Smarter Suffolk Project

Communications Networks for A Smarter Suffolk

Hannah Steventon

Issue 1.0 October 2021

Contents

1 Executive Summary

Suffolk County Council's Smarter Suffolk project is exploring the potential for wider use of connected sensors deployed across Suffolk to inform their services. These sensors require network connections, and within the Smarter Suffolk project suppliers have worked with their choice of network connection. This report describes the technologies used, a selection of associated network technologies, and compares solutions provided by different suppliers.

Shorter and medium range technologies can be used to create local networks between devices and gateways, with commercial cellular networks providing longer distance backhaul from gateways. Alternatively, individual devices can be directly connected using cellular technology. Different network technologies are described in some depth.

Twelve suppliers provided connected sensors to the Smarter Suffolk project, using a wide range of different network solutions. Their solutions are summarised and discussed. Streetlighting suppliers prefer to leverage the networks that control their streetlights to also return data from sensors. Suppliers that supplied sensors only use other existing networks to return sensor data, including LoRaWAN and cellular networks.

This range of solutions indicates that smart city / connected places and sensor connections remains a diverse, evolving market, with different suppliers providing different solutions and actively developing those solutions during the two-year course of the project (2019-2021).

Different networks provide different benefits and challenges, balancing requirements in economic, technical and operational factors.

Recommendations for Suffolk County Council's digital infrastructure development are made by BSI in their "Digital Infrastructure Report". The compilation of a unified approach to, and knowledge of, network connectivity across the county for local authority purposes, and for supporting enterprise, is supported. This would enable networks to be developed without requiring pre-identified use cases to fully justify the network deployment, and for devices to be hosted on existing private networks where appropriate.

It is considered unlikely that a single network solution is appropriate for all use cases, locations and scenarios. Collaboration and strategic oversight would support the efficient use of technologies and networks to enable device uses cases to be developed without individually bearing the burden of network development.

Smarter Suffolk has explored a range of use cases, and observed a range of network solutions being provided by different suppliers. Technologies themselves, and their use by suppliers to the local authorities and to others, will continue to evolve rapidly, as the growth of connected places / smart cities and real time sensing technology continues.

2 Introduction

This report discusses the network access technologies used in the Smarter Suffolk project. It does so by first discussing the generic technologies available, and then their deployment in the Smarter Suffolk project itself.

2.1 Objective and process

This report is intended to address a number of objectives:

- Describe and discuss the different network technologies available for use in the Smarter Suffolk project;
- Support the separate thematic reports produced by University of Suffolk by summarising network technologies used in a single document;
- Review the communications networks used across the Smarter Suffolk project, drawing together the different solutions provided by different suppliers;
- Reflect on recommendations for future connectivity deployments in Suffolk, without being technology-specific.

The report draws on a range of work undertaken by the University of Suffolk during the Smarter Suffolk project. This work process includes:

- Literature review on networks for smart cities;
- Discussions and interviews with project participants and industry experts;
- Collation of data sheets, published and unpublished information from Smarter Suffolk suppliers;
- Review of information gathered.

2.2 Report Structure

After starting with an Executive Summary (Section 1) and this Introduction (2), the report contains the following sections.

Section 3 discusses technical specification and literature review findings for the communication network technologies used in the project, and some other selected technologies not deployed within the project but of similar interest.

Section 4 summarises the solutions deployed by different suppliers to the project, discussing similarities, differences and correlations between these different solutions.

Section 5 discusses benefits and disbenefits of different technologies in the context of the project's use cases. Section 6 reflects on recommendations for network connectivity for connected places in Suffolk, and Section 7 draws conclusions.

3 Network technologies

Smart City / Internet of Things is based on devices connecting over the Internet via an access network connecting the devices into the wider Internet for access. Alternatively, connections may be made directly with suppliers' systems, rather than the Internet, thus improving security. This connectivity is not provided via a single networking technology, but instead can be provided via one or more of a range of different technologies. Which technology is applied depends on the use case and availability of the technology and infrastructure. As this report discusses, different technologies have different benefits and disbenefits, and can be selected to best suit the use.

Within the Smarter Suffolk project, suppliers worked with their own choice of network technology. The range of technologies used within the project is discussed in Section 4.

Key attributes in selecting or assessing network technologies for IoT include (Putland, 2020):

- Data rate – quantity and frequency of data transmission;
- Power availability – access to electricity network power, battery or renewable / rechargeable power;
- Range – short distance connections or long distance from gateway or access point;
- Cost – low cost for economically efficient business case.

There are a wide range of different wireless communication technologies. Different technologies have different strengths in range, power requirements and data rates, where gains in one aspect are associated with reductions in other aspects. For long range technologies to have low power requirements, data rates are limited. These are generally discussed in three range-defined categories (with examples; there are many other technologies in each category):

- Short range: personal area networks (PAN) such as Bluetooth
- Medium range: local area networks (LAN) such as WiFi or Zigbee
- Long range: wide area networks (WAN) such as cellular or LoRaWAN

Focus technologies are illustrated comparatively in Figure 1.

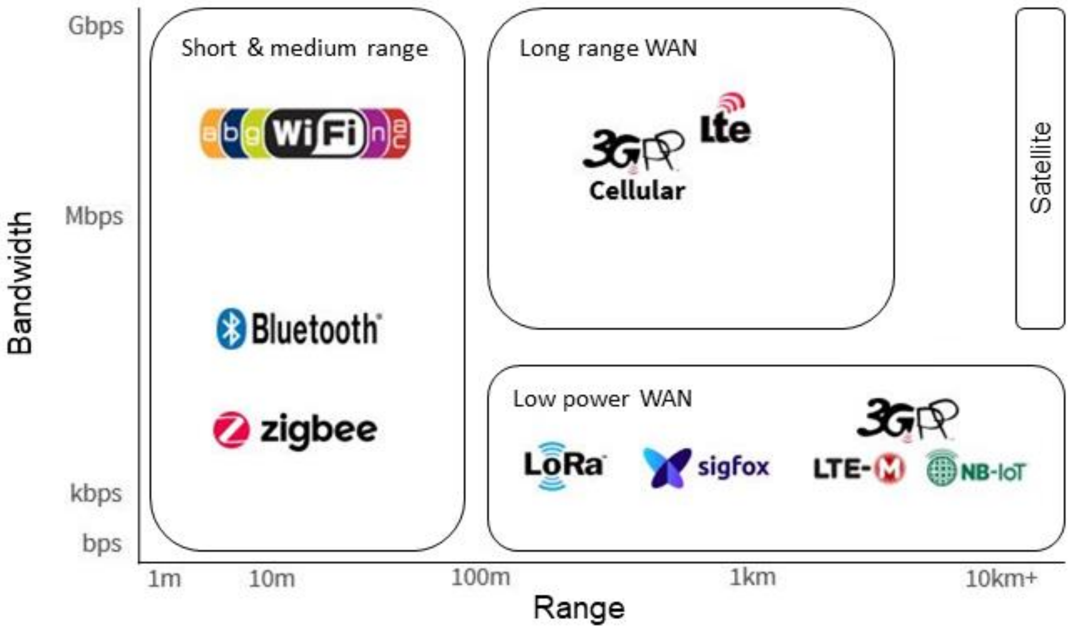

Figure 1: Network Technology by bandwidth and range

Internet of Things and Connected Places / Smart Cities connections generally use a combination of several technologies to provide data from the sensor to the internet, and (where applicable) the reverse journey. Most literature about these technologies has a focus on those relevant to the context of that literature: for example, Webb (2019) focuses on technologies they consider *"the most important – those deployed in the largest volume and most critical to the way we live and work today …* [considered to be] *cellular, Wi-Fi, IoT and satellite …"* Future developments are likely to be to provide faster data rates, efficiency and cost reductions, to enable the provision of more data, faster.

Alongside developments in communications technologies, developments in 'edge computing' providing data processing on the device, to enable the communication of only the required data rather than all data gathered. An example of this is the analysis of video at the device, enabling the transmission of required traffic information, rather than the communication of the entire video feed.

3.1 Shorter and medium range technologies

Shorter range technologies such as ZigBee require the device to be close to a receiving device or gateway. For smart city-type uses, the devices may form a mesh network with multiple devices re-transmitting data until the data reaches a gateway control, which acts as a hub or router, and provides connection from the short-range network to the Internet. Typically these gateways use commercial cellular network technology (discussed in Section 3.3.1).

Mesh networks have relatively high power requirements, as each node is continuously scanning for incoming data signals in order to transmit them. They are therefore suitable where electricity power network is available, and are widely used in street lighting for street lighting management. They have relatively short range, which is achievable in urban street lighting contexts, where street lights are located within a few tens of metres of each other, to provide continuous highways lighting.

Shorter-range technologies are of limited application due to their small coverage areas, and due to the power requirements of their network topologies (Bembe *et al.*, 2019). In the Smarter Suffolk project, short range networks were used by some suppliers for connections between street lighting columns. Short range networks observed in the Smarter Suffolk project are described below; other protocols are available, and are being used in similar use cases.

3.1.1 Zigbee

Zigbee is a specification for short-range power efficient, low cost communications specified by the Zigbee Alliance, intended to provide a suitable network technology for home, industry and city systems. It operates in unlicenced spectrum (2.4 GHz worldwide). It has a range of tens to around a few hundred meters (typically up to 300m line-of-sight. In the smart city / connected places context of this project, it has been used to form mesh networks between nodes on street lighting, and to connect to IoT devices mounted on or within short range of the lighting columns. Using mesh networks, it can cover wide areas with a limited number of gateways enabling backhaul to the Internet. It has low power requirements, and some devices can be battery operated.

SSE who provided a Zigbee-based network for the project describe their system as: "*a smart lighting network … connecting Nodes, Sub Masters, IoT devices and a Back Office System through a*

combination of Zigbee mesh and cellular (3G/4G) networks. Zigbee is a self-organizing and self-healing dynamic mesh network based on open standards, minimising network downtime.
[SSE] *primarily provides a Zigbee IoT mesh network across a local authority's area to connect, control and report data from streetlights and connected IoT devices."*

3.1.2 Proprietary short range technologies in street lighting

Many street lighting companies operate proprietary mesh technology in the unlicenced spectrum, connecting their street lighting control nodes with central management systems in a mesh network with backhaul at intervals.

3.2 WiFi

WiFi is not discussed further here, as it has not been implemented as a component of the Smarter Suffolk project, and has not been found to be a significant component of external smart city / connected places deployments. WiFi is frequently a connecting network technology in internal IoT deployments in office settings.

3.3 Long range WAN technologies

3.3.1 Cellular

Commercial cellular networks provide long range accessibility using 3GPP standards-based technologies, including 3G/4G/5G. Within the Smarter Suffolk project they have been used both to connect individual devices directly, and also as backhaul from gateways serving mesh networks using short range technologies for local connectivity (see Section 3.1).

Devices on cellular technologies, and connection fees, are considered expensive if used for a large number of individual devices on massive internet of things deployments.

3.3.2 Low Power Wide Area Networks: introduction

Cellular networks have relatively high power requirements, and therefore for continuous operation require connection to the electricity grid. They enable higher data transmission rates. Other long range technologies support low data rates with low power requirements, and are referred to as low-power wide area networks (LPWAN). LPWAN technologies are ideal for designing devices with low power requirements. This enables battery or renewably recharged power to be used over the long term (five to ten years is typical). They support low data rates, and therefore are suitable for sending small data packages on an intermittent basis (hourly, for example), and can cover tens of kilometres depending on terrain.

LPWAN technologies are used in IoT and smart city / connected places networks to complement higher powered WAN, and shorter range networks (Bembe *et al.*, 2019; Zhu *et al.*, 2021). It is predicted that a quarter of the forecasted 30 billion IoT devices will be connected with LPWANs by 2025 (Zhu *et al.*, 2021).

Specific examples of LPWAN technologies are discussed in the following subsections. Different LPWAN technologies have different balance of data vs power requirements, and can be better suited for different use cases (see Section 4.1 for further discussion).

Unlicenced LPWAN typically operates in an agreed spectrum band at 868MHz in Europe, and 915MHz in the USA, for which a licence is not required. Rules and national regulations set locally control how this band can be used to enable multiple users to co-operatively access this shared band.

Device management and design techniques are applied to conserve battery life. When not successfully optimised, battery life can be compromised (as has been observed during development of devices by suppliers in the Smarter Suffolk project). While the limited spectrum and power restricts these devices to low data rates, this is balanced against their long range. These technologies are suitable for many smart city uses, though not ones with high data rate requirements.

Different LPWAN technologies use the spectrum in different ways: Sigfox is an Ultra Narrow Band system, accessing only a narrow band of the spectrum. Conversely, LoRa uses chirp spread spectrum which increases security (Putland, 2020) and decreases the impact of interference. LPWAN technologies typically use simple star network topology (Adelantado *et al.*, 2017), with multiple devices connecting to gateways.

Whilst LPWAN technologies have benefits from their low power consumption, they offer low bandwidth. Their low bandwidth constrains use cases to those with lower data rate requirements, which has been seen in this project, with technologies such as video analytics for traffic counting using higher bandwidth cellular connectivity. Zhu *et al.* (2021) indexed LPWANs using latency, reliability and data capacity, and scored them with respect to network practical simplicity, long-term cost efficiency, feasibility, and information security, providing useful comparative tables.

Selected specific LPWAN technologies are discussed in the following sections (Sections 3.3.3, 3.3.4, and **Error! Reference source not found.**).

3.3.3 LoRaWAN

LoRaWAN is an open-standard networking layer specified by the LoRa Alliance, based on the chip developed by Semtech, operating in the ISM licence-free spectrum. LoRa specifies the physical layer, and LoRaWAN the MAC layer. LoRaWAN provides protocols for devices, gateways and servers to support interoperability between manufacturers, vendors and suppliers. Very low data rates enable battery powered devices, with long battery life (multiple years), with asynchronous communication. It operates a star, or star-of-stars, network topology to a gateway or multiple gateways (Adelantado *et al.*, 2017; Mekki *et al.*, 2019), then uses cellular (wireless) or Ethernet (wired) connections for backhaul. Gateways can serve a range of tens of kilometres in open terrain (less in urban areas), and serve thousands of devices.

As LoRaWAN operates in the licence-free industrial, scientific and medical (ISM) band, private LoRaWAN networks can be deployed without requiring mobile operators (Adelantado *et al.*, 2017). Many users choose to construct and operate their own LoRaWA network. LoRaWAN for public access is offered on The Things Network, a collaborative open network; The Things Network have a related enterprise service called The Things Industry offering a commercial service, with improved availability, support and features.

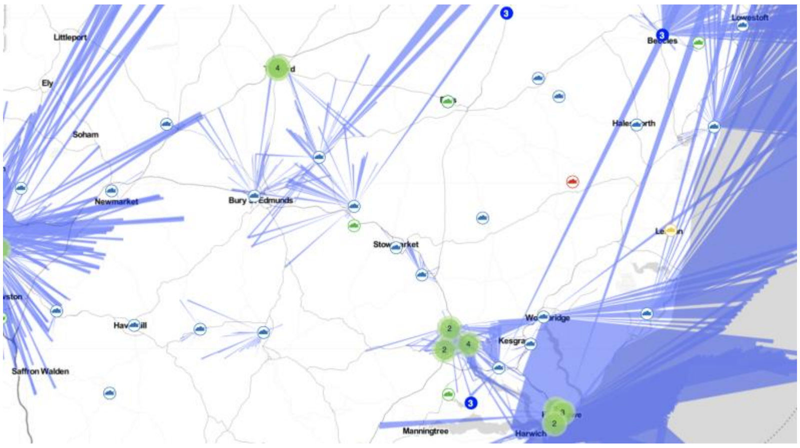

Figure 2: The Things Network's LoRaWAN coverage in Suffolk showing locations of gateways and mapped signal detection from https://ttnmapper.org accessed 17/09/21

LoRa is the physical layer used in LoRaWAN networks, and some LoRa deployments use the physical protocol without constructing a network.

LoRaWAN defines three classes of devices (Class A, Class B, and Class C) with increasing capabilities and functions, relating particularly to uplink and downlink transmission management. The higher classes include greater procedures to minimise data loss, with greater power requirements. Chirp Spread Spectrum is used to provide signal resilience and achieve long-range.

Duty cycle rules built into the ISM band and LoRaWAN protocols require off-periods, which are designed to limit the number and size of data transmissions. This, together with interference between multiple users on shared frequency or shared infrastructure, can lead to a reduction in reliability.

LoRaWAN is considered to be a good solution in smart city, environmental, agricultural, and leak-detection use cases, with wide geographical requirements but which do not have low latency requirements (Adelantado *et al.*, 2017). These applications have periodic data transmission with delay tolerances. For data transfer with a significant number of messages at set times (such as sunset, or at specific times) LoRaWAN is considered appropriate to manage the avalanche of messages at a specific time. As smart city and related uses increase, the impact of the densification of LoRaWAN networks has been considered a challenge to be addressed (Adelantado *et al.*, 2017).

LoRaWAN was researched in a Smart City context for a network of air quality analysers in Southampton, UK, assessing message delivery reliability and delay (Basford *et al.*, 2020). They found that 72.4% of messages were received (similar to other experiments), and 99% of data was received within 10 seconds of transmission, considered acceptable for 15 minute average environmental sensing. They concluded that LoRaWAN is suitable for city IoT deployments, with low priced gateways, independently operated network and long range, and that physically high gateway locations (roof tops) were important for range.

LoRaWAN is the easiest current LPWAN technology to deploy gateways without requiring operator involvement. This is a strength in enabling independence, and also a weakness, relying on the future of manufacturing of the devices and support for the protocol. The TTN community based around LoRaWAN includes tutorials and an annual conference, which encourage innovation and uptake. LoRaWAN has advantages in areas with limited internet connectivity. LoRaWAN has high power efficiency (lower power requirements than NB-IoT for example) and offers battery longevity for off-grid devices (Bembe *et al.*, 2019). LoRaWAN has significant flexibility in configuration (Seferagić *et al.*, 2020) which can be used efficiently when optimising a network and device. Hardware such as chipsets are considered to be cheaper than cellular alternatives, which can make LoRa a cost-effective choice in terms of device costs.

LoRaWAN has a very low bit rate within the protocol, which can be insufficient for many use cases (Bembe *et al.*, 2019). Increasing coverage from NB-IoT, despite its weaknesses, may replace LoRaWAN in many cases (Basford *et al.*, 2020). Restrictions of LoRaWAN downlink and buffering can limit use cases (Seferagić *et al.*, 2020).

During the period of the Smarter Suffolk project, Suffolk and Norfolk County Councils have jointly deployed what they claim to be the largest free-to-use public sector LoRaWAN deployment in the UK, in the Norfolk and Suffolk Innovation Network (Suffolk County Council & Norfolk County Council, 2021). 280 gateways are providing what is anticipated to be almost complete coverage of the area. It aims to support innovation in Internet of Things development, enabling organisations and individuals to connect devices to the LoRaWAN. It is being actively used in Suffolk for supported housing monitoring, education and other uses.

3.3.4 NB-IoT

Narrow Band Internet-of-Things (NB-IoT) is offered by mobile network operators in licenced spectrum, alongside existing mobile services in 200 kHz of guard or dedicated bands of the licenced spectrum to provide peak data rates of about 250 kbps. It is specified by 3GPP protocols, in the same way as other cellular technologies (Adelantado *et al.*, 2017; Mekki *et al.*, 2019). NB-IoT typically uses upgrades to existing cellular base stations, rather than requiring new infrastructure. As it operates in licenced spectrum, it can offer a quality of service that is hard to achieve from LPWAN technologies that operate in the licence-free band, which can be crowded (Li *et al.*, 2018). NB-IoT can maintain long range, useable data rate, security and high reliability; as with most technologies discussed in this report, latency will limit use cases.

Variations in the schedule of upgrading NB-IoT infrastructure across the UK have constrained the geographical coverage of the technology; these variations are due to the commercial operators running the base stations, due to both the technology upgrade required (software or hardware) and the works prioritisation of that operator. NB-IoT can support up to 100,000 end devices per cell (Mekki *et al.*, 2019), with a limited data rate that compares favourably with alternatives.

NB-IoT is designed to lower power demands and transmit limited data, but requires more power than LoRaWAN. These higher power requirements limit battery life or requires mains power connection. NB-IoT offers lower latency and higher data rates than LoRa (Putland, 2020). It is currently more widespread outside the USA, compared with LTE-M (Section 3.3.5) which is more common within the USA. Recent measurements on an actual public NB-IoT network showed that the achievable application layer throughput was significantly lower than advertised (Basu *et al.*, 2019, quoted in Seferagić *et al.*, 2020).

The increasing roll out of NB-IoT is presenting an interesting competitor to LoRaWAN, with a different provision and cost model (Basford et al., 2020). NB-IoT can experience downlink delays due to buffering, similar to other LPWAN technologies (Seferagić et al., 2020). Whilst operator management can increase robustness of provision, it can also lead to delays in maintenance outside the control of the users.

NB-IoT operates in licensed spectrum, which is considered more reliable than technologies in unlicenced, shared-spectrum bands. It has geographical spread depending on operator roll out. NB-IoT has greater range and security than other LPWAN technologies, and can offer greater availability when rolled out by the commercial network operators. However, experience indicates unpredictable latencies, especially in densely used networks, that may restrict applications to those that are less latency sensitive (Seferagić *et al.*, 2020). NB-IoT cannot be deployed privately, and requires a subscription to the network operator. The provision by network operators can make it more robust than privately run alternatives.

Whilst LoRa and Sigfox are found to be better in terms of battery lifetime, capacity and cost, (Mekki *et al.*, 2019; Seferagić *et al.*, 2020) NB-IoT has advantages in terms of latency and quality of service (Mekki *et al.*, 2019).

Telensa's second project with Smarter Suffolk uses NB-IoT for network connections. Sensors (electronic diffusion tubes from Alphasense (Alphasense, 2017)) are connected via Bluetooth to the NB-IoT control nodes for NB-IoT uplink. Using NB-IoT from the individual streetlight supports installation in locations with few lights, removing requirement for a gateway to serve those lights.

3.3.5 LTE-M / Cat-M1

LTE-M / Cat-M1 also operates in licenced spectrum, by mobile network operators, using 1.4 MHz of bandwidth to deliver data rates up to 1 Mbps. It is currently more widespread in North America than Europe. LTE-M is considered to be better for roaming applications, whilst NB-IoT may have strengths in fixed-location applications. LTE-M supports higher data rates, and is thought to be simpler to use, but requires more complex / costly / power-hungry devices.

3.3.6 Proprietary LAN technologies in street lighting

As discussed in section 3.1.2, many street lighting companies operate proprietary technology in unlicenced spectrum, connecting their street lighting control nodes with central management systems using proprietary protocols from backhaul gateways at intervals. An example within this project is Telensa. Telensa's standard streetlighting control solution works on a proprietary Ultra-Narrow Band (UNB) system with streetlighting controllers called Telecells. This uses the licence-free sub-1 GHz ISM band using a star topology (Raza, Kulkarni and Sooriyabandara, 2017; Telensa Inc., 2019b) to base stations up to 16km from the Telecell (Telensa Inc., 2019a, 2019b).

3.3.7 Alternative LPWAN technologies

Other open LPWAN technologies exist, but have not been encountered in use during this project. Selected alternatives are mentioned briefly here.

Sigfox is an LPWAN technology that was developed in 2010 by, and commercially run by, Sigfox, who own their network based on their patented technologies. This Sigfox network ownership model has driven interest to LoRaWAN (Adelantado *et al.*, 2017). Sigfox uses ultra-narrow band in the licence-free ISM spectrum of 869MHz in Europe on a star network topology (contrasting with mesh topologies) (Adelantado *et al.*, 2017; Mekki *et al.*, 2019). Using ultra-narrow band technologies enables power efficiencies and reduces noise levels, with limited data rates. They claim wide coverage of England and Northern Ireland, with patchy coverage in Wales and Scotland. Their coverage map of Suffolk reveals areas with no coverage (Figure 3). Sigfox bandwidth is constrained by the restrictions of its duty cycle (Bembe *et al.*, 2019). It seems to be of reducing visibility and use (discussions with multiple stakeholders and experts).

Figure 3: Sigfox coverage in Suffolk
blue: areas with coverage; pink: no coverage
from https://www.sigfox.com/en/coverage accessed 17/08/21

Weightless (using frequencies of 470–790 MHz) and Ingenu (2.4GHz frequencies) are other LPWAN technologies (Adelantado *et al.*, 2017; Putland, 2020), with less available information on coverage or commercially available devices.

3.4 Power usage in LPWAN

The ‘low power’ aspect of Low Power Wide Area Networks (LPWAN) enables the use of these devices with battery power, in some cases with renewable recharging (solar or wind). To support the lifespan of battery powered devices, device operation is designed to minimise power consumption. This can include (adapted from Webb (2019)):

- Keeping processing power requirements low
- Keeping transmitter power low
- Having extended sleep modes, with wake modes only when required
- Reducing transmissions to transmit or receive only when required

- Scheduling messaging with a known periodicity
- Minimising number of destination addresses
- Minimising message size

4 Use in Smarter Suffolk

Across the Smarter Suffolk project, twelve suppliers have provided connected sensors to the project. One of these (Telensa) has provided sensors under two systems (referred to as Telensa 1 and Telensa 2), and so is included twice in this analysis, making a total of thirteen connected systems. Five have supplied dimmable streetlights, with controllable nodes, hence providing actuators as well as sensors with two-way communication including street light control.

These solutions are summarised in
Table 1, which lists the protocols used for communication between the sensors and the wider internet, and where applicable for communication between sensors and the backhaul gateways.

As different providers had contracts for different numbers of devices, this has not been broken down into numbers of devices connecting via each technology. In Section 4.1 a summary of the solutions is discussed.

Supplier	Communication to internet	Local communication where applicable	Street light control?
Telensa 1	Cellular from gateway Cellular from hub	Proprietary UNB network for lights to gateway Sensors wired to on column hub	Yes
Telensa 2	NB-IoT from lighting nodes	Bluetooth connection between sensors and lighting nodes	Yes
Lucy Zodion	LoRaWAN for lights and sensors		Yes
Cimcon [1]	Cellular from wireless gateway	2.4GHz Zigbee Spec mesh network	Yes
SSE	Cellular from gateways	2.4GHz Zigbee Spec mesh network for lights and sensors	Yes
Enlight [7]	unspecified	enLight proprietary mesh protocol	Yes
Vivacity [2]	Cellular from device		
Omniflow [3]	Cellular from device		
Liveable Cities, LED Roadway Lighting	cellular LTE network as LTE-M (CAT-M1) network has not been fully rolled out in the UK		
InTouch [4]	cellular from gateway	LoRa class A to proprietary gateway, 6km LoS	
Kaarbontec [5]	Cellular from device		
Uniotec [6]	User-supplied LoRaWAN		
IOT Solutions	LoRaWAN		

Table 1: Communications solutions across the Smarter Suffolk project

[1] (CIMCON, 2020) [2] (Vivacity Labs, 2021) [3] (Omniflow, 2017) [4] (InTouch, 2021)
[5] (Farsite, 2021) [6] (Uniotec, 2021) [7] (enLight, 2021)

4.1 Summary of solutions

For suppliers providing just sensors (not associated with street lighting networks), each has a direct data connection, either via 3GPP protocols for mobile data (2G, 3G, or 4G), or in the case of Uniotec and IOT Solutions, to an externally provided LoRaWAN network, such as the Suffolk and Norfolk Innovation Network. Sensor suppliers providing connected sensors work with networks provided to them, or with publicly available licenced connections.
Use of LPWAN protocols is dependent on low bandwidth and data rates, and is not appropriate for all use cases.

Suppliers providing street lighting as well as sensors have a wider range of solutions:

- CIMCON and SSE create their own street lighting network based on the Zigbee protocol. This builds a mesh network between nodes, communicating to gateways providing 3GPP backhaul over commercial data networks. SSE provide sensors that operate with Zigbee communications to communicate into their network, and CIMCON provide sensors that connect with individual 3GPP connections.
- Telensa 1 creates their own street lighting network based on long range UNB technology with a proprietary protocol. This communicates with a star topology communicating to gateways providing 3GPP backhaul over commercial data networks. Sensors connect via wired connections to a hub on the same lighting column, from which a signal is transmitted via individual 3GPP connection.
- Telensa 2 and Lucy Zodion both provide street lights that communicate individually and directly with an available network: NB-IoT in the case of Telensa 2, and SCC's LoRaWAN Innovation network in the case of Lucy Zodion. Lucy Zodion also provide sensors that communicate individually with this network, and Telensa 2 supplied sensors that communicate via Bluetooth with the street lighting nodes, which relay the data using NB-IoT.

It is noted that the only devices encountered in the Smarter Suffolk Project that deploy their own network are street lighting. Other devices within the project use existing networks:

- networks installed for street lighting including the Zigbee network created by two streetlighting suppliers;
- commercially available networks such as 3GPP or, where available NB-IoT;
- LoRaWAN, including the LoRaWAN Innovation Network installed by Suffolk County Council.

This range of solutions indicates that smart city / connected places and sensor connections remains a diverse, evolving market, with different suppliers providing different solutions and actively developing those solutions during the two-year course of the project (2019-2021).

5 Discussion

5.1 Range of benefits

Selecting a specific technology or group of technologies for use depends on the balance of a range of factors. Each technology has different benefits, and will suit different scenarios. Amongst these factors are (Seferagić *et al.*, 2020) (Mekki *et al.*, 2019):

- Price and price model
- Licenced or unlicenced spectrum technologies
- Range and coverage
- Latency
- Reliability and quality of service
- Data rate and payload length
- Energy Consumption including battery life or suitability for renewable power
- Availability of devices and hardware and scalability
- Process of deployment

Selected factors are discussed briefly in the following sections.

5.1.1 Resilience and purpose requirements

Different communications technologies are more robust and therefore more suitable for “mission critical” use cases.

5.1.2 Costs

Deploying your own network (directly or via contract) and using national operator infrastructure have very different cost models, in terms of up-front costs with potentially lower running costs, or minimal initial costs with an ongoing subscription fee.

LoRaWAN base stations are cost effective (around £1000 for an external gateway, plus installation, maintenance and operating costs) compared with other options, and devices can be only a few pounds. In contrast, NB-IoT base stations are provided by commercial operators, with an annual subscription per device.

5.1.3 Licenced vs unlicenced

Licenced spectrum uses technology that is significantly standards based, and development of standards can take time (Putland, 2020). Licenced spectrum can offer better quality of service, with robust design, managed maintenance and potentially less congested spectrum.

5.1.4 Latency, power and bandwidth

Technology features in LoRaWAN that are designed to reduce power consumption and increase battery life have the effect of increasing latency, compared with NB-IoT which offers lower latency at the expense of higher power consumption.

5.1.5 Device availability

Standards-based technologies enable widespread and commercial device development for the open market. This has the impact that there are more IoT end devices available that communicate using those technologies. Some technologies are more widely supported than others. Across this project, it has been seen that suppliers using proprietary protocols have an additional challenging step to link devices into their networks, and have used other communications solutions.

Some protocols manage greater number of end devices per gateway, which supports scalability, though with commercially available networks such as NB-IoT the user is dependent on operator supplied gateways and is in competition with other users, without the ability to supply their own gateway.

5.1.6 Range and coverage

The difference between shorter-range mesh networks and LAN networks with geographically dispersed base stations has been discussed in Section 3. Different LPWAN technologies have different ranges (Sigfox range of over 20km compared with LoraWAN range of 10km in rural areas, less in urban areas). NB-IoT range is around 10km from base stations, and requires operator enabling of the base stations, which is still in progress with no roll out yet in some areas.

5.2 Use Cases

The benefits and limitations of different technologies will determine which are most appropriate for specific Internet of Things end uses. For smart city / connected places applications, different technologies will serve different specific use cases, and there is no single solution. Appropriate solutions will depend on availability and the range of factors discussed above. As has been shown in this project, there are often a range of different solutions being applied by different providers. Consideration of support for, or provision of, communications services should be given attention by Suffolk County Council, in supporting its own services, other local public services and local enterprise. This is addressed further in Section **Error! Reference source not found.**.

6 Recommendations

6.1 Digital Infrastructure Recommendations to Suffolk County Council from BSI

As part of the Smarter Suffolk Project, Suffolk County Council commissioned *"research into the digital infrastructure that may be required in the future to deliver the outcomes envisioned in the project"* (Peel, 2021). This was undertaken by BSI, and reported in their Digital Infrastructure Report (Peel, 2021). That report had a focus on future governance and organisation of digital infrastructure in service delivery, and did not aim to detail specific solutions or technologies, nor the services supplied in the Smarter Suffolk project. It should be referred to for recommendations, and includes a focused Executive Summary.

The questions addressed by the BSI Digital Infrastructure Report are stated as:
"The question was …

- *What digital infrastructure should be deployed?*
- *How it could be delivered?*
- *When?*
- *By whom? and*
- *What barriers and challenges might need to be overcome to deliver the ubiquity that is required."* (Peel, 2021)

They drew eleven conclusions, covering strategic, operational and tactical perspectives. These are detailed and explained in their report, and included here:

"From a strategic perspective the recommendations are:

1. *Consider decoupling the planning, commissioning and operation of digital infrastructure from the creation of use cases for services that will utilise it. …*
2. *Develop and publish a digital strategy (or manifesto) which clearly articulates the ambitions and need for collaboration for all stakeholders across the County. …*
3. *… produce a comprehensive catalogue of assets that can be made available to host/locate digital infrastructure and note any conditions or limitations that effect their potential use …*
4. *… work with all appropriate Government procurement agencies, for example the Crown Commercial Services, to simplify and streamline the procurement process in order to encourage investors.*
5. *… create a digital infrastructure board to provide a governance function for the design, development, and operation of digital infrastructure across the County/region …*
6. [consider] *Appointing a digital infrastructure architect (or small architecture team) to translate the strategy into design principles …*
7. [consider] *Creating a digital infrastructure inventory and map …*
8. *Produce an additional and extensive portfolio of use cases that could deliver value if they were able to access 'appropriate' infrastructure. …*
9. *Produce an initial portfolio of tested and approved IoT devices, sensors etc which have been proven to deliver value to operational teams at the Council. …*
10. *Create a 'lessons learned' briefing describing some of the technical, governance and operational barriers and the solutions employed to overcome them. …*
11. *Create a series of templates to standardise a digital strategy approach and expectations that can be used elsewhere"* (Peel, 2021)

That Digital Infrastructure Report commented on *"whether the County intends to own the bulk of the digital infrastructure across its geography or … create the conditions where digital infrastructure can be deployed and operated by other parties (own or orchestrate)"* (Peel, 2021). It is likely that a combination of owned networks and commercially available networks provide solutions, and that an inventory of existing solutions can support further deployment of devices, development of use cases, and planning of future network needs. Local authority ownership and control of physical and powered infrastructure such as building and lighting columns gives the local authority strengths in supporting the development of new networks, as has been observed in the construction of the Norfolk and Suffolk Innovation Network using LoRaWAN.

6.2 Range of communication network solutions

It is not the purpose of this report to comment on the recommendations drawn in the Digital Infrastructure Report prepared by BSI. In the context of both the technical details of this report, and the business cases of associated reports, the following remarks support those recommendations.

Peel (2021) states that *there are few situations where a single use case (or even a cluster of use cases) produces a business case that fully justifies the deployment of digital infrastructure for the sole purpose of delivering the use case(s) in question*, experience which supports the findings of this research report: the only devices encountered in the Smarter Suffolk Project that deploy their own network are street lighting. Other devices within the project use existing networks, including those installed for street lighting, commercially available networks, or the LoRaWAN network installed by Suffolk County Council. Elsewhere within Suffolk County Council, different network solutions are used for other use cases.

The compilation of a unified approach, to and knowledge of, network connectivity across the county for local authority purposes, and for supporting enterprise, is supported. This would enable networks to be developed without requiring pre-identified use cases to fully justify the network deployment, and for devices to be hosted on existing private networks where appropriate.

It is considered unlikely that a single network solution is appropriate for all use cases, locations and scenarios. It remains likely that infrastructure communication is made up of a combination of short range and long range network protocols, with high or low power and bandwidths. However, collaboration and strategic oversight would support the efficient use of the various technologies and networks to enable device uses cases to be developed without individually bearing the burden of network development. It is considered that as electronic hardware becomes increasingly “plug and play” it will become easier for suppliers to adapt their devices to communicate on a wide range of network protocols. Smarter Suffolk has explored a range of use cases. Within local authorities and local enterprises, a wider range of use cases will be supported by communication networks, including, for example, logistics and asset tracking, agri-tech, metering, and pollution monitoring.

7 Conclusions

This report discussed the network access technologies used in the Smarter Suffolk project. It described the generic technologies, then reviewed their deployment.

Suppliers providing streetlighting control as well as sensors used a range of network protocols for their streetlighting controls, including shorter-range technologies to centralised gateways, and long range technologies on a range of network protocols. Most suppliers used their street lighting network to support communication from additional sensors. Suppliers providing sensors only used other existing networks, and a range of different network technologies were selected.

Smart city / connected places and sensor communications is considered currently to be a diverse, evolving market. Active development was observed in solutions during the project, and is anticipated to continue.

Different technologies have different benefits and challenges. Therefore future solutions are expected to continue to use a range of technologies dependant on the requirements of the devices and location and use case of the deployment.

In a separate report for the Smarter Suffolk project, BSI have made a set of recommendations to Suffolk County Council. These include creating an inventory of existing network assets and assets that can support further network development, and enabling development of digital infrastructure for future use.

It is unlikely that a single use case alone can support creation of the digital infrastructure it requires. Support of creation of digital infrastructure will support the development of uses of it.

Digital solutions will be varied, depending on the requirements and locations of the use cases and devices, and are considered likely to continue to use a range of shorter and long range connectivity technologies. Technologies themselves, and their use by suppliers to the local authorities and to others, will continue to evolve rapidly, as the growth of connected places / smart cities and real time sensing technology continues.

8 Discussions and Interviews

The author has had discussions and interviews with experts in the field, and is grateful to the following for sharing their knowledge during the preparation of this report. Many others have also shared insights, knowledge and views on communications networks across the course of the Smarter Suffolk project.

Paul Putland, Principal Consultant Internet of Things, BT
Andy Fidler, Principal Network Architect Consumer and Enterprise Internet of Things, BT
Dominic Varley, Internet of Things Enterprise Architect, BT
Peter Lewis, Technical Director for Europe, Casa Systems

9 References

Adelantado, F. *et al.* (2017) 'Understanding the Limits of LoRaWAN', *IEEE Communications Magazine TA - TT -*, 55(9). doi: 10.1109/MCOM.2017.1600613 LK - https://uos.on.worldcat.org/oclc/7141000863.

Alphasense (2017) *EDT Electronic Diffusion Tube*.

Basford, P. J. *et al.* (2020) 'LoRaWan for smart city IoT deployments: A long term evaluation', *Sensors (Switzerland)*, 20(3). doi: 10.3390/s20030648.

Basu, S. S. *et al.* (2019) 'Experimental Performance Evaluation of NB-IoT', *International Conference on Wireless and Mobile Computing, Networking and Communications*. IEEE, 2019-Octob, pp. 2–7. doi: 10.1109/WiMOB.2019.8923221.

Bembe, M. *et al.* (2019) 'A survey on low-power wide area networks for IoT applications', *Telecommunication Systems : Modelling, Analysis, Design and Management TA - TT -*, 71(2), pp. 249–274. doi: 10.1007/s11235-019-00557-9 LK - https://uos.on.worldcat.org/oclc/8083131278.

CIMCON (2020) 'CIMCON's Intelligent Lighting Management System', p. 4.

enLight (2021) 'ADEPT Live Labs - Suffolk'.

Farsite (2021) *Liquinet liquid level monitoring*. Available at: https://iot.farsite.com/products/liquinet-flood-sensors/ accessed 19 Aug 21 (Accessed: 21 August 2021).

InTouch (2021) *Gen 4 Data Concentrator Information Sheet*.

Li, Y. *et al.* (2018) 'Smart Choice for the Smart Grid: Narrowband Internet of Things (NB-IoT)', *IEEE Internet of Things Journal*, 5(3), pp. 1505–1515. doi: 10.1109/JIOT.2017.2781251.

Mekki, K. *et al.* (2019) 'A comparative study of LPWAN technologies for large-scale IoT deployment', *ICT Express*. Elsevier B.V., 5(1), pp. 1–7. doi: 10.1016/j.icte.2017.12.005.

Omniflow (2017) 'OMNILED 07 - Smart Energy Platform'.

Peel, S. (2021) *Digital Infrastructure Report*.

Putland, P. (2020) 'Connecting Devices: Access Networks', in Davies, J. and Fortuna, C. (eds) *The Internet of Things: from data to insight*. Hoboken, NJ: John Wiley & Sons, Inc., pp. 9–19. doi: 10.1002/9781119545293.ch2.

Raza, U., Kulkarni, P. and Sooriyabandara, M. (2017) 'Low Power Wide Area Networks: An

Overview', *IEEE Communications Surveys and Tutorials*, 19(2), pp. 855–873. doi: 10.1109/COMST.2017.2652320.

Seferagić, A. *et al.* (2020) 'Survey on wireless technology trade-offs for the industrial internet of things', *Sensors (Switzerland)*, 20(2), pp. 1–22. doi: 10.3390/s20020488.

Suffolk County Council & Norfolk County Council (2021) *Norfolk and Suffolk Innovation Network*.

Telensa Inc. (2019a) 'Telecell : Universal Streetlight Controller'.

Telensa Inc. (2019b) 'Ultra Narrow Band (UNB) Smart City Network'.

Uniotec (2021) *Uniotec Bespoke IoT Solutions*. Available at: https://uniotec.co.uk (Accessed: 19 August 2021).

Vivacity Labs (2021) *The Vivacity Sensor Platform*. Available at: https://vivacitylabs.com/technology/sensors/ (Accessed: 19 August 2021).

Webb, W. (2019) 'Wireless Comms. Beyond 2020', in Dastbaz, M. and Cochrane, P. (eds) *Industry 4.0 and Engineering for a Sustainable Future*. Springer International Publishing AG, pp. 49–64. doi: 10.1007/978-3-030-12953-8_4.

Zhu, H. *et al.* (2021) 'Index of Low-Power Wide Area Networks: A Ranking Solution toward Best Practice', *IEEE Communications Magazine TA - TT -*, 59(4). doi: 10.1109/MCOM.001.2000873 LK - https://uos.on.worldcat.org/oclc/9046182042.

10 Document History

Date	Version	Author	Notes
Sept 21	Draft	H Steventon	Reviewed with Prof N Caldwell
Oct 21	Issue 1.0	H Steventon	Issued to Suffolk County Council