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FALCON KNOWLEDGE DISSEMINATION WHITE PAPER

TELECOMMUNICATIONS WORKSTREAM

The Trade-off Between Coverage, Latency and Cost

DEVELOPING FUTURE POWER NETWORKS

This white paper captures the learning gained from the telecommunications infrastructure rollout work stream of the FALCON programme. A new WiMAX radio based communications network (RAN) which serves the FALCON trials system has been deployed to the Milton Keynes area with trade-offs made between radio coverage, network latency and overall system cost.

About this document

It is a FALCON programme objective to disseminate the knowledge gained while carrying out the trials system implementation work. For the telecommunications work stream, the methods used and the overall knowledge gained in the course of the new radio communications system rollout may be useful to others attempting to do the same, or a similar, piece of work.

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Introduction

This white paper is one of the FALCON knowledge dissemination documents which capture the learning gained from the telecommunications infrastructure rollout work stream of the FALCON programme. Within this work stream a new WiMAX based communications network which serves the FALCON trial systems has been deployed to the Milton Keynes area. The work has included the implementation of radio communications between some 200 electricity distribution substations mainly via a newly available (for evaluation and test) WiMAX frequency at 1.4 GHz.

This paper describes in outline how this was done and captures the lessons learnt when trying to balance innovation with tried and tested methods, specifically in this case the trade-off between coverage, latency and cost when designing and building a real-world system using a WiMAX solution. The principles will apply to any similar 4G RAN type network implementation.

Background

The cost and limited flexibility of traditional approaches to 11kV electricity network reinforcement threaten to constrain the uptake of low carbon technologies. Project FALCON (Flexible Approaches to Low Carbon Optimised Networks) aims to gain an understanding of the dynamic nature of the utilisation and demands placed on this part of the network and to assess a number of alternative solutions to the existing reinforcement methodology currently used.

Project FALCON comprises three main components for development and learning:

- Demand forecasts and scenarios (at distribution substations);
- A network planning tool - the Scenario Investment Model (SIM), and;
- Operational tools and trials.

The SIM will identify network constraints under multiple future network load scenarios and determine the most cost-effective and timely combination of techniques to resolve them.

Six alternative intervention techniques have been identified and are to be trialed initially (and modeled in the SIM):

- Technique 1. Dynamic Asset Ratings (DAR) – utilising dynamic ratings for lines and transformers based on the actual prevailing weather conditions to meet predicted power flows, rather than (e.g.) fixed summer/winter ratings and load curves;
- Technique 2. Automated Load Transfer (ALT) – shifting load dynamically between HV feeders based on the prevailing network conditions by moving the open points;
- Technique 3. Meshed Networks – running parallel feeding arrangements at HV and monitoring the effects, taking account of whatever distributed generation exists;

- Technique 4. Battery Storage – using storage to moderate the peak power flow of HV feeders to postpone reinforcement;
- Technique 5. Distributed Generation (DG) – trialling new commercial agreements with HV customers having appropriate generators that could export power onto the network at appropriate times;
- Technique 6. Demand-Side Management (DSM) – trialling new commercial agreements with HV customers capable of shedding load for finite periods when appropriate.

In addition to being modeled in the SIM, these six alternative solutions, and combinations of alternatives, will be deployed in the network trials area in order to assess their practicality and effectiveness.

The trials will be conducted in the Milton Keynes area and will comprise the electricity distribution circuits supplied by nine primary substations operated by Western Power Distribution. FALCON will implement an additional SCADA monitoring capability at 200 distribution substations within the trials area, located on a mix of rural and urban networks, to collect key measurements such as HV phase voltages and currents and both real and reactive power flows. Subsets of these RTUs will collect additional data to support the DAR, meshed network, ALT and battery energy storage techniques trials.

This paper principally addresses the telecommunications network that supports the trials data gathering for the FALCON project.

Scope

This document relates to the new telecommunications infrastructure for the FALCON trials test area in Milton Keynes. While this is ostensibly a trials support network for the electricity distribution industry, both its architecture and the methods used in its deployment can be seen as readily applicable to any general radio based network implementation.

The network is not a classic Wireless Sensor Network (WSN) where many simple sensors "wake on demand". Numerous widely available papers already report on the energy-latency trade-off for such WSNs. Rather, this is an "always on" base station concept in constant/regular communication with the head-end, with mains powered sensing equipment and fixed telecommunications (WiMAX radio) links.

Abbreviations, Acronyms and Terms

ALT	Automated Load Transfer
CPE	Client Premises Equipment
DAR	Dynamic Asset Rating
DSM	Demand Side Management
DG	Distributed Generation
DNO	Distribution Network Operator
FALCON	Flexible Approaches to Low Carbon Optimised Networks

HV	High Voltage
HSPA	High Speed Packet Access
iBridge	Airspan proprietary WiMAX radio backhaul link solution
IED	Intelligent Electronic Device
JRC	Joint Radio Company
LTE	Long Term Evolution [of radio protocols]
LV	Low Voltage
PLC	Power Line Communications
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service (differentiated services for packet and flows)
RAN	Radio Area Network
RF	Radio Frequency
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SIM	Scenario Investment Model. A complex software suite being developed by the FALCON project for evaluating electricity network management and evolution strategies
UHF	Ultra High Frequency
WiMAX	Worldwide Interoperability for Microwave Access
WPD	Western Power Distribution

FALCON Telecoms Network Overview

System Architectural Approach

The FALCON Communications network design is flexible. There is a communications node per substation location. The overall network typically assigns some twenty secondary electricity substations to each primary substation location. There are nine primary site locations acting mainly as communications network relays, though they have their own intervention equipment as well. There are some two hundred secondary substation sites, and two aggregation sites[1]. The secondary electricity distribution substation sites form two groups: LV monitoring (~153 locations being passive SCADA with 32 being pole mounted deployments) and instrumented locations (47 sites) actively involved with intervention techniques trials where there is therefore more equipment being monitored as well as the LV monitoring.

[1] One of the primary electricity distribution substations (Bradwell Abbey) is an aggregation site.

Figure 1 and Figure 2 show the schematic network architecture and geographic layout of the FALCON trials area. The network supports IP routing of data packets with a hardware solution based on Cisco and Airspan equipment. The network solution and other key aspects of it such as security are described in other FALCON Project knowledge dissemination white papers.

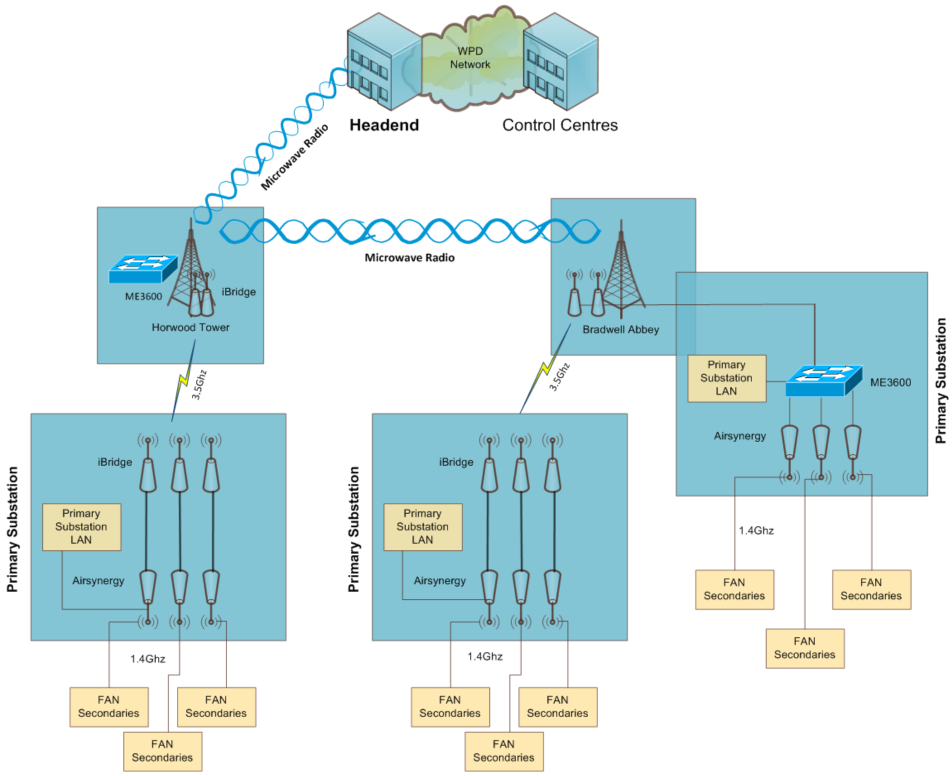

Figure 1 - FALCON Trials Area - Network Architecture

The design is largely resilient although there is only one single backhaul link in the initial trials network implementation.

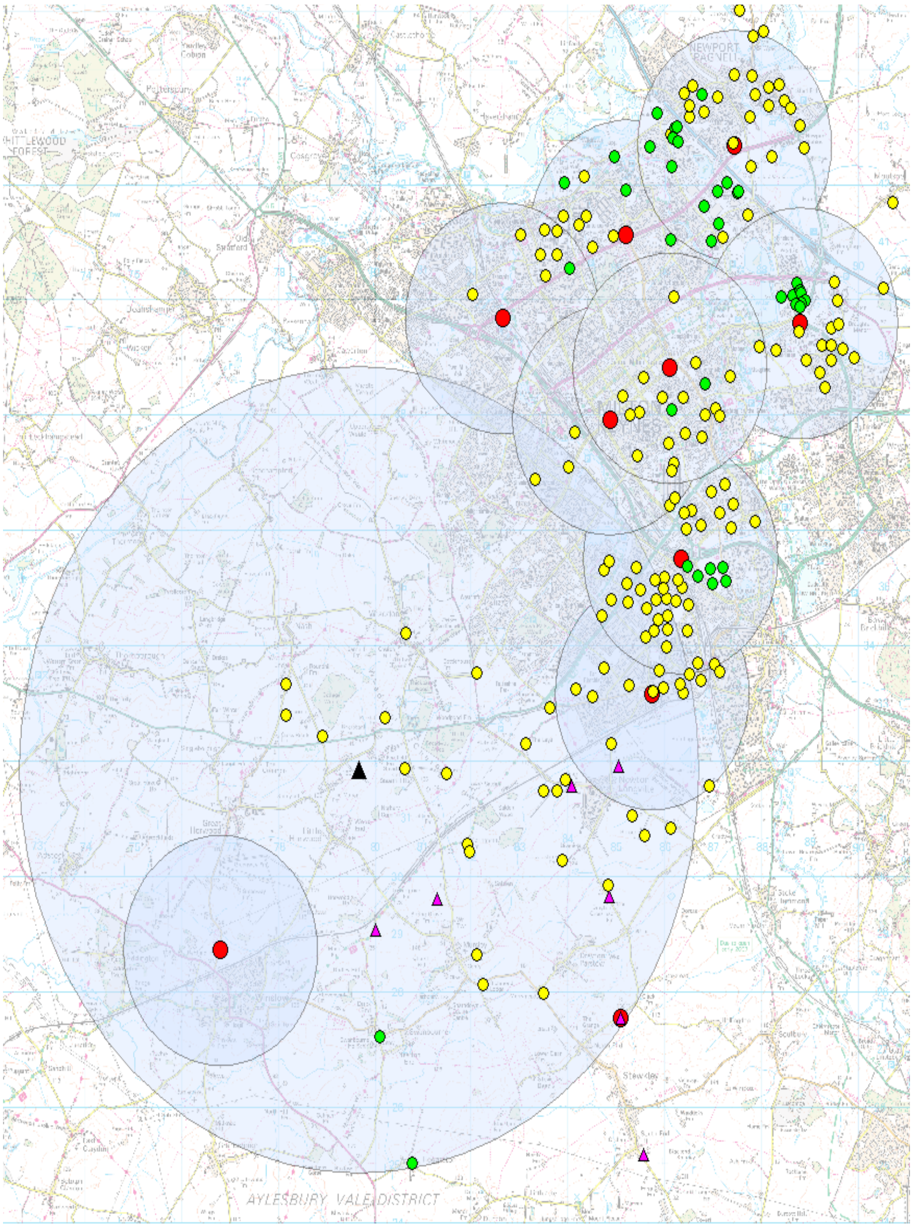

Figure 2 - Geographical Extent of the FALCON Trials Network

Principal Requirements

The following were the principal design requirements for the FALCON trials network.

1) The design and deployment of a secure and reliable communications infrastructure that provides connectivity to the 9 primary substation and the 200 secondary substations identified in the FALCON trials area;
2) The communications network will transport both monitoring and control traffic for the FALCON intervention techniques;
3) Internet Protocol (IP) will be used across the WAN and all the intervention techniques will deploy Ethernet and IP enabled equipment;

4) The FALCON Network will incorporate an Ethernet station bus but the process bus will be hardwired connections. This station bus will provide communications between the IEDs and RTU where appropriate;
5) Once a new communications network based on WiMAX has been proven in concept, the existing monitoring and control in the primary and secondary substations may be migrated from the existing UHF network on to an enhanced future FALCON Network;
6) The communications infrastructure should primarily be on a private network that is in the control of WPD and their partners.
7) Building a secure communications network for FALCON that does not compromise the very tight security policy in use at WPD is a fundamental deliverable.

Also, the high-level communication requirements for the FALCON network are as follows:

8) A private network must be created;
9) A radio based solution must be built;
10) No additional fibre or pilot wires can be installed;
11) All communications will be via Ethernet and IP;
12) A resilient design is required for the communication WAN infrastructure. Whilst the FALCON project will not require resilient router and switch configurations in each substation a resilient WAN is required;
13) No single site failure can take down multiple sites;
14) GPRS is not sufficiently reliable to be used as a primary access mechanism or as a backup;
15) Redundant control centre backhaul points will be used.

The specific requirements of the required radio elements of this solution can be summarised as:

- Fixed position elements;
- Uplink traffic dominates and coverage is critical;
- Low[2] data rate per location;
- Predictable events, even distribution of activity, deterministic latency and jitter;
- Security and data integrity extremely important;
- Primarily machine-to-machine interfaces. In the future the network could potentially be required to include support for some video surveillance (CCTV);
- Workforce remote access;
- Layer 2 network;
- Teleprotection traffic over WiMAX - this is quite unique to this solution;

[2] low compared to an enterprise but not compared to a modem for example.

- Managed Quality of Service (QoS).

Specific Bandwidth Requirements

The bulk of the data flow is uplink from the secondary substations to the primary radio nodes[3] and then on the backhaul links to one of the two aggregation sites. The substation data consists of the following traffic:

Use Case	Network Protocol	SCADA Protocol	Substation Device
Ampacity Measurement	IP	IEC61850	Alstom P341 Dynamic Asset Relay
Environmental & power measurements	IP	DNP3	GE D20 and Schneider T200 RTU
Fan & Pump Control	IP	DNP3	GE D20 RTU
CT & VT Measurements	IP	DNP3	GE D20 and Schneider T200 RTU
Breaker Control	IP	DNP3	GE D20 and Schneider T200 RTU
Battery Control	IP	Unknown	Unknown
TollGrade Measurement	IP	Unknown	Unknown
Battery Monitoring	IP	Unknown	Unknown
PMU Data	IP	IEEE37.118	Alstom P847 PMU
Teleprotection (Directional Overcurrent)	GOOSE Multicast	IEC61850	Alstom P141 Protection Relay (Not confirmed)
Teleprotection (Unit Protection)[4]	TBD	TBD	Alston P543 Protection Relay (Not confirmed)
Event Based measurements	IP	DNP3	GE D20 and Schneider T200 RTU
CT & VT Measurements (Monitoring only Sites)	IP	Unknown	Unknown
NTP Time Sync	IP	SNTP	GE D20 and Schneider T200 RTU
Existing RTU Measurement	IP	DNP3	GE D20 and Schneider T200 RTU
Existing Event Based Measurement	IP	DNP3	GE D20 and Schneider T200 RTU
Existing RTU Control	IP	DNP3	GE D20 and Schneider T200 RTU
Local RTU Access	IP	SSH and/or HTTPS	GE D20 and Schneider T200
Remote RTU Access	IP	SSH and/or HTTPS	GE D20 and Schneider T200
Substation – Substation RTU access	IP	SSH and/or HTTPS	GE D20 and Schneider T200

[3] At the Primary sites locally deployed equipment is connected via WiMAX CPE to the local base station.
[4] Design ongoing

Network Design Guidelines

- Logical building blocks for the network;
- Head end (WPD Tipton Monitoring centre);
- Primary Substation LAN (132/33Kv);
- Secondary Substation (11KV);
- WiMAX network, two tier (1.4GHz to distribution substations, 3.5GHz on backhaul, 802.16r);
- Scalable;
- Simple;
- Template design for primary & secondary sites to ease rollout;
- Latency aware QoS.

Airspan AirSynergy Radio Solution

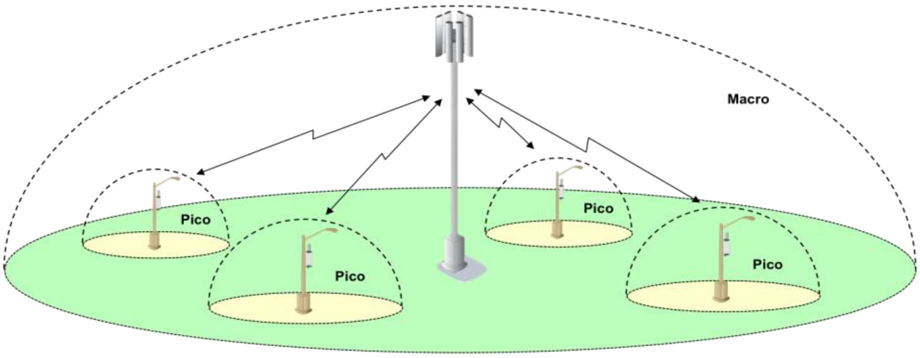

Figure 3 Heterogeneous Network System Architecture

- AirSynergy is a new generation of software defined base station - an evolution of Airspan's commercially deployed macro SDR technology;
- Delivers 2-10x capacity of "macro-only" network, much greater improvements in uplink capacity;
- Enhances coverage in critical locations (in-building and at cell-edge);
- Ensures user fairness / load balancing / uniformity of capacity in coverage area;
- Network robustness and reliability improved by multiple coverage layers;
- Optimised for mounting on utility poles & lamp posts;
- Avoids expensive site builds and cell-site rentals;
- Integrates access and backhaul - one node contains two radio systems;
- Operates in licensed spectrum (400 MHz to 6.0 GHz);
- Free from interference providing high levels of service availability;
- Supports multiple RAN standards;
- 4G WiMAX and 4G LTE for delivering 10's of Mbit/s per end terminal;
- 2G & 3G (HSPA) optional SW loads;

- Low power consumption. Only 120W per combo - access and backhaul node;
- Supports various deployment topologies;
- Pico layer of a heterogeneous network;
- Point to multipoint and relay distribution topologies.

Network Cost, Signal Coverage and Latency

In any network implementation there is a necessary trade-off to be made between cost and the various performance indicators. The general principles involved in this process are well understood. This white paper discusses the three-way pull between cost, radio coverage and latency indicators that have been encountered and dealt with during the FALCON telecoms network implementation.

To provide the analysis, each indicator is first discussed in this section in the FALCON context. The section following then discusses the actual trade-offs that were made to arrive at the eventual FALCON trials area communications network solution with these indicators optimised.

WiMAX Radio Coverage in the FALCON Trials Area

The frequency chosen for the FALCON trials area support communications network implementation between the primary sites and the distribution substations is the 1.4 GHz "WiMAX" frequency. On the backhaul links, the 3.5GHz frequency is used so that the overall frequency approach is two tier, managed inside the Airspan *Airsynergy* units. The 1.4 GHz frequency is newly available on a prototype trial evaluation basis from the MoD who normally utilise this zone of the WiMAX band. Recent policy decisions have made it possible to offer the frequencies for evaluation by national infrastructure users such as DNOs and the FALCON project is one of the first pilots. At the end of the FALCON project continued use of the WiMAX frequency is not assured, although WPD are making appropriate representations to extend the trials licence into full operations.

The WiMAX band chosen has a number of useful characteristics which make it ideal for the sort of short hop 10Mbps bandwidth type links required on FALCON. The bandwidth requirement of *up to* 10Mbps (although typically 2Mbps) was a key driver, this requirement was identified early on in the project.

An initial set of desk based radio coverage investigations were carried out using high resolution (5m) data available from previous work to check the likelihood of the WiMAX frequency being of use to FALCON (model in Figure 4) which shows excellent coverage at 64 QAM and 256QAM with iBridge. These paper checks were then supplemented by site investigation/survey visits, paying particular attention to the presence of buildings and trees which might affect line-of-sight radio links. In some cases electricity substations are actually "hidden" from view, where this is possible, to reduce their visual impact on the landscape. This "hiding" can obviously be detrimental to prospects for radio communications particularly when the sites are located among trees or in dips in the landscape or behind other buildings "out of the way".

Additionally, line of sight issues with trees and buildings are not modeled in the coverage data so this needed to be investigated on the ground - the model takes clutter into account, but not individual trees. Trees in leaf are heavy attenuators of radio signals. A subsequent calibration will be made to refine the model.

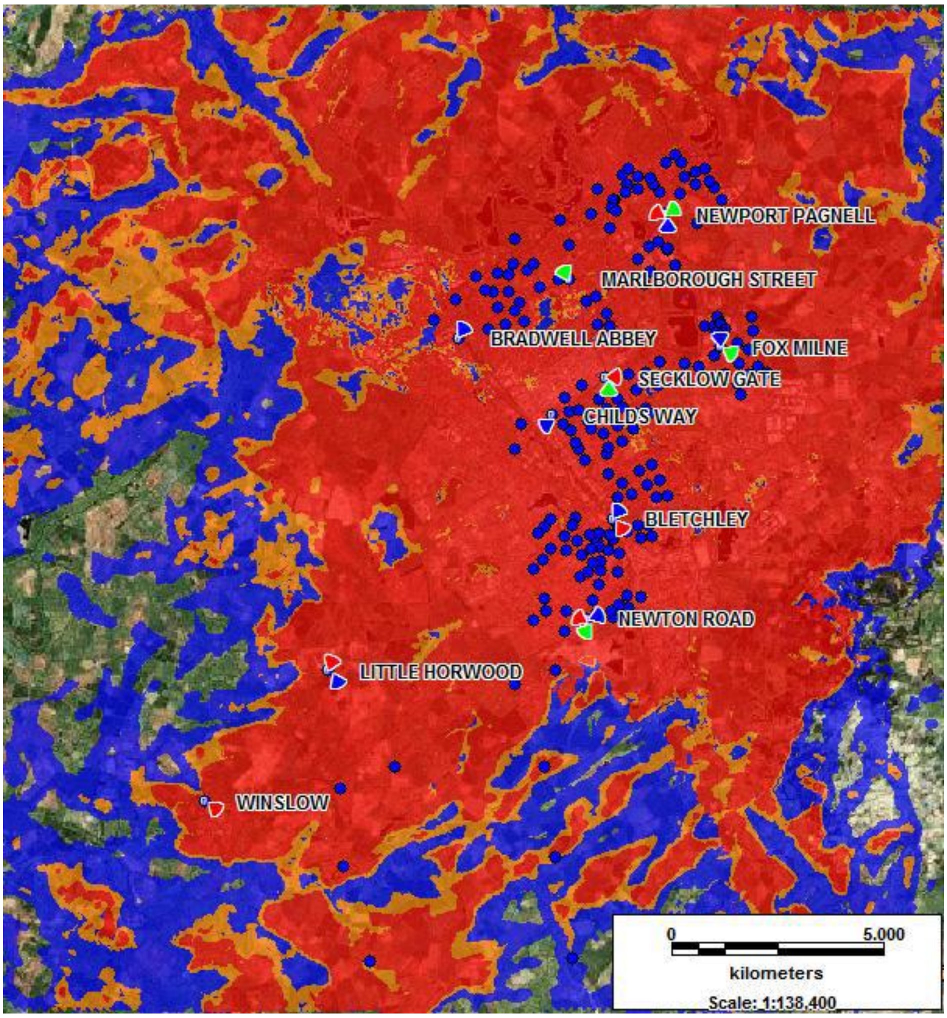

Figure 4 – FALCON Trials Area WiMAX Uplink Coverage

Key:

CH1 1432.5 — QPSK

CH2 1437.5 — 16QAM

CH3 1442.5 — 64QAM

Channel usage is optimised and part of the RF optimisation of the network once initially deployed.

As described elsewhere in this document, the radio signal characteristics allowed for a certain amount of flexibility during the site installation process. Early trials proved that it was possible in some cases to point

Plan In Advance

Model the intended WiMAX deployment area early in the programme. Tools such as Mentum Planet are useful in this regard. Survey for line of sight issues and carefully consider topology, tree cover, buildings and even proposed developments – all of which can impact on coverage.

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the aerial in the opposite direction to the intended relay location and still obtain a usable signal - this is due to the radio supporting reflections from buildings. This provided a large amount of confidence for the main installation phase that it would always be possible to obtain a connection by pointing the local antenna if not at the local primary substation routing hub, then at a more distant but more optimally located one on the Milton Keynes trial area grid.

Falcon Network Latency

The latency in the network is mainly associated with network propagation delays (most significantly in the various telecommunications equipment components and the use of time division half-duplex protocols within the routing nodes) rather than being the result of equipment wake times or from dynamic link reconfiguration delays. Thus, the latency is not primarily due to the router, this might contribute a few milliseconds but the radio elements contribute the majority of the delay which may be in the interface card, and would be present even in a simple layer 2 network.

It is readily seen then that key then to reducing latency in the radio network is the need to minimise the number of links required to service a specific terminating IP location. Latency arises mainly when the radio signal is received, processed and relayed with multiple operations of this type at each hop adding latency in a linear fashion (some 25 ms per node/hop on the FALCON network). The comms network design that has been adopted for FALCON has therefore been implemented with a hub-spoke arrangement which mainly follows the site hierarchy of the electricity distribution network itself, with the nine trials area primary electricity distribution substations also serving as the main routing hubs in the telecoms network which services the trials area. Only in cases where there have been radio line-of-sight issues preventing planned actions taking place has this general approach been changed.

The Figure 1 shows diagrammatically the overall communications network topology. A number of the backhaul radio links ultimately converge on the Bradwell Abbey Primary substation site where a dedicated microwave link with the Horwood site connects the trials network area to the main backhaul link to WPD's Tipton control centre where the trials data is collected and filed for later processing and inspection. The majority of the primary sites communicate directly with Horwood aggregation site however, in particular those sites with the line of site (LOS) difficulties to the closer Bradwell Abbey location.

It should also be noted that because the WiMAX system in use on FALCON is half-duplex, this requires the use of small packet sizes rather than the use of Jumbo frames for data transmission as is often the case for reducing latency and overheads in network implementations. This is not inconsistent with the nature of the data being carried however and we do not in general require many jumbo type frames on the network. Standard Ethernet frames are 1500 bytes in length which is usually necessary for enterprise applications, while the sort of SCADA traffic being carried by the FALCON communications network generally consists of very small packet sizes, usually below 512 bytes, while 64 bytes is common. Essentially in FALCON type applications we are just encoding simple serial based protocols into IP.

It should also be noted that many routers available/used at the low end of the market are software based for economic reasons and do not cope well with lots of small packet throughput - this is an issue about which utilities should be aware - traffic with mainly small packet sizes stresses devices more than large packets. There is a standard test suite many vendors run through their platforms (RFC2544) which tests various packets sizes and throughputs. This is a good indication for the performance of any router or switch but usually has to be requested. For utility networks the requirements tend to be latency and dependability rather than raw bandwidth. Bandwidth is the not the key driver on the FALCON network (this is not a broadband consumer type of service), stability and latency are, and bandwidth may be sacrificed for those in any trade-off.

The half-duplex setup means that the use of smaller packet sizes allows for better interleaving of bi-directional traffic rather than incurring delays that follow from having to wait for completion of larger packets coming in the other direction on the same link. This permits a more deterministic behavior.

FALCON Network Costs

The FALCON telecommunications network is based on equipment and software from Cisco and Airspan. While these two organisations have worked together previously to implement systems in the US, the FALCON network implementation is the first system of its type implemented in the UK.

The cost of the systems deployed in support of FALCON network implementation necessarily reflect the commercial nature of the overall network and include further drivers relating to:

- Communications performance. The IP routing and radio devices deployed must meet /exceed the target requirements for data throughput;
- System reliability. The system must perform reliably and meet target availability requirements for the network. This includes ruggedized design of components exposed to the elements;
- System resilience. In case of failure of any single overall system element, the system should be capable of continuing in some form of degraded mode of operation. Note however that the secondary substations are not resilient to a single failure but the goal for the network was that the whole system would be (apart from the single Microwave link);
- Ease of maintenance. The systems must be capable of being accessed/replaced quickly for maintenance and support purposes, including for routine preventative maintenance operations;
- Initial installation costs for deploying equipment and telecommunications links in the field;

- General operating costs. This includes software and hardware maintenance and any ongoing licence costs plus the cost of operating the main communications links on an ongoing basis.

As is usual, these costs are realised as capital costs (CAPEX) and support/ operational costs (OPEX). The CAPEX elements principally reflect the initial up-front implementation costs which can often be small relative to ongoing operational support costs. The minimisation of ongoing operations costs was therefore considered to be of particular relevance to the FALCON trials area communications support network with its over 200 remote stations to be operated/monitored through the trials, and it was an early decision to use a radio service of some sort to provide the main connectivity solution thus avoiding ongoing third party leasing costs usually associated with fixed line telecommunications.

Fixed Versus Radio Based Communications

Before discussing the main trade-offs for the chosen approach, it is first necessary to look at the drivers that lead to the use of the actual chosen radio solution over others that might have presented themselves.

Most of the sites (including all of the secondary electricity substations) lacked any form of fixed dedicated telecommunications links at the project outset, and only a few of even the primary electricity substations were served by fixed fibre links to other network locations[5]. In such a case the costs of installation of dedicated communications links in virtually all locations would thus be prohibitive and given the nature of the work required, this would also have required considerable lead times on installations[6]. Other than using radio or microwave the only remaining option would then be to utilise existing power lines for the communications links. This approach was discounted early on in the project in favour of a radio solution for FALCON although this may be an option for some. One of the reasons was that in a power outage the PLC comms also goes down, where as the WiMAX hardware is battery backed.

A microwave link solution was similarly discounted on the basis that this requires clear line of sight between the end points. This in turn forces the use of tall, and therefore costly, probably metal framework towers at each primary location. This then carries the installation into new realms of complexity as the installations (200 of them) would need to proceed through the formal planning process with the local authorities. The WiMAX radio solution, while essentially also requiring line of sight, has certain penetration and reflection characteristics which mean that this requirement is not as exacting as it is with microwave communications.

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[5] The Bradwell Abbey to Bletchley fibre link being the only one. This link routes via Child's Way but no fibre connectivity was apparent at that location. Thus only two of the nine FALCON primary substations are known to be served by fibre.

[6] Installation costs for fixed telecoms links would be in the range of several thousand pounds per location, and depending on access and land ownership issues could take several months to clear with wayleaves. Operating costs again could be expected to be several thousands per annum per location.

Propagation of the WiMAX signal is possible through a certain amount of tree canopy /other foliage and it is also possible to capitalise on the ability to reflect the signal from objects such as buildings and even to select a more distant primary substation routing hub than the local one. This also gives enhanced resilience capabilities. As a result the WiMAX radio solution allowed for the use of much shorter comms towers which fell within the 15m height allowed under the much simpler permitted development planning process. This in turn allowed for the use of wood poles, which experience has shown generate much less resistance from neighbours than metal communications towers.

Having thus determined that the WiMAX radio solution offered the most cost effective approach to communications for FALCON, this solution was then pursued. There still remained trade-offs however to implement a low latency solution within the coverage capabilities of the chosen radio bandwidth.

Trade-Offs Between Cost, Coverage and Latency

Having chosen a WiMAX radio solution utilizing the 1.4 and 3.5 GHz frequencies (the latter being the backhaul) as the site interconnectivity solution for the FALCON project, there followed a design process that lead ultimately to the final network topology. In deriving the design it was necessary to trade-off a number of factors to arrive at an acceptable solution that fell within expected cost bounds.

With a future smart electricity distribution grid trials network being monitored as a pilot project, there were a number of freedoms available to trade off. However while latency might not be a huge driver for a substation equipment monitoring only situation, one of the additional FALCON requirements is for the implementation of teleprotection in a number of locations in support of the meshed network trials objectives of FALCON. Therefore, in order to provide a solution which was not limited from the outset it was decided that a low latency approach be taken wherever this did not introduce significant additional costs. This would then allow the more strict latency requirements of teleprotection to be supported transparently by the underlying radio network architecture.

While the principle low latency requirement for the system is between substations, and the main goal was a single hop between teleprotection sites, it is still good practice overall for the network design to minimize the hops going back the centre in Tipton, and this was done wherever possible. However radio signal coverage would not always facilitate this and multiple hops have therefore be required in some cases to implement the connections. The navigation of this three way pull between latency, cost and coverage is the subject of this paper.

Trade-offs are needed when the intended design cannot be implemented in a straightforward manner and some accommodation in the system construction has to be made as a result. Usually, this issue would be expected, and was indeed seen to arise, because of the radio signal coverage not providing the planned telecommunications network linkages. In such a case it is then necessary to consider alternate radio pathways to maintain the overall system integrity, but then this is not always optimal for throughput times and thus is detrimental to the latency.

The discussion below considers some of the issues that had to be managed during the FALCON network rollout.

The Primary substation radio links from Fox Milne, Secklow Gate and Newport Pagnell could not be implemented using a direct connection to nearby Bradwell Abbey aggregation site due to intervening high ground and in some cases buildings, see Figure 5. These locations have therefore been served from the Horwood aggregation site in the South West of the trials area at the far end of what is also the microwave link (but not using it clearly), and in some cases 14KM distant, see Figure 6. High gain antennas have been deployed at additional cost to ensure sufficient signal strength in such a solution.

An option was available to route such problematic locations on the east side of the trials area via Marlborough St. (a site on higher ground) and thence to Bradwell Abbey / onwards to Horwood. This approach did indeed need to be used for one location (Newport Pagnell) even though this introduced additional latency (at a level of around 50ms) because of the additional iBridge hop, each of which adds some 25ms to the total. Thus in all but one location it has been possible to limit the overall latency to around 30ms.

The original project outset system design for the radio network was to have implemented a ring as a comms hub around the various primaries. However this would have introduced too many hops and would have significantly increased latency overall as a result. For some DNO network areas, primary substation sites may already be linked via fixed fibre, however the overall latency issue needs to be considered in such cases.

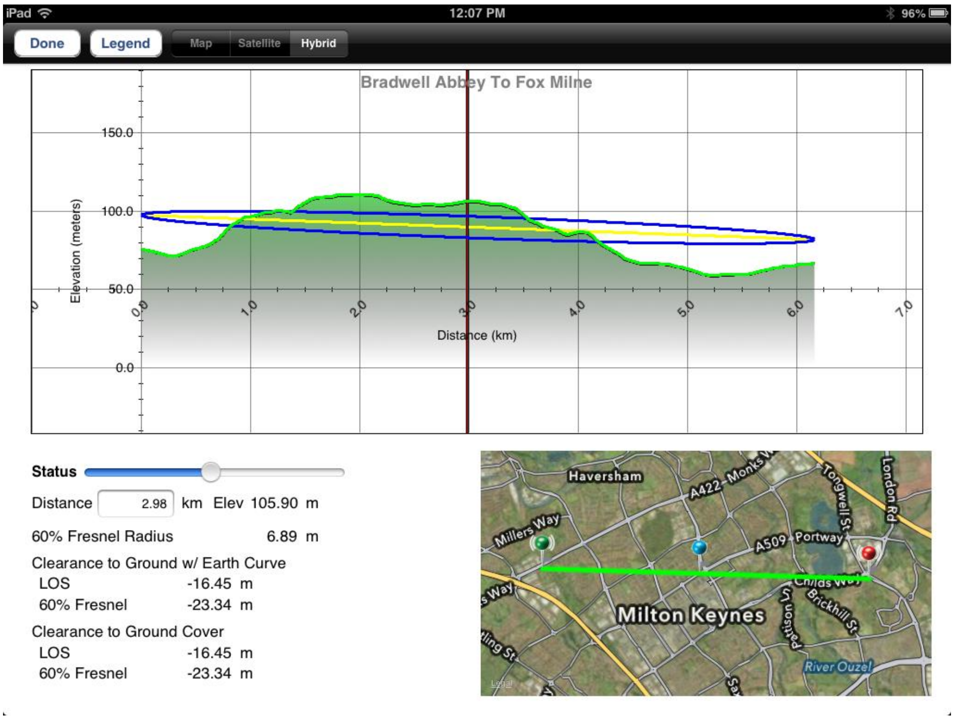

Figure 5 - Radio Profile - Bradwell Abbey to Fox Milne Prospective Link

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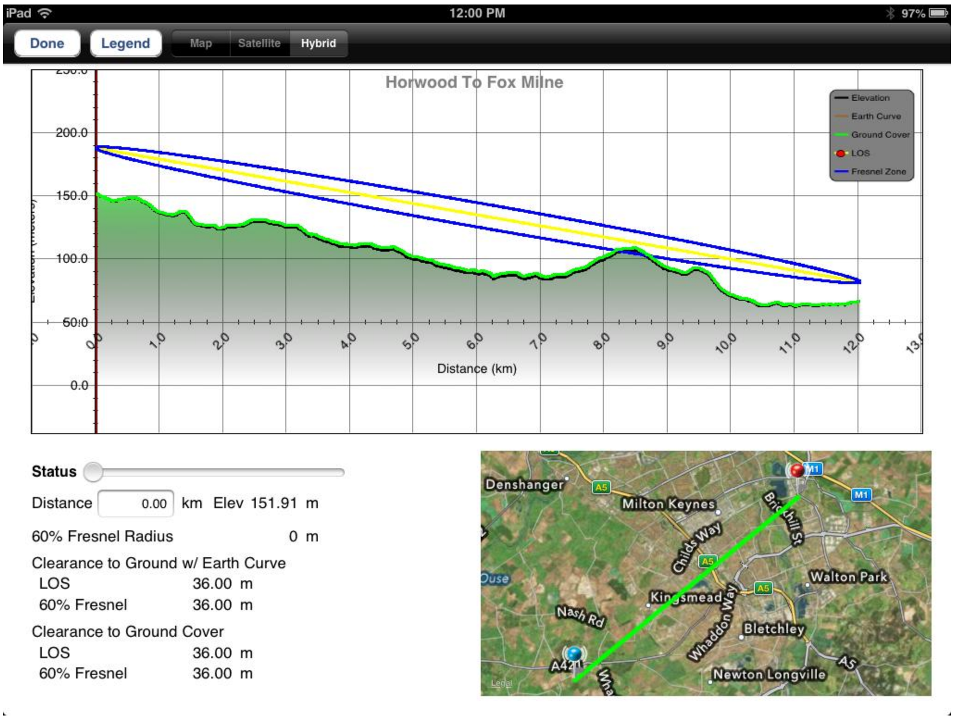

Figure 6 - Radio Profile Horwood to Fox Milne

Summary and Conclusions

Here follow the main Conclusions of this White Paper

WiMAX Radio technology and IP routing provides a highly efficient and cost effective solution for implementing the supporting telecoms infrastructure for the Electricity Smart Grid.

A bespoke WiMAX radio based telecommunications system based on commercial components from Cisco and Airspan used to support the operations of an electricity smart grid has been deployed in Milton Keynes as part of the project FALCON implementation work. WiMAX has proved to be a suitable radio technology for this application yielding a low overall installation and operational cost solution while giving high levels of control to the DNO when compared to other alternative candidate solutions such as fixed line;

WiMAX radio is implemented using AIRSPAN radio units coupled with ruggedized Cisco Router technology for the IP routing capability. This offers a resilient IP network solution for use by utilities and others where site access and installation may be an issue, and particularly for locations where there is no existing telecommunications infrastructure;

A low latency solution may be implemented by minimising the number of routing node hops necessary to communicate with terminating equipment. Where additional hops are necessary in the link path due to coverage considerations, the solution still provided a low latency capability for the FALCON trials network and the same can be expected for other implementations. This allows a teleprotection scheme between secondary substations to be run over the WiMax network;

The use of half duplex communications on the radio links is not inconsistent with the typical network traffic consisting of mainly small SCADA data packets;

Alternative pointing directions for any given site are highly likely to be available in a grid implementation of the type supported by the FALCON electricity distribution and matching telecommunications routing networks. This may result in more distant links and high gain antennas may be required to support such alternate routings where line-of-site issues exist (if directing a link towards a distant aggregation site, see next);

Rather than implementing additional hops in most cases, on the FALCON project, the radio coverage permitted the direct communication between the distant Horwood location and the primaries affected by LOS issues to the closer aggregation site at Bradwell Abbey;

The nature of the WiMAX radio solution for telecommunications support infrastructure for an electricity smart grid environment readily lends itself to adaptation and adjustment in the field should expected theoretical signal coverage not be realised. This is primarily due to the number of alternate relay locations that are likely to be present;

The cost of the rugged WiMAX radio based solution for Project FALCON is modest when compared to the likely costs for an IP network infrastructure based on fixed line telecommunications. However the potential licence costs associated with extending the use of the WiMAX solution from test to full operations is not factored into this assessment as it is currently unknown;

It would be advantageous to utilities and other critical national infrastructure organisations to have access to the WiMAX radio frequency. Representations are being made in this respect through the JRC.

Others have drawn similar conclusions to the above, In Ref 1, Senza Fili Consulting LLC working for Alvarion Ltd. state that:

Because they combine high throughput, low latency, and wider coverage, 4G technologies can host and integrate all smart grid applications, and also act as the unifying platform that provides backhaul connectivity for other wireless networks using BPL, ZigBee (Institute of Electrical and Electronics Engineers [IEEE] 802.15.4), Wi-Fi (IEEE 802.11), or license-exempt wireless technologies. For utilities, a single wireless technology like WiMAX that is widely deployed within their territory means lower costs, less complexity, improved control over applications, and better overall performance.

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References

Empowering the smart grid with WiMAX™ - A standards-based, advanced, and globally deployed technology supports a wide range of smart grid applications. Senza Fili Consulting LLC. White Paper prepared for Alvarion Ltd;

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About Western Power Distribution

Western Power Distribution is the electricity distribution network operator for the Midlands, South West and Wales regions of the United Kingdom. The company delivers electricity to 7.8 million customers over a 55,300 square kilometers service area. Its network consists of 216,000 km of overhead lines and underground cables, and 185,000 substations.

Ofgem's Low Carbon Networks Fund was established as part of its current price control arrangements for electricity distribution businesses (DNOs). It allows up to £500million of support between 2010 and 2015 to projects sponsored by companies that trial new technology, operating and commercial arrangements.

At the time of publication of this white paper in September 2013, WPD has five Tier Two projects and eleven of the 34 Tier One projects. This is more than any other UK Distribution Network Operator for both categories.

For further information on the FALCON project, please visit www.westernpowerinnovation.co.uk. If you have any questions on this specific or any other FALCON white paper, please contact westernpowerinnovation@westernpower.co.uk.