TELECOM INFRA PROJECT

Connected City Infrastructure Requirements for Dublin

TIP Requirements Document

TIP Connected City Infrastructure Solution Project Group

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Contributors

Michael Guerin
Smart Docklands

Graeme Baker
Carabiner Networks

Pádraig Ó Seighin
Aspire Technology

Neil Bullock
Telecom Infra Project

Jamie Cudden
Dublin City Council

Lorcan Burke
Carabiner Networks

Declan Friel
Aspire Technology

Seamus Storan
Dublin City Council

Milutin Davidovic
Aspire Technology

Ketaki Mangalmurti
Facebook

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OVERVIEW

“Digital connectivity infrastructure, both fixed and wireless, plays a critical and increasingly important role in Dublin's economic development. Covid-19 has reinforced the importance of connectivity in our cities and towns. Having the right type of connectivity is also essential for Dublin’s future competitiveness. We are entering a new era of super connectivity with the emergence of fifth generation (5G) mobile networks” – Smart City Programme, Dublin City Council

Wireless networks are essential to a city’s economic and social development. Cities must develop innovative, collaborative frameworks in order to offer high quality mobile experiences for citizens, tourists and local businesses.

This Telecom Infra Project (TIP) Connected City Infrastructure project led by Dublin City Council and the Connect Research Centre will develop commercial and technical approaches that facilitate the provision of high capacity 5G and Wi-Fi networks in Dublin’s city center using street assets. The project will explore the sharing of assets to improve the business case for service providers and minimize the footprint on city streets both during and after installation. The learnings from this project will provide guidance to city governments and operators worldwide.

1

Introduction

1. Introduction

Dublin City

Dublin is the capital city of Ireland. It has an urban population of approximately 1.2 million. It is situated on a bay on the east coast, on both sides of the River Liffey. The city has a large commercial district centered on the Docklands, to the east of the city center. The main shopping district is in the city center on the north side of the river. To the south is the university area. Between the city center and the Docklands are the main transportation hubs for the city. The city's built infrastructure is moderately dense with buildings generally not exceeding five floors. There are a number of pedestrianized streets in the shopping district. Dublin City Council is the local administrative authority for the city.

Status of Mobile Networks

Dublin is served by three mobile network operators: Eircom Limited ("eir"), Three Ireland (Hutchison) Limited ("Three") and Vodafone PLC. All of the operators offer 3G and 4G service and introduced 5G services in late 2020. 5G coverage is already extensive in urban areas, provided primarily from existing macrocell towers. Although the deployment of 5G services provides some capacity relief, increasing mobile data demand in a number of locations within the city is pushing against the capacity limits of the existing network infrastructure. In addition, the deployment of mmWave 5G services, which would add significant new capacity, is not practical using macrocells.

Densification of Mobile Networks

To mitigate these capacity limits (and, in the longer term, to enable mmWave 5G), it is necessary to densify the network by deploying additional network infrastructure at the street level. There are a variety of street assets that might be suitable: streetlights, camera poles, traffic lights, bus and tram shelters, billboards, and digital signs, building frontage and rooftops. Many of these assets are owned by and under the control of the city council.

The exploitation of street assets is not a new idea. There have been many trials and studies conducted but widespread adoption has been limited due to operators' continued ability to meet coverage and capacity needs through optimization at the macrocell and the high capital and operational costs associated with street level deployment. With the options for macrocell capacity increase mostly exploited, there is a heightened need to address the technical and business aspects of street level deployments.

City Motivations

City governments have a strong interest in the provision of high quality mobile network service to their citizens: it improves quality of life, supports business needs, and can enhance digital inclusion. The city also has other goals around providing a platform for public services, public safety, and environmental management.

This must be reconciled with city needs for a high quality environment and an orderly planning process. The current ad-hoc approach to deployments at the street level can have a number of undesirable consequences:

- Unsightly additions to existing street assets
- Unnecessary clutter due to the collocation of separate street facilities without regard to asset sharing
- Repeated disruptive civil works due to the uncoordinated installation of power and data services to street assets

		
Unsightly additions	Unnecessary street clutter	Disruptive civil works
Source: © takomabibelot	Source: © Google	Source: © iStock

By taking a holistic planning approach, the city can obtain a number of benefits on behalf of its citizens:

- Consideration of the streetscape in general and the requirements of heritage districts in particular will drive improved aesthetics
- Shared open access and innovative design will result in the more efficient use of street assets and the reduction of street clutter
- Coordination and futureproofing of civil works will mean less disruption and lower costs

Operators and city governments must address these different aspects as they develop a more cohesive approach for the installation of new, or reuse of existing, street assets as part of network densification initiatives.

Impact of Regulation

The nature of the negotiation has changed with the taking effect of the European Electronic Communication Code (EECC) in December 2020. Under Article 57 of the EECC, an operator may install small cells, and any backhaul from the small cell site to the operator network on any publicly owned street asset, usually without an individual permit, as long as they satisfy certain technical criteria. The city may impose terms and conditions, but no fees may be charged beyond necessary administrative charges. More detail is provided in the Appendix on Regulation.

The EECC applies to European Union countries, but similar regulations have been (or are likely to be) adopted in other regions; for example, the FCC Small Cell Order.

- Configuration, e.g., for automating and optimizing the network services creation and processes.
- Status, e.g., for automated configuration depending on current network status.
- Events (Alarms), e.g., for automated initiation of countermeasures.
- Current and Historical Performance Values, e.g., for perpetual network analysis.

Collaboration between Stakeholders

The purpose of this collaboration within the TIP Connected City Infrastructure solution group between the city, operators and other stakeholders is to proactively identify technical and commercial approaches that balance the need of operators to densify their networks efficiently and cost effectively with the need of the city to further their digital agenda at the same time as being good stewards of the city's resources and streetscapes, within the context of the EECC and national regulations.

The Smart City team within Dublin City Council collaborated with a number of stakeholders to develop 5G and Future Connectivity - An Emerging Framework for Irish Cities and Towns. The key output of this discussion document is a suite of recommendations to support the rollout of 5G across Ireland through better alignment at both local and national levels. The recommendations provide an important input for the activities of this solution group.

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Stakeholders and Assets

2. Stakeholders and Assets

Mobile Network Operators

Existing Service

The operators have deployed 4G - LTE service in the 800 MHz, 900 MHz, 1.8 GHz, and 2.1 GHz bands. They are in the process of deploying 5G service in the 3.4-3.7 GHz band, and the 2.1 GHz band with dynamic spectrum sharing. The operators have generally good coverage across the city using a number of conventional macrocell sites.

Capacity Constraints

The operators face capacity constraints in the highly trafficked areas of Dublin city center. Examples of these locations are:

- Grafton Street
- Henry Street
- O'Connell Street
- Pearse Street
- Connolly station
- St Stephen's Green

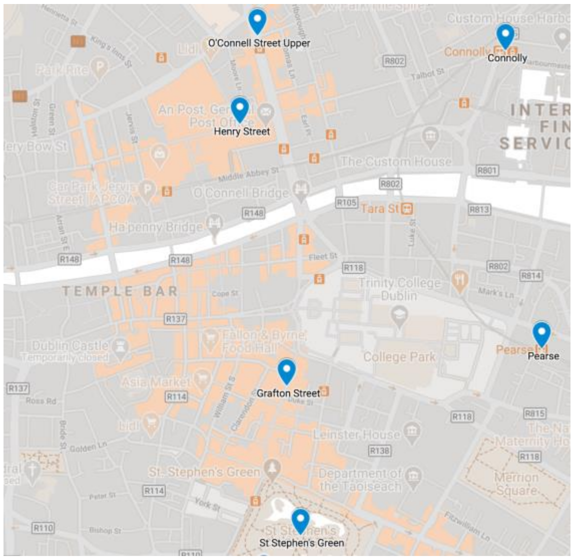


Figure 1 - Example Locations in Dublin City

Source: Map Data © 2021 Google

The operators want to provide additional capacity by implementing a microcell underlay to their macrocell coverage in the congested areas.

Operators foresee the need for thousands of small cells across the city in the long term. The number and density of small cells increases both with data demand from existing applications and from new applications with high data requirements, such as autonomous vehicle connectivity.

City Operated Services

In addition to supporting the provision of high quality mobile services, the city has other important functions that are addressed through street level assets:

- Public safety requires the availability of cameras and other sensors in pedestrian areas to monitor the flow of pedestrian traffic and detect public nuisances
- Traffic management requires the availability of cameras and other sensors in the highway to monitor and control the flow of traffic and ancillary activities such as parking
- Environmental monitoring requires the availability of sensors to monitor noise and exhaust pollution
- Business development (for example, shopping and tourism) and digital inclusion requires the availability of public Wi-Fi access points

Infrastructure Providers

Traditionally, operators have built and operated their own cell sites. This has been encouraged by governments as an indicator of the operator’s commitment to service coverage. As mobile networks have built out and densified, commercial considerations have caused operators to partner with infrastructure providers (often called “tower companies”) who provide passive infrastructure, as a sole occupant or one of several. Government policies have also shifted to support this behavior. This effect is most marked in rural areas, but the same underlying commercial issues is expected to drive this evolution in urban areas as well. A limited number of urban deployments have been completed to date:

Cellnex

Cellnex has installed and owns several street poles in suburban parts of the city. Typically, two operators share the physical infrastructure. Currently there is no sharing of RAN equipment or spectrum.

Dense Air

Dense Air has installed approximately twenty 4G small cells on existing streetlights and traffic poles in the Docklands area. Dense Air provides a neutral host service to the mobile network operators using spectrum that the company has licensed.

Virgin

Virgin Media is providing Wi-Fi as a managed service to the City at approximately 30 locations under the WiFi4EU program, a European Commission scheme to support the provision of free Wi-Fi access in indoor or outdoor public spaces.

Broadband Service Providers

There are a number of companies that provide backhaul services on a wholesale basis:

1. Eir Telecom
2. ESB Telecom
3. Virgin Media Ireland - a local operating company of Liberty Global
4. Enet
5. Colt

To connect the radio equipment in the street asset to the service provider’s core network, the service providers typically prefer to use fiber. However, dense deployments of fiber to support large numbers of street assets is expensive and time consuming. Wireless backhaul between street assets and the core network may be a viable alternative, at least in the short term.

Ducting

The city has historically supported the delivery of multiple communications services by partners through underground ducts. This approach fulfills the city’s role in enabling the delivery of services while complying with the legal constraints on the city with respect to the provision of service.

The city has entered an agreement with Novegen for the management of fiber ducts in the Docklands area.

Service

Traditional RAN architectures with collocated radio and baseband processing (Split 2) require backhaul capacity in the range of several 100 Mbps to several Gbps and low latency (1-10 milliseconds). More recent architectures which separate the radio and baseband processing (for example, split 7.2) require backhaul capacity in the range of 10 Gbps up to 25 Gbps and very low latency (~100 microseconds). Small cell deployments currently use a traditional Split 2 architecture.

For a Split 2 architecture, the broadband service providers typically offer a 1 Gbps or 10 Gbps symmetric Ethernet service with a suitable quality of service. The service is delivered over either a single strand per operator or a shared strand with optical multiplexing using different wavelengths. The demarcation point at the street asset is an industry standard SFP+ (Small Form Factor Pluggable Plus) connector.

Street Assets

Street assets must satisfy a number of criteria in order to be suitable for the attachment of communications and sensor equipment:

- Provide line of sight or near-line of sight to give adequate coverage over the required area, or sufficient exposure to the environment
- Provide protection for the equipment and to the public
- Support the provisioning of power and data connections

There are many candidates: streetlights, camera poles, traffic lights, bus and tram shelters, billboards, and digital signs, building frontage and rooftops. They fall broadly into two categories, the public domain (the street) and the private domain (private property).

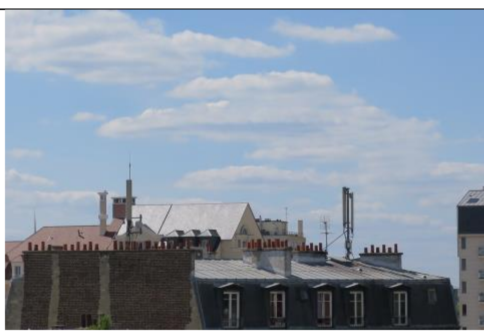
The city has a large inventory of existing street assets. Many of these assets are owned by the city and operated by different city departments; for example, streetlights are operated by the Public Lighting department, while traffic lights are operated by the Traffic department. Other assets are owned and operated by other entities; for example, An Garda Síochána (“the Garda”), the national police service of the Republic of Ireland, have street poles supporting surveillance cameras.

Some city districts have particular design constraints - for example, a historic district may have a heritage light pole design - that must be taken into consideration during the selection and procurement of street assets.

The actual implementation may be through purpose-built assets such as smart poles or through the adaptation of existing street assets.

 © Ligman	**Smart Pole** A smart pole is a purpose-built asset that is specifically designed to house communications and sensor equipment. The equipment is contained within the structure so that it is not visible. It provides internal support for the provision and distribution of data. A smart pole might be standalone or incorporate public lighting or traffic signals. There are two common design approaches: modular sectional, where discrete sections of the pole house individual functions (Wi-Fi, camera, sensor, etc.) or modular with a podium where the functions are distributed through the pole but with a concentration of equipment at the bottom of the pole

 © Bigbelly	**Waste Bin** The collocation of communications and sensor equipment with waste bins is attractive. They are located where people congregate, which is also where wireless service is in greatest demand. They are commonplace and therefore more easily accepted. The bins have sufficient capacity for the equipment and there is easy access for maintenance. Antennas are mounted on a pole integrated with the bin (as shown) or on an adjacent pole.
 © Dense Air	**Conventional Street Pole** The conventional street pole is either an existing street asset or a new street asset but of conventional design. In the latter case, the pole may incorporate design features that facilitate the integration of communications and sensor equipment, such as attachment points and routing for cables with internal chambers for separation of services. Conventional street poles are the cheapest solution but as all communications and sensor devices are external, they are less visually appealing. Regulations also limit the equipment size on each pole.

 © LA Wad	**Pedestrian shelters** Shelters at bus and tram stops provide both a high density of users and a convenient location for the installation of equipment. Typically, the equipment is installed in the shelter structure and the antennas are installed on the roof of the shelter in order to provide better coverage and comply with regulations.
 © infomatique	**Communications Cabinet** Cabinets or the delivery of fixed broadband services over fiber-optic or coaxial copper cable are very suitable for hosting wireless communications equipment as they are powered and provide backhaul to the mobile operator network. They are often located in areas of demand. Antennas and radio equipment are mounted on a closely located pole.
 © GoToVan	**Digital Sign** Digital signs provide a convenient location for equipment installation. They are usually located in high traffic areas. They do not readily support external antennas and are more suitable for low power communications equipment, as well as sensors.
 © Suresh /R	**Building Attachment** Facades and rooftops of private or public buildings can be used for equipment location. Rooftops provide more space, but coverage of the street below may be inadequate. Careful planning is required. Facades provide better coverage but are highly visible which limits the amount of equipment that might be carried

Power

The city council owns and operates the large majority streetlights. Power to streetlights is provided by the Electricity Supply Board (ESB), the semi-state-owned electricity company operating in Ireland. The streetlights are typically fed from an unmetered power supply and the city pays according to a fixed tariff. The streetlights may be daisy-chained from a single connection to the power supply. There is currently no efficient way to attach low power equipment (such as small cells and IoT devices) to existing unmetered powered assets.

Based on a study conducted by ESB and Dublin City Council, two candidate configurations for site power have been identified: The site power for this project will utilize two configurations:

1. A new interface micro pillar fed from the electricity provider underground network.
2. A local Authority network feed from an existing interface box connected to the electricity provider underground network.

Further background information can be found in 5G and Future Connectivity - An Emerging Framework for Irish Cities and Towns, section 3.3 Power Challenges (page 26). The city is legally constrained from selling power to other consumers attached to the streetlight.

Stakeholder Summary

Table 1 - Stakeholder Summary

Dublin City Council	Traffic Public Lighting Public Realm Waste Management
Operators	Eir, Three, Vodafone
Infrastructure Providers	Cellnex, Dense Air, Virgin Media
Street Asset Providers	Bigbelly, Ligman, Schréder, Signify

Electricity Supply	Electricity Supply Board
Fiber Provider	Eir Telecom, Enet, ESB Telecom, Virgin Media, Colt

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Technical Requirements

Technical Requirements

The following subsections enumerate the RAN and Transport technical requirements.

Radio Access Network (RAN)

Capacity Improvement

The primary purpose of the street-level deployment is to improve outdoor capacity in the areas of highest demand. Indoor coverage and capacity improvements are desirable but a secondary objective.

Performance metrics

These performance metrics could be measured via hourly cell counter data (measured during peak hour) or User Equipment (device) performance tests.

Table 2 - Requirements and KPIs

Counter Key Performance Indicators (KPI)	Throughput	Accessibility	Retainability	Availability	Utilization	Integrity	Required Value	Measurement Method
5G-NR FR1 Key Performance Indicators **(KPI)**								
5G-NR ENDC Call Setup Success Rate [%] ENDC: **E**UTRA **N**ew Radio **D**ual **C**onnectivity		x					99.99%	Cell Counter Data
5G-NR Drop Call Rate per cell [%]							0.01%	Cell Counter Data
5G-NR Total Downlink Traffic volume per hour per cell (peak hour) [MB/hr]						x	NA	Cell Counter Data
5G-NR Total Uplink Traffic volume per hour per cell (peak hour) [MB/hr]						x	NA	Cell Counter Data
5G-NR Cell-Edge Downlink PDCP User Throughput [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	x					x	10 Mbps	Cell Counter Data
5G-NR Cell-Edge Uplink PDCP Throughput User [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	x					x	5 Mbps	Cell Counter Data
5G-NR Peak Downlink PDCP User Throughput [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	x						TBD	UE Performance Tests at 0% cell loading
5G-NR Peak Uplink PDCP User Throughput [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	x						TBD	UE Performance Tests at 0% cell loading
5G-NR Cell Availability [%]				x			99.99%	Cell Counter Data
5G-NR Number of Simultaneous Active UEs per cell per TTI [#] UE: **U**ser **E**quipment					x		15	Cell Counter Data
4G LTE Key Performance Indicators **(KPI)**								
4G LTE Call Setup Success Rate [%]		x					99.99%	Cell Counter Data
4G LTE Drop Call Rate per cell [%]			x				0.01%	Cell Counter Data
4G LTE Total Downlink Traffic volume per hour per cell (peak hour) [MB/hr]						x	NA	Cell Counter Data
4G LTE Total Uplink Traffic volume per hour per cell (peak hour) [MB/hr]						x	NA	Cell Counter Data

4G LTE Cell-Edge Downlink PDCP User Throughput [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	**x**					**x**	5 Mbps	Cell Counter Data
4G LTE Cell-Edge Uplink PDCP Throughput User [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	**x**					**x**	3 Mbps	Cell Counter Data
LTE Peak Downlink PDCP User Throughput [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	**x**						TBD	UE Performance Tests at 0% cell loading
LTE Peak Uplink PDCP User Throughput [Mbps] PDCP: **P**acket **D**ata **C**onvergence **P**rotocol	**x**						TBD	UE Performance Tests at 0% cell loading
4G LTE Number of Simultaneous Active UEs per cell per TTI [#] UE: **U**ser **E**quipment					**x**		10	Cell Counter Data
4G Cell availability [%]				**x**			99.99%	Cell Counter Data

RAN 4G/5G Operation

The RAN will use 5G non-Standalone mode. The deployment of cores supporting 5G Standalone mode in the mobile networks is not anticipated in the timeframe of the project.

The RAN will support 5G non-standalone mode (5G NSA), option 3x. Option 3x represents a network having both LTE and NR radio access but using only the EPC core of LTE to route the control signals. In this option, LTE is used as the control plane anchor for NR, and both LTE and NR are used for user plane traffic.

RAN Architecture

The RAN will use 3GPP 5G NR Split Option 2 (PDCP/RLC split) (equivalent to LTE Release 12 Dual Connectivity option 3C for user plane) and the F1 interface. This interface is approved in 3GPP TS 38.47x and is the predominant standard for mid-haul.
This approach mitigates the risk associated with reconciling non-standard implementations of the eCPRI interface which would be required for a lower-level split.

Cell Site Spacing

An analysis of the propagation characteristics of the licensed bands with some equipment assumptions indicates that the maximum spacing between cell sites is 200 meters. Operator input suggests that the inter-cell distance could be as low as 75 meters. This is consistent with other public deployment studies. The lower inter-cell distance is more likely for mmWave service deployment.

Transport / Backhaul

The Transport network will provide Ethernet-Line (E-Line) layer 2 service type.

The Transport network will provide 1 Gbps data throughput. This provides sufficient transport throughput for current small cell implementations and other services at the node.

The Transport network will optionally provide 10 Gbps data throughput. This will provide sufficient throughput to match the maximum aggregate capacity at the node, including 802.11ax Wi-Fi and 5G NR Split 2.

The Transport network will optionally provide 25 Gbps data throughput. This will provide sufficient capacity for 5G NR Split 7.2.

To accommodate the potential needs of different services at the node, the Transport network will support IPv4 and IPv6.

Since the data may travel over untrusted links and the RAN nodes themselves have the potential to be compromised, the Transport network will support IPSec security.

The Transport network will provide in-band synchronization, such as PTP, 1588 and/or SyncE delivery.

4

Commercial Requirements

4 Commercial Requirements

Asset Ownership and Management

A standardized approach to asset ownership and management is required. The approach will allow:

- the management of the relationship with operators and infrastructure providers separately from the asset
- the addition, removal, substitution of service partners and their equipment without physical change of asset
- the control of access to the asset - particularly important if there is a lighting component of the asset

The approach must comply with the city's requirements for the management of liability.

Power

Where new electric service must be installed or an existing electric service must be adapted, a process to provision power quickly and efficiently is required. The process will allow:

- the separation of circuits between city and non-city services
- the provision of unmetered circuits for lighting and metered circuits for other services
- multiple service partners

The process should minimize the need for additional structures (pillars, pods) outside of the street asset being served.

The number of implementation variants should be minimized.

Deployment

The initial deployment will be aimed at alleviating network congestion in the areas illustrated in the map below:

- The shopping areas - Henry Street, O'Connell Street, Grafton Street, and Dawson Street
- The transit locations - Connolly Station and Pearse Street Station
- The public parks - Merrion Park and Saint Stephen's Green

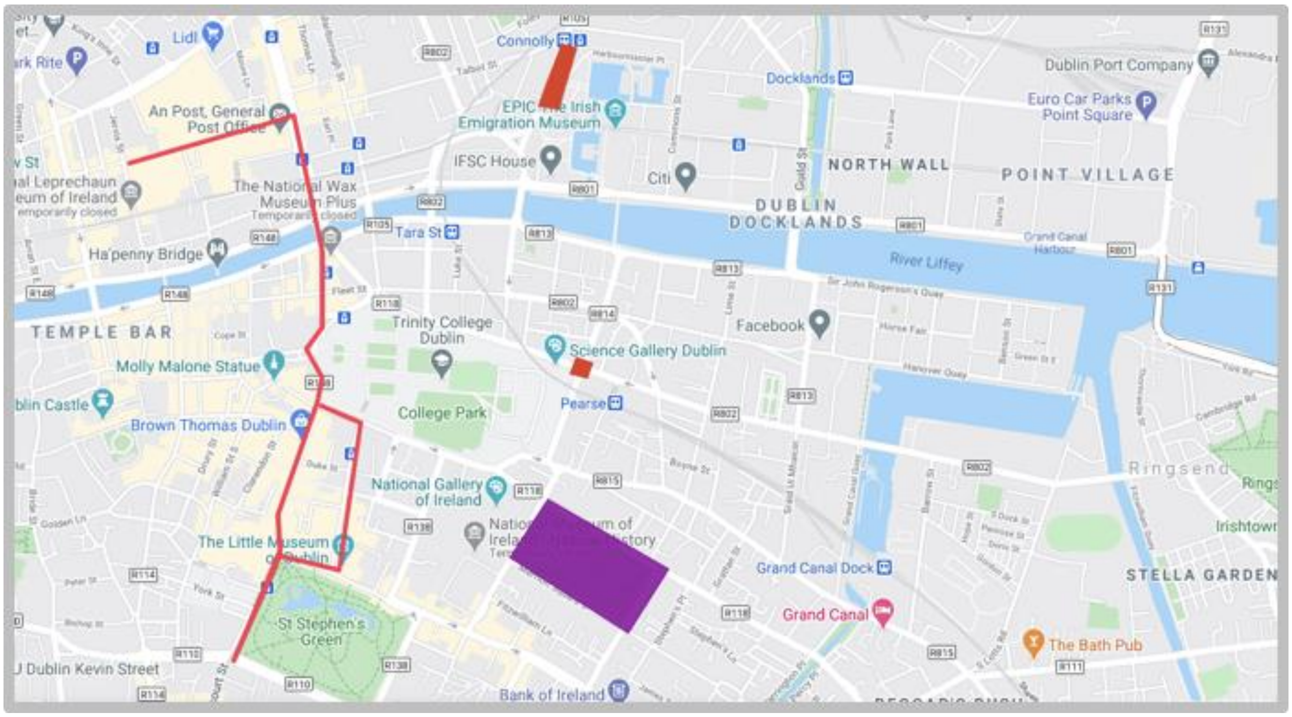

Figure 2 - Network Congestion Areas

Deployment Considerations

Street Clutter

Urban centers are highly trafficked, and the outdoor environment must be managed to ensure good traffic flow for pedestrians and vehicles and to meet consumer expectations of the appearance. To avoid clutter, assets should be shared between services and existing assets should be used or replaced rather than new poles added.

Heritage Districts

Certain historic areas of the city have a specific design style that is connected to a certain period in the area's development. The street poles in these areas are designed to conform to the design style and do not lend themselves to adaptation or replacement to accommodate communications and sensor equipment. In general, other suitable street assets in the area must be found.

5

Outputs

5. Outputs

The solution group goal is a technical implementation built from "open ecosystem" components that is scalable and commercially viable.

Technical Implementation

At the street level, the solution is comprised of equipment and infrastructure that meets the following needs:

- Performance appropriate for relatively short-range coverage in urban areas
- Aesthetics that meet (or exceed!) citizen expectations for the urban environment
- Modularity to create an open market, ease installation and maintenance

The solution must also include backhaul to the core network with appropriately sized capacity to meet the envisaged demand at the cell site.

Technical viability is **strongly** dependent on the ability of the solution to provide additional capacity at the street level in coordination with the operators' existing networks.

Commercial viability

The total solution has an equally important commercial element that, to be scalable, is comprised of both an appropriate business model and a holistic "way of working":

- An asset-sharing model that brings economies at scale and reduces the burden on the city
- A comprehensive planning process that incorporates stakeholder needs
- A commercial framework that provides a consistent basis for the use of city assets
- An approach that is compliant with EU and national regulations

Commercial viability is **strongly** dependent on the ability of the solution to provide additional capacity in the most densely trafficked parts of the city, which also present some of the greatest challenges in terms of asset suitability and availability.

Blueprint

The solution blueprint will be published on TIP Exchange to accelerate global deployments.

6

Appendix

- Regulation
- References
- Attributions

Regulation

European Electronic Communications Code (EECC)

Under Article 57 of the European Electronic Communications Code (EECC), an operator may install small area wireless access points (SAWAPs), usually called small cells, and any backhaul from the small cell site to the operator network on any technically suitable publicly owned street asset. This includes light poles, street signs, traffic lights, billboards, bus, and tram stops.

No individual permits are required from the local authority, except in special locations, for example, historical districts. There is a requirement to notify the national authority within 2 weeks of the equipment installation.

The City may impose reasonable and non-discriminatory terms and conditions, which must be made public at a single information point. However, no fees may be charged beyond necessary administrative charges.

To be eligible under Article 57, the small cell equipment must satisfy a number of technical criteria as defined by the commission implementing regulation:

- The equipment must be integrated within the street asset, or the visible part to not exceed 30 liters and be visually consistent
- The equipment must comply with certain RF transmission power and emissions limits for public safety

References

European Electronics Communications Code (EECC)

EU Directive 2018/1972: http://data.europa.eu/eli/dir/2018/1972/2018-12-17

Direct link to Article 57: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02018L1972-20181217&from=EN#tocId85

Commission staff working document: https://op.europa.eu/s/oIAN

Regulation implementing Article 57: https://op.europa.eu/s/oIAP

FCC Small Cell Order

FCC 18-133 Declaratory Ruling and Third Report and Order: https://docs.fcc.gov/public/attachments/FCC-18-133A1.pdf

RF emissions

European Standard EN 62232:20175 - "Determination of RF field strength, power density and specific absorption rate (SAR) in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure".

Planning

Section 254, Planning and Development Act 2000 (Eire)

http://www.irishstatutebook.ie/eli/2000/act/30/enacted/en/print#sec254

Connectivity Strategy

5G and Future Connectivity - An Emerging Framework for Irish Cities and Towns

https://smartdocklands.ie/wp-content/uploads/2020/08/5G-and-Future-Connectivity-in-Ireland-Discussion-Paper.pdf

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