and design methodology from this analysis in a more realistic multi-site deployment and in the presence of both inter and intra-cell interference. This will establish the technical characteristics required for the real-time operational control of DSO networks, integrating with and eventually replacing legacy communications networks. It may also consider any requirement for operational voice and non-critical data communications.

The details of the further work should be agreed in order to:

Assess the interference effects between overlapping base stations, especially their influence on capacity;

- Measure the performance in a live operational environment;
- Examine the resilience of an LTE network where substations can connect to more than one base station;
- Confirm the propagation modelling and predicted data rates in challenging geographic locations;
- Test the interoperability of equipment from a diversity of vendors; and
- Trial the extensibility of the network to accommodate mobile voice and data connectivity.

16 Contact

Further details on replicating the project can be made available from the following points of contact:

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Glossary

Abbreviation	Term
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 a Grid Substation which transforms voltages down from 132kV to 66/33/11kV.
Byte	8 bits of digital data
dB	Decibel, a unit of measurement used to express the ratio of one value against another, on a base-10 logarithmic scale.
Distribution Substation	A substation transforming voltage down 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
eNodeB	Evolved Node B (Equipment for one base station sector)
FDD	Frequency Division Duplex, a method of radio communication using two channels, one for sending information and the other for receiving information.
GHz	A frequency of 1000 MHz
Gbit / Mbit / kbit	1 Gbit = 10^9 bits (1,000,000,000 bits) 1 Mbit = 10^6 bits (1,000,000 bits) 1 kbit = 10^3 bits (1000 bits)
kHz	A frequency of 1000 Hz (cycles per second)
LTE	Long Term Evolution, the 4th Generation mobile phone technology (4G) specifically designed to carry data traffic.
MHz	1,000,000 cycles per second, usually referring to a radio frequency (equivalent to 1000 kHz)
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 with 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 voltages down from 66/33kV to 11kV.
RF	Radio Frequency
Rural	Areas where coverage is the predominant factor in optimising LTE network design
SCADA	Supervisory Control and Data Acquisition
'Served' location	A location with an acceptable level of LTE coverage to be able to reliably communicate with a base station.
Substation	A substation is a part of an electrical generation, transmission, and

	distribution system whose primary function is to transform voltage from one voltage level to another voltage level.
TDD	Time Division Duplex, a method of radio communication using a single radio channel for two-way communications.
UHF	Ultra-High Frequency, referring to the radio frequency range 300 MHz to 3000 MHz (or 3 GHz)
‘unserved’ location	A location where the LTE signal level is insufficient to be able to reliably communicate with a base station.
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
WPD	Western Power Distribution