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Smart Street Lighting as a Smart City Platform

Applications and Connectivity Best Practices

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Section 1

EXECUTIVE SUMMARY

1.1 From Street Lighting to Smart City Platforms

Ever since London's Pall Mall became the first street in the world to be illuminated with gaslights in 1807, street lighting has become fundamental to our urban experience. Today, street lighting is once again a focus for urban innovation as lighting networks become a platform for a range of smart city applications.

Replacing a legacy street lighting system with LEDs can reduce a municipality's energy bill by half. Integrating those lights with networking and intelligent controls can provide a further 30% in savings—and provide a platform for current and future smart city applications that can enhance public safety, traffic management, health, comfort, and more.

1.2 Connecting the City

City planners and leaders are embracing smart, connected lighting upgrades—and are confronting an array of connectivity choices that may (or may not) enable the city to achieve its goals. These choices range from low cost ultra-narrowband options to higher cost, high capacity broadband.

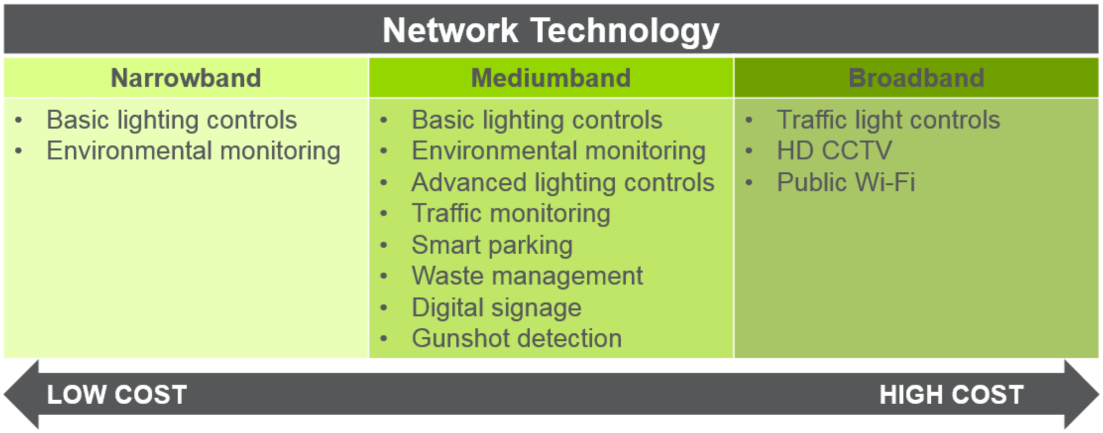
For city managers, this abundance of choice can be confusing. Not only do upfront and ongoing operating costs have to be weighed when evaluating smart street lighting, but longer-term goals and future needs must also be considered. Planning ahead can significantly reduce lifetime costs.

Navigant Research analyzed a dozen connectivity technologies and their suitability as a smart street lighting/city platform. Characteristics of each technology, including cost, reliability, security, data latency, power requirements, bandwidth, and technological maturity, were weighed against the requirements for 10 smart city applications.

Figure 1.1 shows that mediumband solutions prove to be both reasonably affordable and technically suitable for the largest number of potentially desirable applications. In contrast, narrow and high bandwidth solutions were found to be optimal for a smaller number of applications, with tradeoffs around cost. For example, narrowband networks are cost-effective but limited in terms of future uses; broadband networks, while highly functional, are more expensive.

There is no single answer to the question of which is the best street lighting network for a given city. The challenge for municipalities is to balance short-, medium-, and long-term requirements against the costs and benefits of different network options. Does the proposed network have the bandwidth, flexibility, and functionality to meet current and anticipated needs at an affordable cost? This paper provides a framework for municipal leaders to answer that question for their cities.

Figure 1.1 Technology/Application Suitability Map



Network Technology		
Narrowband	**Mediumband**	**Broadband**
• Basic lighting controls • Environmental monitoring	• Basic lighting controls • Environmental monitoring • Advanced lighting controls • Traffic monitoring • Smart parking • Waste management • Digital signage • Gunshot detection	• Traffic light controls • HD CCTV • Public Wi-Fi

(Source: Navigant Research)

In this paper, 10 smart city applications and their networking requirements are described; a dozen network technology options are also explained in some detail. Navigant Research performed a quantitative analysis of network attributes and application requirements, summarizing the study results in a heatmap that illustrates which technologies are best suited for each smart city application. Details are included in Section 3 of this paper.

1.3 Study Findings

Key takeaways of the study include:

- Mediumband networking solutions occupy the sweet spot, balancing cost and support for the largest number of high value smart city applications.
- Installation of networking and controls simultaneously with LED deployments will reduce overall costs, increase the efficiency and functionality of street lighting and provide a platform for future smart city applications.
- The right smart street lighting platform can help cities deal with issues such as crime and antisocial behavior, pedestrian and driver safety, and city revitalization projects.
- Cities need to outline long-term goals and priorities before selecting a smart street lighting network. They should also recognize that the right solution may combine more than one technology for different applications; for example, medium band for most applications and dedicated fiber or Pt2Mpt for security cameras.
- In a world that depends on ubiquitous access to power and connectivity, the street lighting network is a valuable asset. In addition to improving the efficiency and value of city services, that network can also become a source of new revenue for the city.

Section 2

THE CASE FOR SMART STREET LIGHTING

2.1 The Transformation of City Street Lighting

LED lighting and communication networks are transforming street lighting. As a consequence, city lighting networks are becoming the platform for a wide variety of smart city innovations. This vision of the city lighting network as a smart city platform is the next frontier for street lighting.

Falling costs and improvements in quality are making LED lighting the default option as cities replace and upgrade existing lighting systems. LEDs can reduce energy consumption for street lighting by up to 50%, and as the price and the quality of LED lighting continue to improve, that appeal is growing. New York City, for example, expects $6 million annually in energy savings from replacing its 250,000 street lights with LEDs and a further $8 million in maintenance cost savings.

But installing LED lighting is only the first step. Many municipalities now realize that upgrading street lights also provides an excellent opportunity to install a lighting controls network. This network, in turn, offers cities an opportunity to deploy a range of solutions that can save money, keep residents safe, improve sustainability, and attract new people and businesses.

2.2 The Benefits of Connected Street Lighting

Connecting street lights together in a computer-controlled network opens the door to a wide range of innovative capabilities that save energy and improve the performance of the lighting system. Beyond those applications lie the broader possibilities for deploying non-lighting solutions on the lighting network, making it a ubiquitous platform for smart city applications. Enabling a connected network at the same time as upgrading to LED lighting also reduces overall costs and removes the need for a second installation program.

2.2.1 Street Lighting Management

At the most basic level, lighting controls provide elementary features such as remote on-off control, dimming, and scheduling functions. There is also a wide range of advanced functions that can be enabled by intelligent controls:

- **Energy monitoring and billing:** Accurate information on energy consumption is an important element in reducing energy costs. In addition, as street lighting becomes part of more complex electricity system, accurate and real-time information on energy usage becomes more important for optimization and grid management.

- **Performance monitoring:** One of the most cited benefits of a networked street lighting system is the ability of a manager to remotely monitor outages. This eliminates time spent on nighttime patrols to identify malfunctioning lights and ensures that problems can be fixed in a timely manner.
- **Color controls:** Early LED lighting deployments were associated with a monotone, even harsh, light. But modern LEDs can be adjusted to select the color temperature of the white light provide by street lamps. For example, lighting may be adjusted for public safety purposes, to fit with special events, or for the different needs of retail or business districts. Recent developments in full color tuning permit even greater control of illumination, allowing an almost infinite range of color and temperature options.
- **Adaptive lighting:** Sensors that monitor local conditions can enable networked systems to adapt the brightness of street lighting as necessary. Linking light controls to traffic volumes, for example, can provide considerable energy savings. If no traffic is present or traffic volume is extremely light, then full brightness street lighting is not necessary. Similar motion detectors can enable lighting levels to match street activity. Weather sensors can also enable adaption to rain, snow, or other conditions. For example, lights may be turned up during rain showers and back down when the weather clears.
- **Emergency response:** Networked street lighting systems give city managers a number of features for dealing with public safety issues and emergencies, such as flashing lights in front of a house that emergency workers are attempting to find or brightening lights at an accident or crime scene. Other common applications include the use of adaptive light controls to provide warnings to drivers in school safety zones.

Note that many of these current and future applications benefit from designing in extra lighting power, so that if or when needed, lights can be brightened beyond normal levels.

2.2.2 Smart City Platform Applications

Beyond the capabilities for advanced lighting controls, street lighting networks also have the potential to support a range of non-lighting applications as part of the broader deployment of Internet of Things (IoT) solutions for smart cities:

- **Environmental/air quality monitoring:** Connected street lighting poles enable air quality and noise sensors to be easily deployed in specific locations or to provide citywide real-time monitoring capability.
- **Traffic monitoring:** Traffic sensors connected to the street lighting can provide a more accurate and flexible monitoring of traffic and congestion levels.
- **Smart parking:** Street lighting networks can provide the network infrastructure for parking sensors embedded in parking spaces or be used to mount video cameras that use vehicle detection software to provide occupancy information.

- **Gunshot detection and location:** Gunshot detection systems can be deployed on lighting poles and use the network to transmit information on detected events to the operations center. Advanced systems can provide precise information on the specifics of the event, including the shooter's location and integrated video monitoring.

These applications can be deployed using sensors attached to the street lighting controls. A wider range of applications also benefit from sharing the same network infrastructure:

- **Traffic light controls:** Traffic lighting that is adaptive to congestion levels, weather conditions, accidents, or other events can improve traffic flow, reducing travel times, fuel consumption, and pollution.
- **Smart waste management:** Sensors in trash bins and dumpsters can provide data to optimize waste collection and identify problems from overfilling. Waste sensors can use dedicated networks or a common city network to relay data to the waste management team to help them plan collection routes.
- **Public messaging/digital signage:** Public information networks now span a range of devices, including traffic and parking information panels, public information broadcasts, and dedicated kiosk services. Linking public information to real-time urban monitoring systems—like smart parking systems—provides more accurate and timely information. A common city network also allows public information to be relayed through a broader range of devices, including to smartphone or in-car systems.
- **High definition (HD) video surveillance:** Many cities are using closed-circuit TV (CCTV) to provide video monitoring for traffic management and for public safety. The bandwidth requirements for HD video traditionally required a fixed broadband network—but high bandwidth wireless networks are increasingly capable of supporting such applications.

2.3 Case Studies

Each city has its own priorities for street lighting and a specific set of local circumstances, opportunities, and challenges. One of the benefits of connected street lighting is that it provides flexibility to municipalities as they look to address local issues and challenges. The following case studies demonstrate some of that flexibility, each focusing on different city requirements, and demonstrate how the new capabilities provided through smart street lighting can enable innovative approaches to improving city amenities.

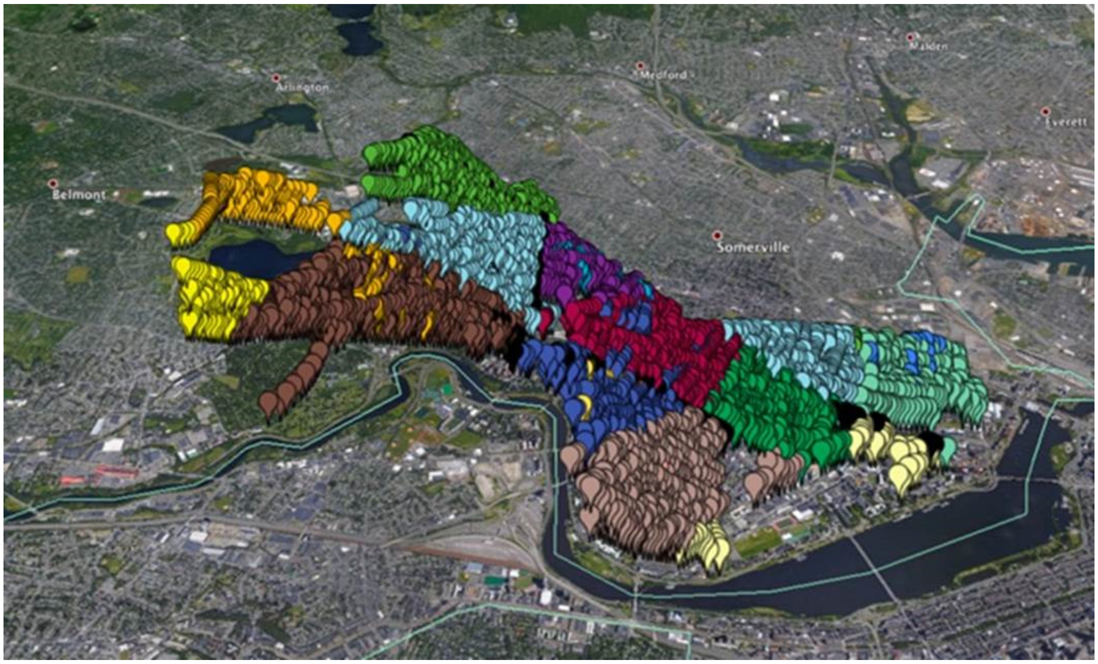
2.3.1 Cambridge, Massachusetts: Neighborhood-Specific Lighting Profiles

Cambridge was one of the first cities in the United States to complete a citywide LED street light retrofit using adaptive controls. The city achieved an 80% reduction in energy usage, and the project costs are expected to be recouped fully over the first 4.5 years of operation. The project is estimated to produce $500,000 per year in energy savings (totaling $10 million over the project's 20-year lifespan) for Cambridge.

The smart street lighting project began in the summer of 2014 and involved the conversion of the city's 7,000 high pressure sodium street lights to LED. Wireless adaptive controls were added in an effort to generate additional energy savings beyond the LED upgrade, as well as to enable the city to have energy monitoring capabilities. Each new LED fixture installed in Cambridge included an Echelon wireless control node that connects to network gateways and the company's central management system software. The system enables real-time dynamic adjusting of light levels, enhanced energy conservation, and energy usage monitoring.

The project in Cambridge is of particular interest, as the lighting intensity is dimmed differently based on neighborhood-specific profiles (see Figure 2.1). For example, street lighting dims to 30% of possible output at 10 p.m. in 13 areas of Cambridge, while six smaller neighborhoods dim their street lights to 30% by 8 p.m. Heavier trafficked streets, such as Broadway and Massachusetts Avenue, do not dim lights to 30% until midnight.

Figure 2.1 Neighborhood-Specific Street Lighting Profiles and Scheduling in Cambridge



Note: Different pinpoint colors on the map denote neighborhood-specific lighting profiles for different areas of Cambridge, Massachusetts.

(Source: Echelon)

2.3.2 Northwestern United States: Integrating School Zone Beacons

A city in Washington State is using its street lighting network to upgrade school flasher beacons, providing greater control and adaptability for its warning signals. This project, currently in the implementation phase, is a good example of how street lighting networks can be extended to support other innovative urban applications.

Currently, the school's crossing beacons are supported and programmed over soon to be discontinued 2G cell networks, requiring cellular service for each sign. The signs are programed based on the current school year and cannot support special events or holidays.

A single gateway solution is connected through wireless radio frequency (RF) controls and supports and communicates with the entire school network of flasher beacons. The solution allows the school to make changes to the flashing beacons dynamically, which ensures the lights are flashing during desired times and thus improves safety for the students. Remote scheduling and monitoring capabilities are greatly improved since specific schedules can be assigned to particular groups of beacons and the schedules can operate autonomously in the case of a loss in communications. Additionally, the flashing beacon solution can be expanded in the future to support the community's outdoor lighting network.

2.3.3 White Bear Lake, Minnesota: Innovations in Lighting

White Bear Lake is a suburb of about 23,000 residents located near Minneapolis-Saint Paul. It is home to two proof-of-concept projects in the town's Railroad Park focused on the benefits of white light tuning and the use of predictive weather controls for lighting.

The white-tunable and connected LED lighting solution allows municipal managers to vary the color and intensity of the lighting in the park, as well as the wattage. This enables energy savings and for the lights to be dynamically adjusted to meet the needs of residents and visitors for special events hosted at Railroad Park. Cooler color temperatures enhance visibility and awareness whereas warmer color temperatures minimize disruption to sleep cycles and create more aesthetic public spaces. Tuning of the lights can be pre-scheduled or adapted dynamically in order to address particular situations (e.g., aid visibility for first responders and safety officers). The solution also addresses concerns raised by organizations such as the American Medical Association around the adverse effects of blue-white LEDs.

The second proof-of-concept utilizes Echelon's partnership with IBM to leverage IBM Watson's analytics capabilities for weather adaptive lighting. This solution enables dynamic responsiveness during challenging weather conditions such as heavy rainstorms, fog, blizzards, and dust storms. Weather adaptive lighting can also provide predictive inputs to lighting systems and a platform for creating public weather-related warning systems.

Section 3

SMART STREET LIGHTING AS A SMART CITY PLATFORM

3.1 Mapping the Connectivity Landscape

The development of multi-application networks for smart cities presents an immense opportunity to accelerate urban innovation. However, the plethora of networking options open to cities offers a confusing picture that makes future planning more difficult.

To help clarify this picture, this section outlines the requirements for the some of the applications being deployed on city networks and the suitability of different smart street lighting networks to support them. The aim is to provide a guide to understanding current and emerging opportunities for building multi-application street lighting networks.

3.2 Smart City Applications: Networking Requirements

As cities look to deploy more sophisticated street lighting systems and to use the street lighting network as a platform for other applications, they face increasing complexity in the technology and investment choices they need to make. There are a large number of competing network technologies that can support street lighting networks. These solutions can be seen as a spectrum of options, from relatively low cost and easily deployable solutions for basic services through to the most expensive, high performance systems suitable for the most demanding requirements.

Understanding the communication requirements for each possible smart city application provides a guide to which solutions are likely to fit a city's main requirements over the considered timeframe. One of the first distinctions is between the needs of basic and advanced lighting management. Each application has its own signature, the relative balance of priorities for speed, reliability, bandwidth, security, and cost, for example, and the tradeoffs that are possible across these attributes.

For lighting management, the main distinction is between basic and advanced lighting features:

- **Basic lighting** controls such as on-off commands, dimming, and scheduling place little demand on the communication network—reliability and low cost are therefore the main requirements. Historically, a range of communication options have been used to provide these controls, including power line carrier (PLC), 2G cellular networks, and proprietary RF systems.
- **Advanced lighting** management introduces a much broader range of control features, which require faster response and greater security (as a wider range of functions are accessible). There is also a presumption that additional features will be added over time, so the ability of the network to accommodate future upgrades is more important.

Advanced lighting management also presumes the ability to integrate additional lighting (such as school zone flashers) or sensor controls with the network.

The picture becomes more complex once support for non-lighting applications is considered as well. These applications can be loosely grouped into three categories in terms of their network requirements and criticality of the systems they support:

- **Monitoring applications:** Applications such as air quality, noise monitoring, traffic, or pedestrian activity monitoring place relatively light demands on the network. The attraction of a smart city platform is to be able to deploy a wider range of sensors across more parts of the city to provide new data on the city environment. Ease of deployment, low operating costs, and breadth of coverage will be important considerations.
- **Operational systems:** Applications such as smart parking, gunshot detection, or smart waste collection require reliable secure networks that can ensure accurate and timely information. Response times are important as part of overall message systems but medium or possibly medium-high in terms of network latency.
- **Critical systems:** Controlling traffic lights, public safety cameras, and other critical operational equipment requires highly secure, reliable networks, often with significant bandwidth and low latency requirements. Such applications are typically supported by dedicated broadband networks.

Public messaging and digital signage cover a wide variety of potential applications. In some cases, the performance and security requirements will be relatively low (advertising, non-critical public information). Yet, these systems can also include traffic and public safety messaging, which have greater reliability and security requirements. As public information systems become more integrated in to other real-time city systems—including vehicle information systems—reliability and security aspects will become more significant.

Table 3.1 provides an overview of the general considerations and technical requirements for the most commonly identified smart city applications to be deployed using a street lighting platform.

Table 3.1 Smart City Application Communication Requirements and Expectations

Application	Upfront Costs	Ongoing Costs	Reliability	Security	Power Requirement	Latency Requirement	Bandwidth
Basic Lighting Controls	Low-Medium	Low-Medium	Medium	Medium	Very Low	Very Low	Very Low
Advanced Lighting Controls	Medium	Medium	Medium-High	Medium-High	Low-Medium	Low-Medium	Medium
Environmental/Air Quality Monitoring	Medium	Low-Medium	Medium-High	Medium	Low	Low	Very Low
Traffic Monitoring	Low-Medium	Low-Medium	Medium	Low-Medium	Medium	Medium	Low
Smart Parking	Medium	Low	Medium-High	Medium	Medium	Medium	Low
Waste Management	Medium	Low	Medium-High	Medium	Low-Medium	Medium	Low
Traffic Light Controls	Medium-High	Medium	High	High	Medium-High	High	Medium-High
Public Messaging/ Digital Signage	Medium	Medium	Medium	Medium-High	Medium-High	Low-Medium	Medium
Gunshot Detection/Location	Medium	Medium	High	Medium-High	Low-Medium	Low-High	Low-Medium
HD CCTV	High	Medium-High	High	High	High	High	High

(Source: Navigant Research)

3.3 Networking Options: From Ultra-Narrowband to Broadband

Networking options applicable to smart street lighting and smart city applications abound, ranging from ultra-narrowband options such as LoRa and mediumband technologies such as PLC or RF mesh options to full broadband connectivity such as with Wi-Fi.

Table 3.2 provides the relevant characteristics for each of 12 communication technologies that may be employed for basic street lighting or more advanced smart city applications. Section 3.3.1 through Section 3.3.3 provide additional detail on the various networking options.

Table 3.2 Smart Lighting/City Networking Options and Characteristics

	Technology	Upfront Costs	Ongoing Costs	Reliability	Security	Power Requirement	Latency	Bandwidth	Market Maturity
Narrowband	Sigfox	Very Low	Very Low	Medium-High	Medium	Very Low	Very High	Very Low	Deploying
	LoRa	Low	Low	Medium-High	Medium	Very Low	High	Low	Deploying
	NB-IoT	Very Low	Low-Medium	High	High	Very Low	Medium-High	Low	2018 Launch
	RPMA	Low	Low	Medium-High	Medium	Very Low	Medium-High	Low	Deploying
	LTE-Cat-M1	Very Low	Low-Medium	High	High	Very Low	Medium	Low	2017 Launch
Mediumband	PLC	Low-Medium	Very Low	High	High	Very Low	Medium	Low	Deployed
	RF Mesh	Low-Medium	Low	High	Medium-High	Low	Medium	Medium	Deployed
	Hybrid PLC/RF	Low-Medium	Low	High	Medium-High	Low	Medium	Medium	Deployed
	LTE-Cat-1	Low	Medium	High	High	Medium	Low-Medium	Medium-High	Deploying
Broadband	3G/4G Cellular	Low	Medium-High	High	High	High	Low	High	Deployed
	Wi-Fi	Medium-High	Very Low	Medium	Low-Medium	Medium-High	Low	High	Deployed
	Pt2Mpt	Medium-High	Very Low	High	Medium-High	Medium	Low	High	Deployed

(Source: Navigant Research)

3.3.1 Narrowband Options

Narrowband options, also known as low power wide area networking (LPWAN), include the proprietary Sigfox network, the open LoRaWAN standard, ingenu's proprietary random phase multiple access (RPMA) technology, and two emerging cellular-based standards: narrowband-IoT (NB-IoT) and Long-Term Evolution (LTE)-Cat-M1.

The narrowband technologies are characterized by very low costs—radios cost $10 or less each, and service costs may be as low as just a few dollars per year. Battery life for these solutions is also long—10 or more years. LPWAN solutions also have good propagation for reaching underground or in-building locations, although this is not typically a need for smart lighting or city applications.

Where basic street lighting control is the primary goal and frequent communications with devices is not necessary, a LPWAN technology may well do the job for years to come at a low price. But the ultra- and narrowband networks may not support a multitude of overlaid applications. Where cities are interested in a network that can support new applications over time (i.e., a more future-proof solution), a medium or broadband technology may be more appropriate.

The emergence of narrowband offerings from cellular carriers is adding to the complexity of the narrowband market. NB-IoT and LTE-Cat-M1 are network overlays being deployed by major cellular carriers. In the United States, LTE-Cat-M1 is expected to launch by mid-2017 by both AT&T and Verizon. In Europe, more emphasis is on the NB-IoT standard, which is expected to launch in 2018.

Ongoing service costs for these new networks will be a fraction of traditional cellular costs, but they retain the advantages of relying upon private, typically carrier-owned spectrum rather than unlicensed bands. As such, they may offer better security than solutions that rely upon unlicensed spectrum.

It is also worth noting that although LTE-Cat-M1 is generally grouped with emerging LPWAN technologies, its potential throughput puts it close to some mediumband technologies in terms of performance.

3.3.2 Mediumband Options

Mediumband options for smart lighting/city applications are widely available and offer significant flexibility to city managers at a relatively low cost. Each of the leading mediumband networking options is described in more detail below.

3.3.2.1 PLC

PLC technology is particularly interesting because it carries the signal over power lines that are already connected to most street lights. For that reason, outside of the United States and the United Kingdom, PLC has traditionally been the leading method of communicating with outdoor lights in a networked system. Although this is changing, as RF mesh technology is now being deployed in various European smart city trials, PLC is still a significant network technology for lighting controls. Large numbers of lights run on dedicated power lines without the interruption of frequent substations. As a result, these power lines can be used as the backbone for networked communications. Segment controllers communicate over these lines to up to 200 light points, motion sensors, photocells, or other control equipment. Information is then transferred to a data center—usually over Transmission Control Protocol/Internet Protocol (TCP/IP). This approach reduces the total amount of wiring for a given project.

Echelon's LonWorks is a communication protocol for PLC that has been used widely for lighting controls. As an open-source protocol, it can be adopted by any manufacturer of lights, ballasts, controllers, software, or other smart city components. OSRAM and Flashnet are two examples of companies that offer an outdoor lighting management system that incorporates networking control technology from Echelon.

3.3.2.2 RF Mesh

An RF mesh network forms a web-like network topology. Any node not in direct communication range of its target destination (a gateway or collector) will have its data relayed by another node in the mesh (e.g., another street light). A given data packet between a source and destination node may hop through many intervening nodes, extending the effective range of the network well beyond the range of any single transmitter or receiver.

Effective mesh networks are self-configuring and self-healing. They automatically determine which nodes are in range and reconfigure when the topology changes, such as when a node is added or removed or an obstacle between two nodes is added or removed. Virtually all the RF mesh technologies use unlicensed spectrum within the Industrial, Scientific, and Medical (ISM) frequency bands for their communications:

- **902 MHz-928 MHz:** Within North America, Latin America, Australia, Israel, parts of Africa
- **868 MHz-870 MHz:** Within Europe (also referred to as the short-range device band)
- **2.4 GHz-2.5 GHz:** Global
- **5.725 GHz-5.875 GHz:** Global

Any radio implementation in these bands must be able to tolerate interference from other ISM devices, be subject to various transmit power limits (generally less than 100 MW), and (in some cases) transmit duty-cycle limitations.

Evaluating the performance of the various RF mesh implementations is difficult given the range of options. The actual network performance of a mesh network depends on considerably more than the specified link speeds. Other factors include the actual topology of the network (the number of hops from the endpoint to the headend system), the number of nodes visible to other nodes, and the number of nodes per concentrator.

Given these factors, one of the issues with RF mesh networks is the lack of predictability of key throughput and latency performance characteristics. This is usually not an issue when RF mesh technology is used for basic smart lighting networks, but can be a concern when using the same mesh network for traffic light controls, for example.

Finally, the prevalence of unlicensed spectrum band use raises the question of how future IoT applications might affect the unlicensed spectrum bands in which they operate. Interference could also limit RF mesh networks in terms of their ability to perform some real-time applications. Increasing the density of the mesh may help alleviate some of these concerns—but at a higher cost. Nonetheless, the flexibility of the RF mesh architecture makes it attractive for early smart city applications, particularly street lighting and parking.

US regulators have generally been more open to the use of RF technologies than their European counterparts, making the country a leader in the adoption of this type of control for applications such as smart meter communications and (increasingly) smart lighting. Silver Spring Networks is deploying its IPv6 mesh networking technology to connect and control a large-scale lighting system across Florida Power & Light’s 35-county territory. In 2017, European cities are increasingly looking at RF mesh for smart street lighting and other smart city applications.

3.3.2.3 Hybrid PLC/Mesh

While these networking technologies have traditionally operated independently of one another, more companies are working on using multiple types of control with a single system. These technologies enable flexibility to use wired and/or wireless links where it makes sense in each application. Wireless can be particularly difficult in situations that require navigating tunnels, walls, and tall buildings. These hybrid solutions can offer more flexibility.

In April 2016, Echelon introduced an outdoor lighting control solution, the Lumewave Powerline-RF Gateway, that integrates power lines and wireless to enable lighting systems to mix and match connectivity options while still being managed through a single central management software. Echelon deployed such a system with the city of Bellingham, Washington, where 3,615 street lights are connected into a single network—86% wireless and 14% wired.

Greenvity Communications, based in California, also has a patented Hybrid Mesh technology with a hybrid control chip capable of using both PLC and wireless communications. This Hybrid Mesh technology allows communication to hop from PLC to wireless and back seamlessly while always staying connected.

3.3.3 Broadband Options

Greater bandwidth, such as that offered by traditional cellular networks, Wi-Fi, or point-to-multipoint (Pt2Mpt) systems, offer greater flexibility and robustness in terms of the applications they may support—but typically come at a higher price than the narrow- and mediumband options. The dominant broadband options for smart street lighting/city applications are described more fully below.

3.3.3.1 3G/4G Cellular

Cellular communications have grown in popularity for outdoor lighting applications thanks to nearly ubiquitous coverage globally and also to the fact that carriers have lowered pricing and begun to aggressively court the business. Because of low latency and higher bandwidth, 4G cellular technology can be a good choice when pairing smart lighting with other smart city applications. Depending on the specific technology, distance from the base station, and network congestion, data rates of 50 Mbps-100 Mbps (and even 1 Gbps promised for future versions) are possible, though 1 Mbps-5 Mbps speeds are routine today in most situations.

In April 2016, Sensity Systems (now part of Verizon) announced a new cellular product, Core Node EX-C, which enables outdoor smart lighting and sensor data to use cellular data networks. This product is in addition to Sensity's existing portfolio that uses Wi-Fi networking. The new cellular option enables a solution to implement LED lighting controls in residential, suburban, and other city areas that lack sufficient Wi-Fi coverage. The Core Node EX-C outdoor lighting control product will include capabilities such as scheduling, dimming, ambient light detection, and energy monitoring among other optional sensor features.

Philips Lighting also has a cellular connectivity option with its CityTouch connected lighting solution. CityTouch is a software-based lighting management system that enables the management of city street light infrastructure. Philips has deployed a large collected lighting solution with 4G LTE wireless technology in Los Angeles, California among other cities globally.

Many suppliers are experimenting with the use of 3G and 4G networks for the advantages listed, and costs are falling. However, there is some concern over the roadmap for cellular technologies with the emergence of the upcoming 5G networks. As cell phone users eventually move over to the 5G network, the fear is that older networks could eventually be turned off, as is happening now with 2G networks. The contribution from the public infrastructure is much smaller than that from cell phone users. Cellular providers need to continue to assure customers of the long-term value of their investments.

3.3.3.2 *Wi-Fi*

In a mesh topology, Wi-Fi can provide wide area communications at a low cost, and such solutions have been deployed in numerous municipal utility smart grid deployments in the United States. Generally, a Wi-Fi-based system may be more cost-effective in denser environments than a Pt2Mpt solution and has the added benefit of allowing the city to provide community Internet access, if it is willing to risk sharing access to the network.

In the smart city context, Wi-Fi may be considered both as an access layer and for the aggregation/ backhaul layer. It can be deployed as a standalone access point—providing wireless access to a cafe, a home, or a business facility—or as a mesh technology. The mesh topology of Wi-Fi, which could include up to 10 routers per square mile in dense urban areas, provides an adaptive and low latency network that could be useful in smart city deployments. Several US utilities have deployed Wi-Fi in smart grid projects that also enable community Internet access and support other smart city applications, including Burbank Water & Power and Silicon Valley Power.

One interesting development is the expansion of Wi-Fi into even more areas of the city. Veniam, a Portuguese startup now expanding into North America and other markets, is installing Wi-Fi capabilities in city vehicles to create a dynamic communication network. Veniam has deployed its solution to 600 buses and other vehicles in Porto, Portugal, and the system currently has 60,000 unique monthly users.

3.3.3.3 *Point-to-Multipoint*

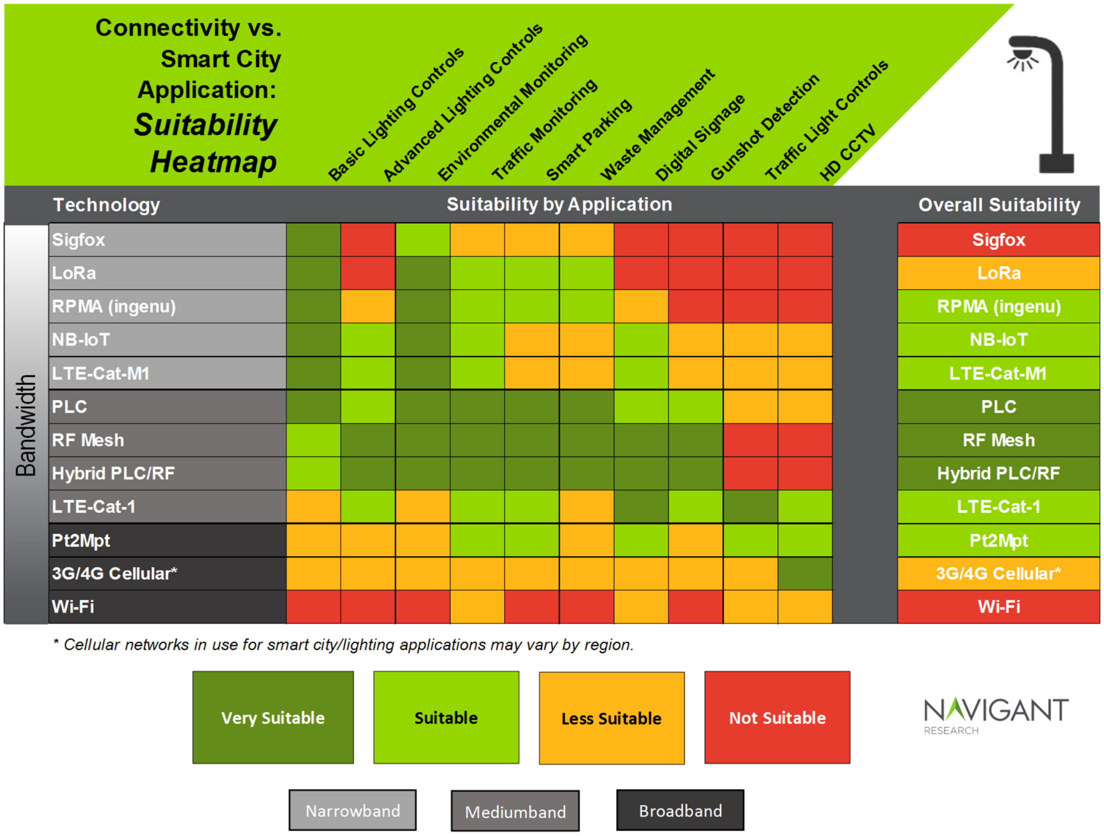
In a Pt2Mpt network, multiple devices communicate through a central point. In this configuration, various nodes each send signals back to the centralized collection point. This approach is efficient, as only one data collection point is required for many nodes, and a failure at one node will not affect any others. However, if the hub fails, not all data from that central point will be sent to the master controller. That said, for some applications, a Pt2Mpt hub network will work well and may be less expensive and simpler to deploy than a mesh network. In addition, companies that use proprietary communication protocols and put an emphasis on network security seem to favor this type of system.

Pt2Mpt solutions targeted at smart city deployments are available from vendors such as Sensus and Aclara.

3.4 Suitability Heatmap

In order to map diverse application requirements and networks capabilities, Navigant Research analyzed the core requirements for ten smart city applications (shown in Table 3.1) and compared them with the networking technology characteristics shown in Table 3.2. A scoring system was devised based on how well each networking solution meets the requirements of each application in order to generate a heatmap of the most attractive networking solutions for each application and overall. The heatmap provides a visual representation of the strengths and weaknesses of the networking solutions reviewed.

Figure 3.1 Smart City Platforms and Applications: Suitability Heatmap



Technology	Bandwidth	Basic Lighting Controls	Advanced Lighting Controls	Environmental Monitoring	Traffic Monitoring	Smart Parking	Waste Management	Digital Signage	Gunshot Detection	Traffic Light Controls	HD CCTV	Overall Suitability
Sigfox	Narrowband	Very Suitable	Not Suitable	Suitable	Less Suitable	Less Suitable	Less Suitable	Not Suitable	Not Suitable	Not Suitable	Not Suitable	Not Suitable
LoRa	Narrowband	Very Suitable	Not Suitable	Very Suitable	Suitable	Suitable	Suitable	Not Suitable	Not Suitable	Not Suitable	Not Suitable	Less Suitable
RPMA (ingenu)	Narrowband	Very Suitable	Less Suitable	Very Suitable	Suitable	Suitable	Suitable	Less Suitable	Not Suitable	Not Suitable	Not Suitable	Suitable
NB-IoT	Narrowband	Very Suitable	Suitable	Very Suitable	Suitable	Less Suitable	Less Suitable	Suitable	Less Suitable	Less Suitable	Less Suitable	Suitable
LTE-Cat-M1	Narrowband	Very Suitable	Suitable	Very Suitable	Suitable	Less Suitable	Less Suitable	Suitable	Less Suitable	Less Suitable	Less Suitable	Suitable
PLC	Mediumband	Very Suitable	Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Suitable	Suitable	Less Suitable	Less Suitable	Very Suitable
RF Mesh	Mediumband	Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Not Suitable	Not Suitable	Very Suitable
Hybrid PLC/RF	Mediumband	Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Not Suitable	Not Suitable	Very Suitable
LTE-Cat-1	Mediumband	Less Suitable	Suitable	Less Suitable	Suitable	Suitable	Less Suitable	Very Suitable	Suitable	Very Suitable	Suitable	Suitable
Pt2Mpt	Broadband	Less Suitable	Less Suitable	Less Suitable	Suitable	Suitable	Less Suitable	Suitable	Less Suitable	Suitable	Suitable	Suitable
3G/4G Cellular*	Broadband	Less Suitable	Less Suitable	Less Suitable	Less Suitable	Less Suitable	Less Suitable	Less Suitable	Less Suitable	Less Suitable	Very Suitable	Less Suitable
Wi-Fi	Broadband	Not Suitable	Not Suitable	Not Suitable	Less Suitable	Not Suitable	Not Suitable	Less Suitable	Not Suitable	Less Suitable	Less Suitable	Not Suitable

** Cellular networks in use for smart city/lighting applications may vary by region.*

Very Suitable | Suitable | Less Suitable | Not Suitable

Narrowband | Mediumband | Broadband

(Source: Navigant Research)

Among the narrowband options, Sigfox stands out as one of the lowest cost options available today, but its functionality is limited to the simplest applications due to its very low data transfer aspect. LoRa also has limited bandwidth in most deployments, and the services fees can get higher for big data volumes. The cellular-based narrowband solutions—NB-IoT and LTE-Cat-M1—enjoy the security benefits that major carrier networks (built on privately owned spectrum and carefully safeguarded) offer. But service costs into perpetuity mean the total cost of ownership will be higher than with some other options. Additionally, these networks have no track record as of yet. Sigfox, LoRa, RPMA, and RF mesh solutions all leverage unlicensed spectrum, leaving them potentially vulnerable to interference over time.

As the only wired option, PLC is inherently more secure than wireless network choices, but it will cost more upfront than the narrowband solutions. Also, it will be somewhat less flexible due to that hardwiring: the communications can only travel where power lines are installed. The emergence of hybrid PLC/RF mesh solutions addresses this drawback.

Generally, the broadband options will cost more than the narrow- or mediumband solutions, and in many cases, they will provide more features than are needed. The 3G/4G cellular options can become quite expensive if data traffic becomes high. Wi-Fi networks can also be expensive to deploy. However, broadband options can also be considered more future-proof and are able to support the widest range of applications.

In summary, each of these networking technology choices has its relative pros and cons. Today, as the heatmap demonstrates, mediumband options tend to score best overall in terms of balancing upfront and ongoing expense with flexibility and robustness to support a variety of applications.

Section 4

RECOMMENDATIONS AND BEST PRACTICES

4.1 Selecting Street Lighting Solutions

The development of IoT networks for cities provides an exciting opportunity to improve the efficiency and quality of city services while reducing costs and energy consumption. However, the technical landscape is complex, and it is not easy to compare alternative approaches to the needs of a specific city.

The challenge for municipalities is to balance short-, medium-, and long-term requirements against the costs and benefits of different network options. There is no simple answer to the question of which is the best street lighting network for a city. The choice will depend on current requirements and existing investments, medium-term priorities, and the long-term vision that is shaping the needs of any particular city. Together, these requirements need to be assessed against potential connectivity solutions. Do the proposed networks have the bandwidth, flexibility, and functionality to match all requirements?

This report outlines the relative strengths of the leading networking options and maps them against current and emerging requirements. The result is a spectrum of options mapped in a suitability heatmap (Figure 3.1) that compares applications and solutions.

4.2 Recommendations

A technical comparison is only one element in developing a street lighting and smart city platform strategy. Lessons from early adopters suggest that cities embarking on this journey need to consider several other factors a well. Key insights from early adopters are discussed below.

4.2.1 Connected Lighting Is Becoming Mainstream

The business and environmental case for upgrading to LED street lighting is widely accepted. Cities are now also recognizing the many advantages of implementing a connected solution at the same time. The benefits of networking and remote management technologies for street lighting have been shown by many cities globally. In addition to reducing the total cost of deployment, an integrated upgrade—installing a lighting controls system capability simultaneously with LEDs—can create a platform from which future smart applications can be deployed. It can also shorten the payback time through further decreases in energy and maintenance costs.

4.2.2 Understand the Potential of Smart Street Lighting

As well as the financial benefits of lower energy and maintenance costs, smart street lighting provides a wide range of additional benefits in terms of the quality of lighting and the level of control. It is important to understand how these features can be used to help with city issues such as crime and antisocial behavior, pedestrian and driver safety, or city regeneration projects. Technology is an enabler for these applications, but the priorities should be set by city needs. Even if not planning to use advanced lighting management features in the near term, municipalities should consider possible future applications—and use that planning to inform technology choices.

They should also consider how the lighting upgrade will be deployed across the city. Will it be a long-term incremental replacement program or a more focused citywide rip-and-replace exercise? What are the implications for the level of network coverage needed and the incremental investment program?

4.2.3 Be Clear on Local Smart City Priorities

Just because many applications can be supported on a street lighting network does not mean that all will be equally important to all cities. For some cities, air quality is already a public health issue that requires action; improving monitoring of the local environment can help decide which steps to prioritize. Other cities are already looking at smart parking as one element in their plans to address congestion. And while gunshot detection has already been deployed in a number of cities, it has little relevance to those with minimal gun violence.

Any city looking to deploy a street lighting network should have at least an outline plan for how it will engage with the growth in the use of digital and IoT technologies for city operations and services. How do these developments fit with existing city development strategies? What are the priority local issues and what are the local assets that provide the starting point and make the plan distinct to the needs of this city?

4.2.4 Set Short-, Medium-, and Long-Term Objectives

It is important to assess the applications that are likely to be deployed on the street lighting network in the short (1-2 year) to medium timeframe (3-5 years). This assessment should be based on realistic expectations and not an ideal model. It should be recognized that it will take the city some time to develop the skills and processes to get the most out of the lighting management features, and then to work with residents, businesses, and other city departments to understand which additional applications will provide most benefit in which parts of the city. Longer-term goals should also be considered, but inevitable changes in city priorities and technology developments mean that these should be seen as aspirational pointers rather than fixed requirements in most cases.

4.2.5 Examine Different Financing and Procurement Options

The payback on street lighting upgrades means that they can be financed through a number of models, including municipal bonds, state or national government programs, with the help of development organizations like World Bank, or through various form of energy performance contracts.

Cities should also review procurement processes to ensure they are getting the best value from their lighting investment. In particular, the potential to add future services to the network means better coordination across city departments is essential. The challenge for cities and the industry is to build business cases that show the additional value that a street lighting network can bring across the city. Restricting the procurement to the traditional concerns of just the lighting department may limit the ability to realize those additional benefits. Coordination of networking requirements and procurement across multiple city departments—and even involvement of other stakeholders such as local utilities—should be considered.

4.2.6 Look at Street Lighting as an Asset

Cities should recognize that in a world that depends on ubiquitous access to power and connectivity, the street lighting network is a valuable asset. In addition to improving the efficiency and value of city services, that network can also become a source of new revenue. Street lighting poles, for example, can incorporate small cell communications to extend cellular access EV charging equipment, or digital signage for advertisers. These additional services are all potential revenue sources for the city authority.

4.2.7 Realize the Future Is Hybrid

While integration across departments and the consolidation of requirements is a sensible approach, it is also important to realize that one approach will not satisfy all needs. Most cities are likely to require a number of solutions to address the span of applications from low risk Living Lab projects, through specific services applications such as street lighting and smart parking, to critical city systems for public safety. To meet these needs, suppliers are increasingly offering multiple options—offering a low power variation for less demanding or off-the-grid applications or combining fixed and wireless connectivity solutions to extend coverage.

In summary, most cities will end up with several or many networks designed and designated for different needs and applications. Because of their ubiquity, street light-based smart networks based on mediumband technologies offer the potential to economically support a broad range of those applications. As a result, cities should give consideration to installing such networks (or at least smart network-ready nodes) as they make LED retrofit upgrades, thereby minimizing their installation costs and maximizing their future flexibility.

Section 5

ACRONYM AND ABBREVIATION LIST

2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
CCTV	Closed-Circuit Television
EV	Electric Vehicle
Gbps	Gigabits per Second
GHz	Gigahertz
HD	High Definition
IoT	Internet of Things
IPv6	Internet Protocol Version 6
ISM	Industrial, Scientific, and Medical
LED	Light-Emitting Diode
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
LTE	Long-Term Evolution
Mbps	Megabits per Second
MHz	Megahertz
MW	Megawatt
NB-IoT	Narrowband-IoT
Pt2Mpt	Point-to-Multipoint

PLC	Power Line Carrier
RF	Radio Frequency
RPMA	Random Phase Multiple Access
US	United States

Section 6

TABLE OF CONTENTS

TABLE OF CHARTS AND FIGURES

Section 7
SCOPE OF STUDY

Navigant Research has prepared this white paper to provide an independent analysis of the current development of smart street lighting and smart city communication platforms. The report is intended for city leaders and managers responsible for smart city projects, public works and street lighting departments, government agencies and other bodies supporting cities, and suppliers seeking to better understand the street lighting market.

The major objective of this Navigant Research white paper is to provide an objective assessment of the leading street lighting communication technologies and their applicability to a range of smart city solutions.

SOURCES AND METHODOLOGY

Navigant Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Navigant Research's analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Navigant Research's analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Navigant Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

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