Smart Junctions 5G

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Summary

The Smart Junctions 5G project aims to deliver VivaCity's AI traffic control systems to reduce congestion and pollution as well as improving productivity by cutting waiting times at traffic signals. The project aims to use a 5G small cell network to decrease infrastructure costs for the connection of sensors at every junction. Critically, the system requires low-latency communications to achieve its goal - making small cell 5G the perfect technology to deliver this saving.

Following advancements in open architectures for virtualized networks, SJ5G implements an innovative deployment approach that allows for new players to contribute with network densification, maximising the social value created by digital infrastructure.

For SJ5G, Weaver Labs has designed and deployed a cloud-native 5G private network with the necessary governance, security and service layer components to integrate into existing 5G public networks. This solution addresses the core technical and commercial aspects of 5G, including:

- Interoperability between hardware and software
- Heterogeneous networks addressing convergence of technologies
- Openness and diversity in the telecoms supply chain
- Integration of neutral host networks, and extension of public networks into private

TfGM have explored further benefits of adding 5G to the product, to the public sector and beyond, with benefits including:

- Removing the need to mount hardware onto buildings in district centre locations, making small cell networks more cost effective to deploy
- Enabling 5G-connected vehicle-to-infrastructure communication, supporting connected bus projects and other mobility based public services
- Providing public Wi-Fi at minimal marginal cost
- Providing a new business case to promote capital investment into small cell network, by incentivising the public sector to contribute with connectivity assets, which could be rented for use by Mobile Network Operators, as well as contributing to network densification to maximise the social value potential of digital infrastructure

Overall, the results showed that there is still further development required within open RAN 5G networks. VivaCity devices on a 4G network were measured to typically achieve >95% on the KPI of "acceptable latency and uptime". In its current state, the network is too unreliable to run a use case successfully, particularly one in real time. The current unreliability resulted in greater periods of downtime and unacceptable latency over a public 4G alternative, alongside a limited

number of attachable devices at present. It is also evident that downtime has a much greater impact to disrupt a real time use case and as such VivaCity's uptime KPI is vital and overweighs any reduction in latency measured over a 4G connection

There were periods of promise whereby the results showed that a private 5G network could improve current connectivity methods and benefit a use case such as Smart Junctions - given development time. In periods of stability, the network was able to achieve acceptable latency measurements lower than a 4G network. These peak periods in particular are of importance to real time traffic control where the 4G network performance often degrades due to higher traffic.

Cost analysis also proved that a private 5G network presents a more appealing solution for a local authority to future-proof their network for use with public authority use cases alongside a potential revenue stream from the private sector. This ability to stack use cases adds lots of potential benefits over current available networks utilised by a local authority. The costs associated with an Open Ran solution resulted in a 75% saving over a single vendor approach and presented a compelling business case for rolling out at scale.

However, all of these potential benefits are still very much dependent on further required work across all vendors that are looking to integrate into the ecosystem.

Introduction

The Smart Junctions 5G project led by VivaCity and joined by Weaver Labs and Transport for Greater Manchester, brings together SME's and a Local Authority to explore the potential benefits of Private 5G connectivity.

Consortium

VivaCity

VivaCity's vision is to make cities smarter, safer and more sustainable. VivaCity's AI sensors and 'Smart Junctions' signal control gather detailed and anonymous data 24/7 on transport modes, traffic flow and travel patterns, supporting strategic decisions to help optimise the transport network and improve urban infrastructure.

VivaCity was awarded the Queen's Enterprise Award for Innovation in 2021, with sensors deployed in over 100 towns and cities across the UK - with international growth well underway. VivaCity is passionate about the protection of personal data and the sensors have been developed using privacy-by-design principles to ensure that personal data is never compromised.

VivaCity is developing the use case for testing the 5G networking through a real time Reinforcement learning based traffic signal control algorithm utilising data from our above-ground AI video based sensor hardware. For more information please visit: www.vivacitylabs.com

Weaver Labs

Weaver Labs is a Web3 startup working to make networks more accessible, by democratising access to Telecommunications infrastructure and accelerating the adoption of connectivity.

The company builds Cell-Stack, a software product to manage telecoms infrastructure to access it *as a service,* with an extensive focus in Smart Cities. Cell-Stack aggregates all the telecoms infrastructure that exists in a region in a shared pool of assets, it then opens it up to be consumed in an open marketplace. This software exists in the middle between those who supply telecoms connectivity and those who demand connectivity.

Through Cell-Stack, owners of networks can manage their cloud-based assets as a traditional orchestration tool. For those requiring connectivity, Cell-Stack is a portal where connectivity is offered in a “Network as a Service” portal that abstracts all the complex elements of the network and instead offers a selection of Telecoms assets in the area.

TfGM

Transport for Greater Manchester (TfGM) is the local government body responsible for delivering Greater Manchester’s transport strategy and commitments. More than 5.6 million journeys are made across Greater Manchester’s transport network each day. TfGM aims to keep the city-region moving and growing, working hard to make travel easier through a better connected Greater Manchester.

TfGM is responsible for investing public money in improving transport services and facilities, to support the regional economy.

TfGM works closely with bus, tram and train operators to help improve the full journey experience; to promote and invest in walking and cycling as safe, healthy and sustainable ways to travel, to keep traffic flowing on some of Greater Manchester’s busiest roads by managing a 360 mile ‘Key Route Network’. TfGM looks to develop easier, smarter ways to travel and plan journeys by using data and technology and play a leading role in coordinating Greater Manchester’s plans to reduce transport-related air pollution.

Smart Junctions 5G with its innovative use of data, technology and connectivity saw a real opportunity for Greater Manchester to look to address some of our major challenges and assist in the delivery of our strategic objectives.

Aims and Objectives

The core objective of the Smart Junctions 5G project is to deliver a 5G Private Network that will reduce the ground works needed to install the Smart Junctions product across Greater Manchester, and at the same time provides a platform for innovation where other use cases can be onboarded efficiently.

The urban traffic optimisation use case core concept is about using AI-powered video sensors to detect road users, and Reinforcement Learning (RL) methodologies to use this data to optimise traffic signal control. The benefits of utilising AI to control traffic signals include a reduction in congestion and waiting times for various modes of transport. The Smart Junction solution also aims to increase the use of active transport modes such as walking, cycling or public transport and thus improve air quality within the region.

The aims and objectives of the SJ5G project were defined by 3 core categories:

1. Smart City Use Case - Demonstrate the benefits to real time traffic control and cost benefits of rolling out Smart Junctions 5G.
2. Vendor Diversification - Deliver a 5G private O-RAN network that seamlessly integrates between assets whilst prioritising cyber-security alongside developing a network as a service software layer to enable other use cases to use the network.
3. Business Model - Demonstrate long term commercial benefits using a NaaS commercial model with a local authority owned network. Building the business case for capital funding through Webtag and revenue funding by private sector rental

The core requirements to be used as design principles in the 5G Network are:

- 5G Network that is strictly separated from the public, where the stability of the latency can be ensured. This is a requirement coming from the Application Layer, in particular from the Smart Junctions product, where a high variability of latency can impact the result of the policies enforced in the traffic lights.
- A 5G Network that is affordable and easy to maintain. In particular, a network that presents similar deployment and maintenance issues as that of a public WiFi network. With this we aim at reducing the gap of adoption for 5G Networks, by using a commoditised approach to connectivity.
- Leverage the existing public infrastructure such as Traffic Control Cabinets to house equipment, and the traffic lights to mount the small cell antennas.
- A 5G Network that is able to accommodate more than one application, with separation of services and that opens the door to a commercial route, creating a sustainable business model for public authorities investing in infrastructure.

Project Approach

Technology

Design Principles

In order to successfully deliver a 5G Private Network that complies to the requirements set out by the core objectives, the technical design principles are:

1. E2E Network and Deployment Principles:
    a. A Cloud-based network running in commercial off-the shelf computing hardware (COTS).
    b. Compute nodes housing the virtualised network functions must run in the Traffic Control Cabinets, making the network design distributed in nature.
    c. The network must be able to scale by adding more compute nodes that are easily added to the existing connected elements. This means the orchestration and management framework must facilitate the creation of hyper-scalable networks.
2. Radio Access Network Design Principles:
    a. Radios must support the shared access license bands allocated by Ofcom. This being an outdoor 5G Private Network, the most appropriate band is 3.8-4.2GHz
    b. The size and weight of the small cell antenna must meet the structural requirements of mounting to a traffic light, where an extension pole will be used to extend the length of the traffic light mounting.
    c. The compute power for the Centralised RAN and Distributed RAN components must be low (to comply with design principle 1.b), while still maintaining reasonable levels of capacity for a 5G Use Case.
    d. The RAN must follow a softwarised API approach, whereby integration with other radios, 5G Core elements is feasible (i.e., O-RAN)
    e. The selected RAN equipment vendor must facilitate access to open APIs for network automation, control and service orchestration
3. Core Network Design Principles:
    a. The 5G Core must support Stand Alone mode of operation
    b. The 5G Core provider can be closed source, however it must provide open APIs for network automation, control and service orchestration.
    c. The 5G Core software architecture must be designed with a flexible NFV placement in mind, and not a single collapsed cloud deployment.
    d. The compute power for the control and user plane network functions must be low (to comply with design principle 1.b) while still maintaining reasonable levels of capacity and number of users connected.
    e. The 5G Core must be addressable and deployed in different compute units
4. Use Case Connectivity
    a. A UE that is capable to connect to a 5G SA network on the appropriate band

b. The UE must be easily retrofit to the existing sensor design and be structurally sound for attaching to a traffic signal pole
c. Remotely accessible and easily controllable/configurable
d. Suitable for outdoor environments

Vendor Assessment

Radio Access Network

	Type of radio	**DU Integrated**	**Size**	**Weight**	**vRAN Configuration**	**Integration through Open Access to APIs**	**Delivery timeline**	**5GTT References**
Accelleran	5G NR Small Cell	Third party for DU	310 x 310 x 02 mm	3.5Kgs	O-RAN between DU and CU	dRAX platform offers APIs to integrate Orchestration (see dRAX document)	16 weeks lead time	
Airspan	5G NR Small Cell	Same vendor DU	280 x 500 x 170 mm	12kgs	O-RAN between DU and CU	Possibility to open up APIs	16 weeks lead time	Milbrook testbed
Cable Free	5G NR SDR	Integrated			SDR - not vRAN		Claim 8 weeks - customer feedback says it's increasingly more, no customer has received product yet	Quickline (Yorkshire), AQL (Leeds)

Core Network

	Type of Core	**Provider**	**Compute power Requirements**	**QoS (min)**	**Integrated with radios**	**Software Architecture**	**Flexibility to changes**	**Timelines**
Vendor Specific								
Attocore	5G SA	Closed source	TBD	TBD	Accelleran/Airspan	Flexible NFV Placement with Kubernetes - June 2021 Q1 - Centralised NFV Placement	They're part of a 5G Create project and will be working on 5G SA	Feasible within timeline
Metaswitch	5G SA	Closed source			Accelleran/Airspan	Started with 5GCore from scratch, looking at a microservice architecture. Containerised deployment, can run on a box using Azure or VMWare. APIs from VIM to manage is available	Single collapsed deployment because radio vendors want to prioritise that. Architecture can do flexible deployments.	Feasible within timeline
Athonet	5G SA	Closed source	Scales on a sw - 2vCPUs		By definition all radios work with their core, test core for ETSI	Running in Virtualisation environments, running on Docker VIM, preference VMWare, APIs to manage the core network	Flexible to place any NF	Ready to use
Quortus	5G SA - Pre Commercial	Closed source	Can run on a RaspPI - quadCore	32 Users, sub 100Mbps with 1 Core	Testing NSA, 5G SA with a lead customer RAN provider.	Kubernetes - what about addressing and configuring the network? They rely on	Flexible to place any NF - even in 4G. Single collapsed deployment -	Feasible within timeline

					Accelleran will be one of those. They will help with integration tests as part of the project	system integrators to configure and create networks	but all network elements are addressable	
Druid	5G SA	Close d sourc e	Run on low-end HW 4Core CPU 4G RAM		They want to be radio agnostic - accelleran is one of them. Airspan as well - have done interop with HW. Done testing with ZTE for SA, Nokia done NSA	Network slicing (?). REST-full API for connect. Run on any VM/Container...	Seems very configurable through APIs	Read y to use
Open Sourc e								
ONF (OME C)	4G Cloud	Open Sourc e						
OAI	5G Cloud	Open Sourc e						
Magm a	4G Cloud	Open Sourc e						

Network Design

The final network design was an edge-cloud based network using 5G SA OpenRAN band 77. Each cabinet will have the following deployment using Accelleran OpenRAN offering and Attocore SA 5G Core:

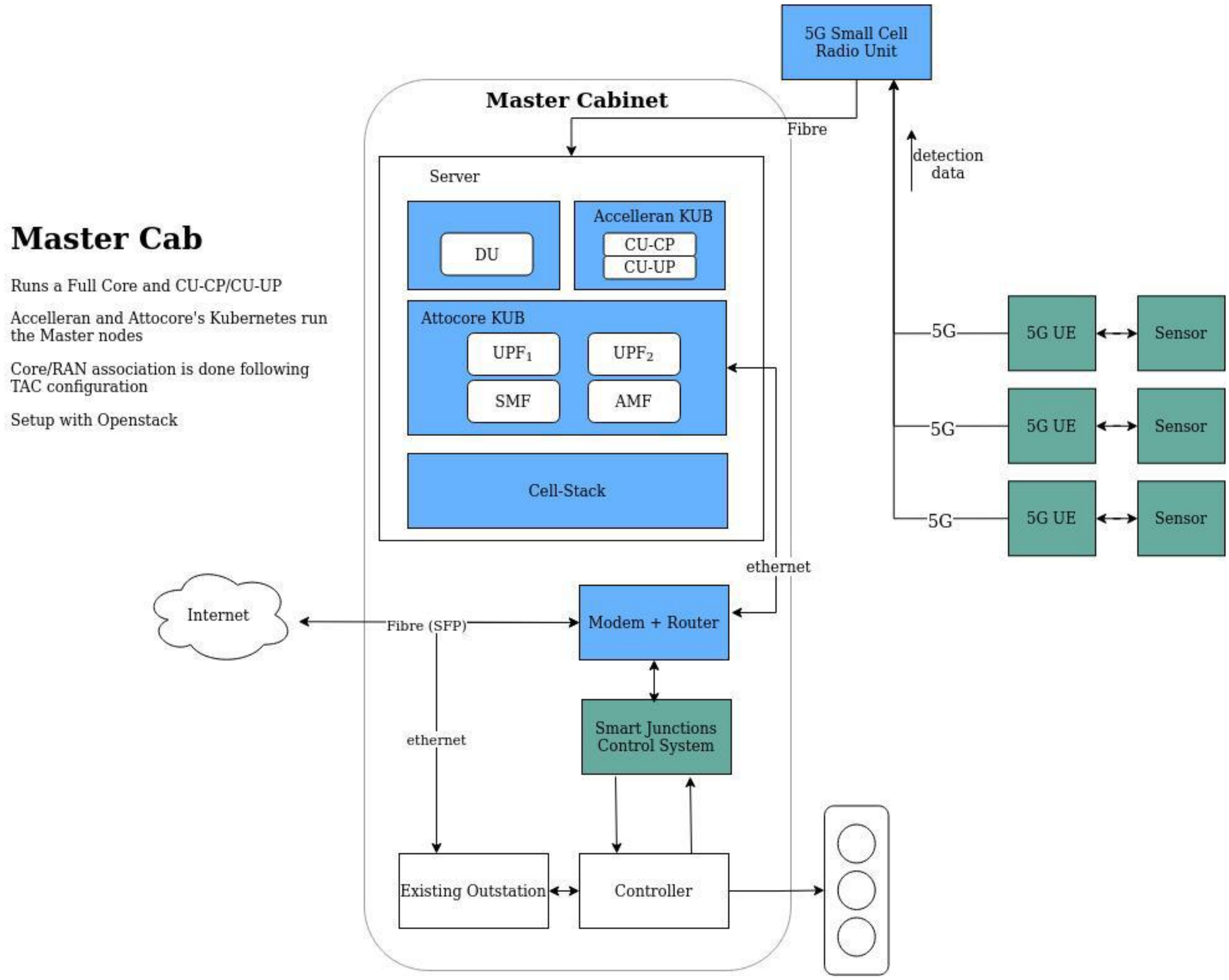

Figure 1: Master cabinet 5G Network and Smart Junction layout Design

UE Device

The UE device selected needed to provide the existing VivaCity sensor hardware with a SA 5G connection on band 77 as well as being retrofitted to the existing hardware with ease. The UE required was to be installed in an outdoor environment and so was required to be IP protected and mounted to a traffic signal pole. Due to its environmental placement, the router must also withstand higher temperatures possible in the summer period.

The initial targeted solution was to integrate a 5G M.2 modem directly into the existing VivaCity Sensor. Unfortunately, due to a shortage in modem's for direct integration based on the number required for a pilot production, some issues faced with integration through USB2.0, and general performance issues connecting to band 77, the decision was made to explore more commercially available solutions.

The device selected to provide a 5G connection to the VivaCity use case sensors was the Comms365 mini 5G router. This router was able to connect to a SA band 77 network in a small form factor and was readily available for a larger production rollout. It did require re-housing into an external IP box in order to be installed in an outdoor environment. An image of the router and housing can be seen below.

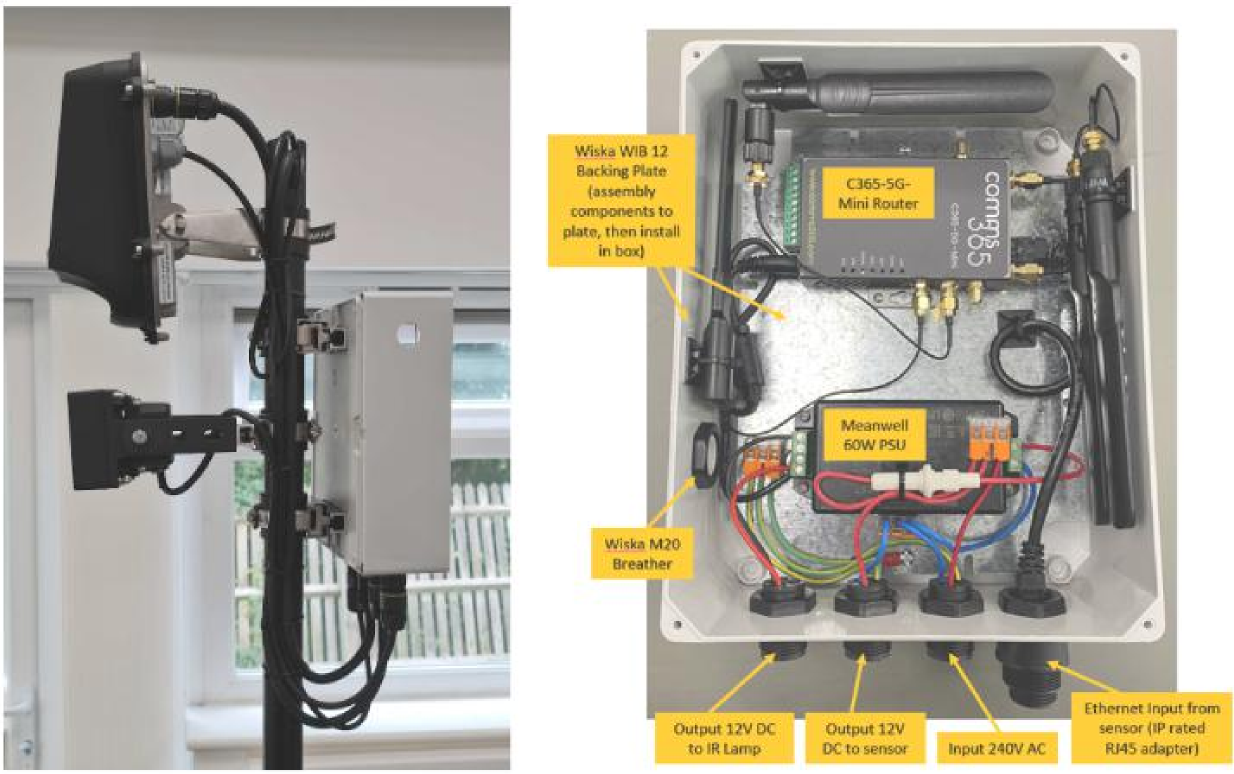

Figure 2: Smart Junction Sensor trial installation and Comms365 router housed in IP box

Cabinet and pole design

Controller cabinets follow the design depicted in below diagrams:

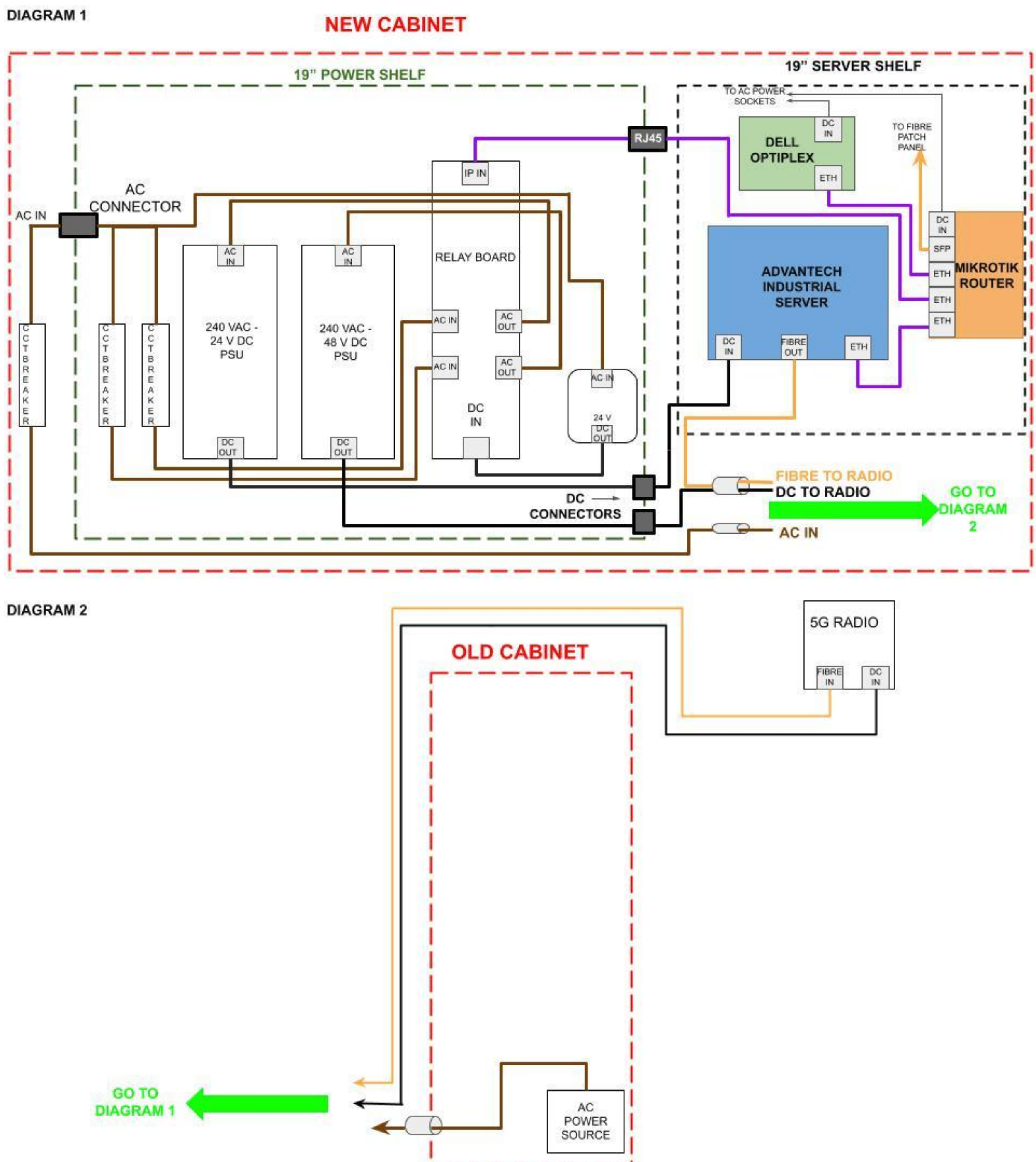

Figure 3: Controller cabinet 5G network hardware power shelf, network shelf and layout drawings

The 19’’ power shelf is used to power the Benetel radio through the 48V and the Advantech server through the 24V power supply. The relay board is activated and controlled via the Dell Optiplex controller using the software client provided by Weaver Labs.

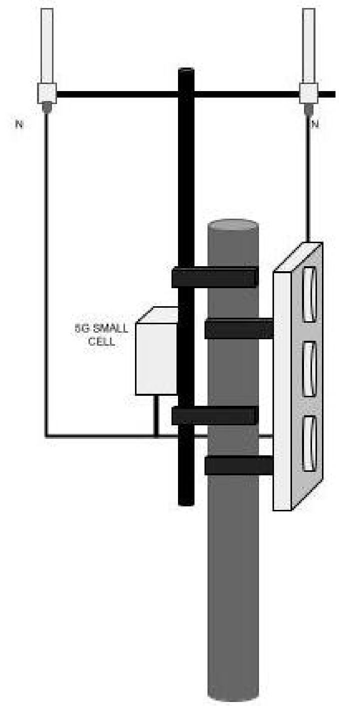

Figure 4: Proposed installation layout for the 5G small cell and antennas onto a traffic signal pole

The small cell radio is attached to the traffic signal pole using an extension pole. The extension pole is attached at 2 mounting points on the traffic signal pole using custom made brackets. The small cell radio is fastened between these mounting points in order to support the weight, with the antenna configuration installed towards the top of the extender pole.

Smart Junctions Use Case

The VivaCity Smart Junctions use case is an AI-powered video sensor and Reinforcement Learning approach to urban traffic optimisation. The sensors are edge devices capable of detecting, classifying and counting different modes of transport with a high level of accuracy. This data is sent to a cloud based AI algorithm which acts to make a decision to optimise traffic control at a junction, sends the action down to VivaCity’s control hardware and in turn, controls the traffic light sequence and timings.

The system aims to introduce revolutionary new capabilities to signal control:

- Multi-modal optimisation

- Efficiently and effectively enacting new city wide policies as they change
- Better optimisation across local, regional and city-wide scales
- Dynamic and adaptive control to quick changes in demand
- Automated calibration with a modern interface

System Design

The overall system design can be seen in figures 1 and 5. The system consists of:

1. VivaCity Sensors, connected up to the 5G UE device, attached to traffic signal poles, as seen in figure 7.
2. Controller cabinet hardware, as seen in figure 6, including various power supplies, a small computer and IO integration, a 5G router, and an external antenna.
3. A Traffic simulation model that is utilised to train the model prior to deployments.
4. A cloud based AI traffic signal control algorithm.
5. A User Interface used by VivaCity to monitor system performance

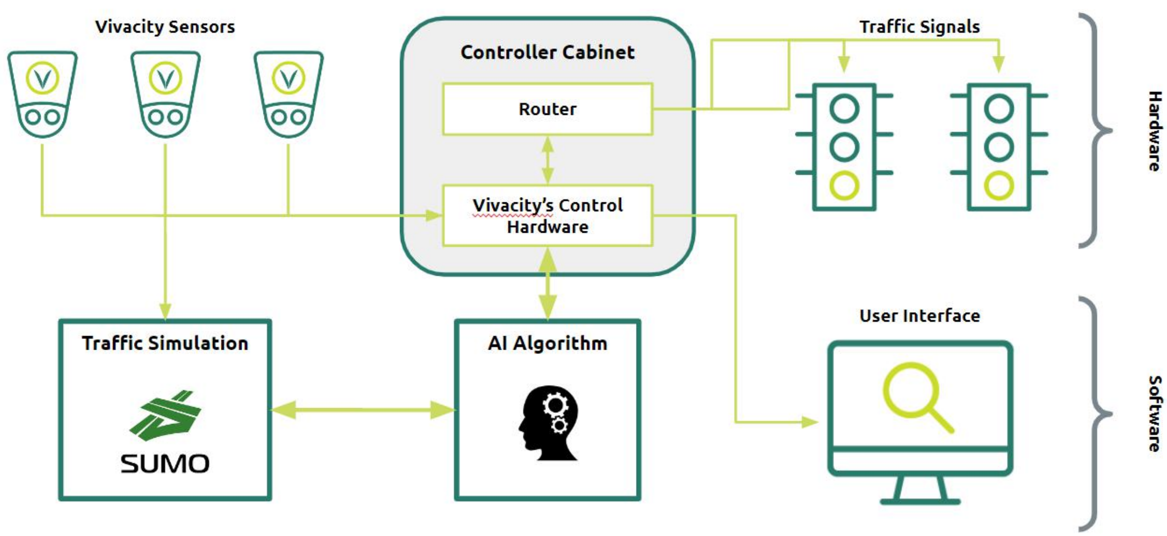

Figure 5: VivaCity Smart Junctions Design

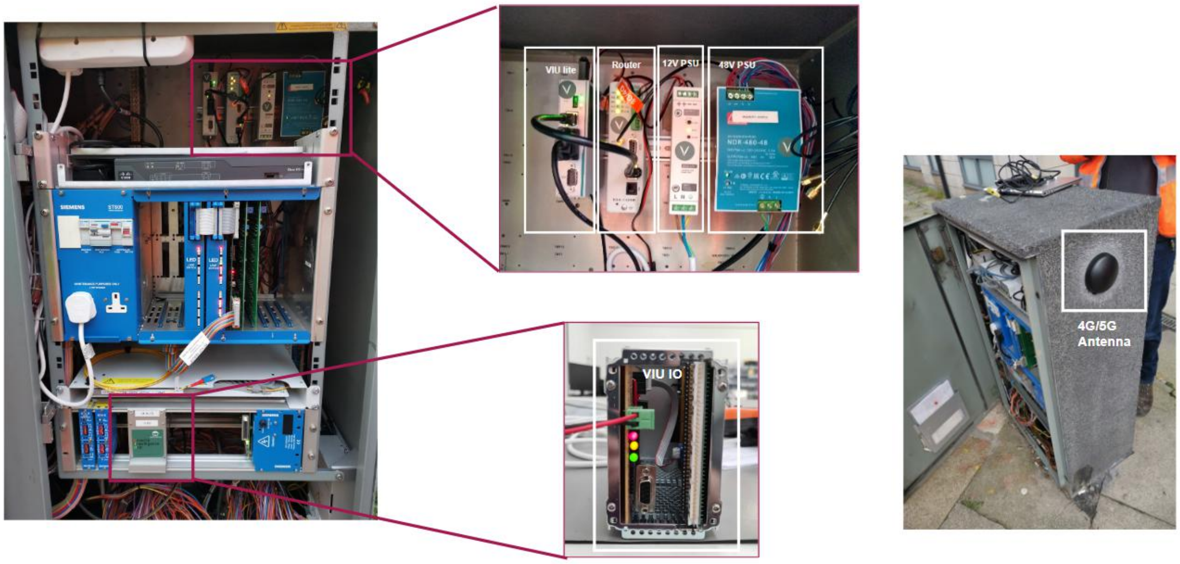

Figure 6: VivaCity Smart Junctions installed cabinet hardware

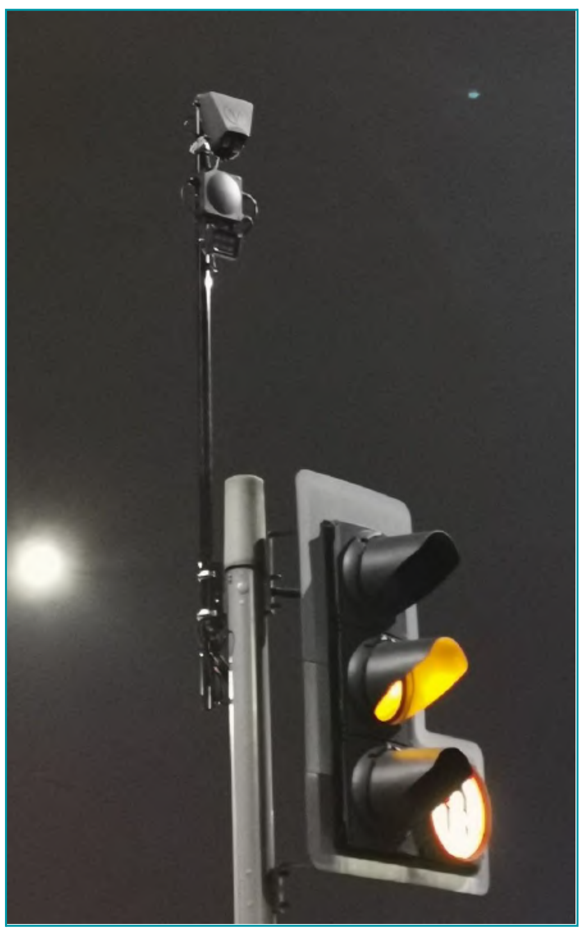

Figure 7: VivaCity Sensor installed using an extender pole onto a traffic signal pole

Assessing project objectives

The Smart Junctions use case will be utilised to assess the project objectives. The use case requires a stable, consistent and low latency connection in order to operate effectively in real time. The Smart Junctions use case has been under development for a couple of years prior to the SJ5G project commencing and has already been tested under a 4G connection in Manchester, providing baseline data for comparison. The use case allows for key metrics to be recorded against latency and uptime whilst assessing the real world impacts to traffic control.

Furthermore, retrofitting 5G capabilities to existing sensor hardware across a large number of test sensors allows the project to test seamless integration with the network by an increasing number of UE's. Also, having already established a baseline cost for a 4G and wired ethernet rollout at a junction, the project can assess the cost benefits of a real world deployment utilising a 5G network. This cost analysis can also be fed into the building blocks of a business case for the rollout of a public authority owned 5G network with an example local authority use case stacked on the network.

Deployment Process

First phase: requirements gathering and system level design

During the first months of the project we worked extensively on understanding the use case requirements as well as the deployment constraints mentioned in the design principles. Those end user and network design constraints served as input to the design choices we had to make when creating the network architecture.

Once the design principles were clear, we started the second phase.

Second phase: choice of vendors and backhaul

We worked to source vendors which could actually fulfil the list of design principles this project was set out to achieve. The network design in this project is very innovative and therefore required a very specific assessment of the existing technologies available. We have provided our findings from the vendor assessment.

Important items to consider in this phase where:

- Ability to run in the cabinets with limited power and computing resources as well as industrial temperature requirements
- Software modularity which would ease systems integration
- Ease of retrofitting to existing hardware, including weight and size limitations for mounting
- Spectrum and size constraints

- Delivery timelines given COVID constraints

On the backhaul we explored all possible options to connect the cabinets, and partnered with a fibre provider who was able to deliver what we needed for the project within budget. Note that this process revealed a large discrepancy in quotes between providers with the highest coming from the larger providers.

Third phase: Deployment planning and Installation

The assets that required equipment mounted to include roadside cabinets and traffic signal poles. These assets are located at congested locations for both vehicle and pedestrian activity, along a busy stretch of main road that provides a major route in and out of Manchester city centre. For this reason, a lot of planning, permission and permits are required in order to install the required network and use case equipment. In some instances, the permission and permit process required full road closures which extended the process for approval, delaying the installation and commissioning phase; in this case, permit approval for TTRO’s was quoted with up to 6 weeks lead time by Salford City Council but can be longer depending on the authority managing the assets. This also required night works in some instances in order for permit approval to be granted.

The installation of the fibre backhaul was outsourced to a provider and expert who fully managed the planning, installation and commissioning phases with support from TfGM.

For the installation of the radios and cabinets we worked alongside:

- TfGM engineers - experts in installing and maintaining equipment inside the cabinets and on top of the signal poles where required
- Yunex engineers - experts in installing roadside cabinets, equipment on top of the traffic signal poles, power installations and some cabling through ducting, as well as maintaining the signal pole assets
- Core - fibre engineers that routed the fibre cables between the signal poles and the cabinets through pre-existing ducting
- Telet Research - to oversee the deployment on site and wire the equipment in the cabinets

For the installation of the VivaCity Smart Junction Use case hardware, this was undertaken and supported by:

- VivaCity engineers - trained and skilled in installing and commissioning VivaCity sensors
- TfGM engineers - supported in installing preparatory kit onto traffic signal poles and inside of controller cabinets

Figure 8: Installation of network hardware inside of Roadside cabinet & Benetel RAN650 small cell radio installed onto traffic signal pole using an extender pole

Fourth phase: system integration

After the site installation and subsystem component check, the fourth and final phase of deployment is the system integration and network set up.

For this phase we worked with:

- Accelleran - the RAN systems integrator, providing integration of all OpenRAN components
- Attocore - 5GSA core integration troubleshoot
- Telet research - End-to-end systems integration

Important items to consider in this phase were:

- The large number of suppliers requires very organised and up-to-date documentation that is supported by all suppliers
- A stable development platform is essential before moving into onsite testing
- Clear integration milestones are necessary to progress in the network stability

Cyber Security

As part of the work in WP3 focused on cybersecurity, the team at Weaver Labs started researching best ways to construct an organisational posture which would result in a security technical architecture for the platform. The team went through extensive effort to review the existing standards and policies, in order to construct the project's cybersecurity strategy.

There is no clarity on the standards that should be adopted and the resulting security profiles expected, and more importantly there is no unified way to:

- Consult cybersecurity standards and policies in a way that can be used to efficiently create a CS strategy for an organisation
- Map security principles and policies with specific postures and best practices - for example, Weaver Labs wanting to adopt Zero Trust principles, but having no way to map that to NIST core principles and policies.
- Measure risks of a given organisation in accordance with the standardised policies

After having carefully reviewed the existing standards and applying best practices as an organisation, Weaver Labs concluded that there is no pool of policies that any organisation can efficiently use to build a cybersecurity strategy. The problem this creates is twofold:

1. Companies will have to invest significant amount of money and resources to go through the standards and practices to design a CSF strategy, which further impacts the commercial blockers that currently exist to pay importance to CSFs
2. A slower adoption of security best practices across the industry, including telecoms operators, vendors and any new player wanting to invest in telecoms infrastructure.

As a solution to this problem, the project created a first workable version of a cybersecurity ranking tool, i.e., score-card, as a solution to:

- Create cybersecurity postures for any organisation in the supply chain,
- Obtain an action plan that is aligned with the nature of the business and the software product,
- Calculate a score that is representative of the level of risk the organisation's current profile has.

The objective of the card is to measure the risks and impacts of a given organisation's current and controlled postures with regards to business processes including:

- The organisation's technical posture and procedures
- Management and Operations protocols

The score-card inputs the existing security posture, analyses the existing risks and gives the organisation an understanding of the risk exposure and the threat landscapes. This way, gaps are easily identified and an action plan is put in place. As an output of the analysis, the score-card provides:

a. A comprehensive risk gap analysis
b. An overview of the current security profile
c. The target security profile and the existing gaps to get there
d. An action plan, with the policies and references to execute it

This is done through a process of policy aggregation and mapping, for example doing a mapping of UKNSCS Zero-Trust to the NIST.SP.800-53 security controls. The risk analysis is done as a means to identify the threat landscape, in both controlled and uncontrolled risks. The objective is to identify the impacts of both controlled and uncontrolled risks, apply risk scores and risk mitigation strategies. It also provides a means to set and monitor the risk goals and measure the risk progress. To create the target profile, the tool provides a simple way of selecting policies and associating it to the risks, it also gives the ability to set priorities to the policies and tasks in the action plan.

As an output, the organisation is able to see a comprehensive analysis of their baseline security risks and threats, and a score associated with it. This score is a means of grading an organisations' risks and the policy selections.

There are two main factors impacting "real time" data provision:

Results

Methodology

Network Performance Data

The Smart Junctions control system has to be able to respond in "real time", which VivaCity defines as less than 2s. This is because Smart Junctions system evaluates actions at a rate of once every 600ms, therefore VivaCity has established the following performance criteria for "real-time data":

- 0 - 600ms = Good
- 600ms - 1200ms = Mediocre
- 1200ms - 1800ms Poor
- > 1800ms = Bad

- Latency - is the system's ability to maintain a stable connection from the edge device via the local cell network to the cloud system i.e. is there a lag or delay in data being sent

- Uptime - is the reliability of the data connection between the edge device and the local cell tower i.e. do we lose data because of a lack of availability

In order to monitor the performance of the junctions and the control system, VivaCity have built a series of dashboards utilising real-time and historic data to allow us to control the junctions in confidence and to analyse and understand historical events after the fact.

Our control system feeds a time-series database which allows our dashboard to query the data in real-time.

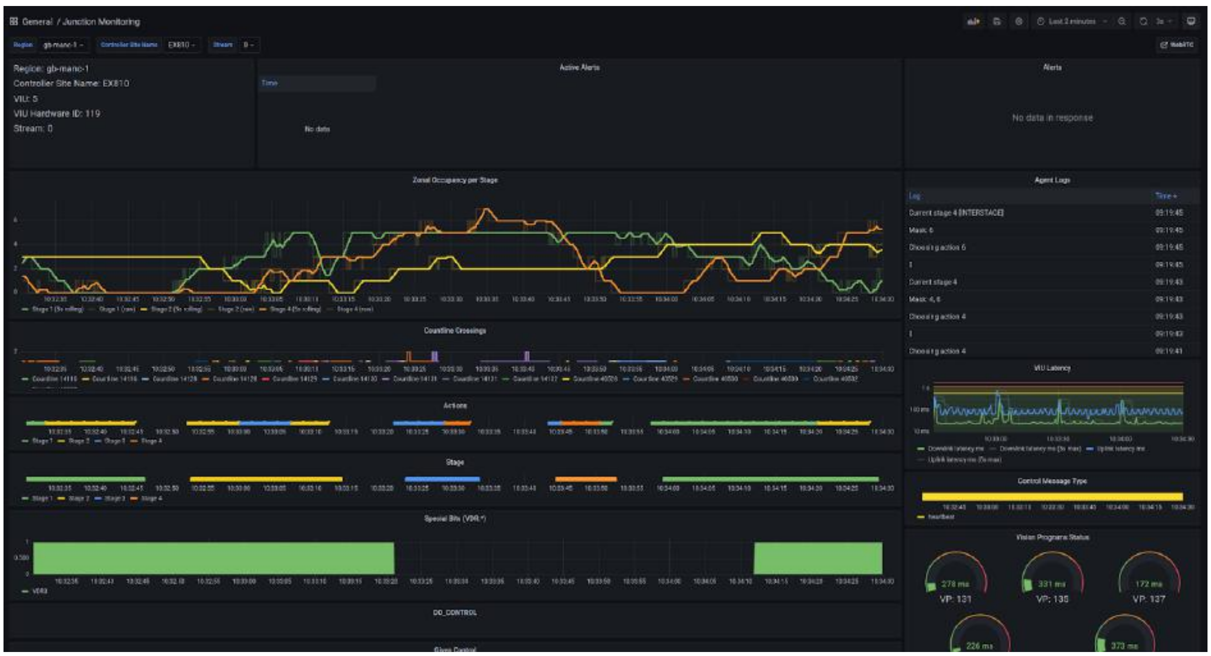

Figure 9: VivaCity Smart Junctions real-time monitoring dashboard

The dashboard allows us to visualise a number of aspects of the junction and system performance:

- Junction traffic metrics
- Junction controller state
- Agent actions
- Alert monitoring
- Infrastructure performance and latency data

The infrastructure performance and latency data is what we are capturing as parts of these tests in order to assess the performance of the network and to compare 4G connectivity with 5G. A visualisation of this data being captured in real time is displayed below. This data is also stored for historical analysis which is the data that has been utilised in our comparative results. The metrics captured here include:

1. VIU (Junction Controller) latency history
2. Sensor status and latency
3. Sensor latency history
4. Infrastructure CPU usage
5. Infrastructure CPU throttling
6. Infrastructure Memory Usage

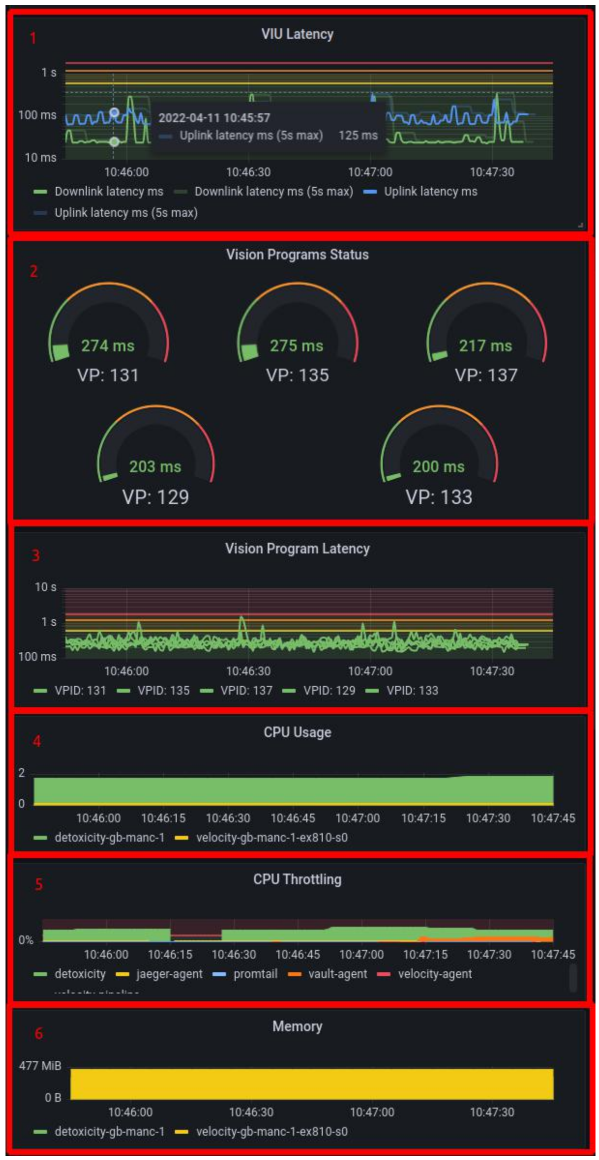

Figure 10: Infrastructure performance and latency data from VivaCity's Smart Junctions dashboard

Journey Time Data

VivaCity carried out a series of deployments during June and July on the following junctions:

- Junction x810 - is a four-arm junction with bike lanes and advance stop lines for cyclists at each junction. Located at the junction of Chapel Street, New Bailey Street and Bloom Street, the junction is right next to Salford Central station and has an elevated railway serving the nearby Manchester Victoria station.
- Junction 830 - is a four-arm junction with bike lanes and advance stop lines for cyclists at the east approach. Located at the junction of Chapel Street, A6042 and the Ring road, this is a very busy junction in and out of Manchester city centre. This site is also the next upstream junction from 810 by 150m.
- Junction 834 - is a dual stream pedestrian crossing junction located along the A6 directly outside of, and cutting across, the campus of Salford Central University and within close distance to Salford Crescent railway station.

Hashed licence plates were collected at each of the 14 detection locations using VivaCity's sensors. These locations included upstream sites, beyond the end of typical queues, and downstream sites, past the exit of the junction, as shown in figures 10 and 11. These licence plates were then matched between all upstream sites and all downstream sites, except for prohibited manoeuvres. This matching, and all of the analysis, was separated into 2 sets of junctions; 830 and 810 were grouped together due to their proximity, and 834 was analysed in isolation. Through this capture and matching, journey times were collected for the majority of vehicles which passed through the junctions.

The journey times were then automatically filtered to remove outliers: this filtering includes duplicate removal (for vehicles which are observed to pass through the exit detector multiple times, eg taxis), and removal of vehicles which are deemed to have made an optional stop or detour between the upstream and downstream (using a nearest neighbours algorithm). The same algorithm and parameters are used to filter all of the data.

Journey times were then compared between 3 methods of control:

A. The incumbent method of control, SCOOT,
B. VivaCity's Smart Junctions, using 4G
C. VivaCity's Smart Junctions, using 5G (this was not available for junctions 830 and 810)

For junctions 830 and 810, the VivaCity control period included Wednesday, Thursday and Friday: the 2 months of data for this analysis was filtered to only include these days of the week for both VivaCity and SCOOT. For junction 834, VivaCity control using 4G occurred on a Friday, so a comparison with the incumbent system was conducted using only Fridays within the 2 month period. VivaCity control using 5G occurred at 834 on a Wednesday, so this analysis only included wednesdays. The full dataset for junction 834 spanned 6 weeks.

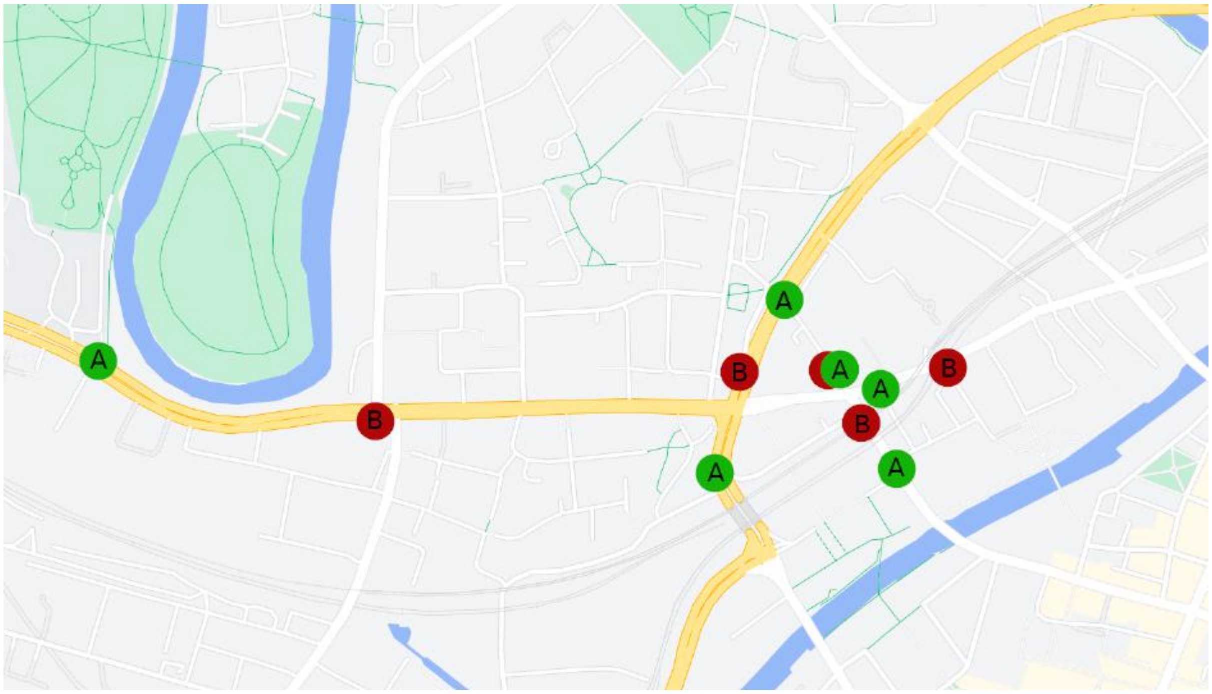

Figure 11: Detection locations for 830-810 analysis. A = upstream site, B= downstream site

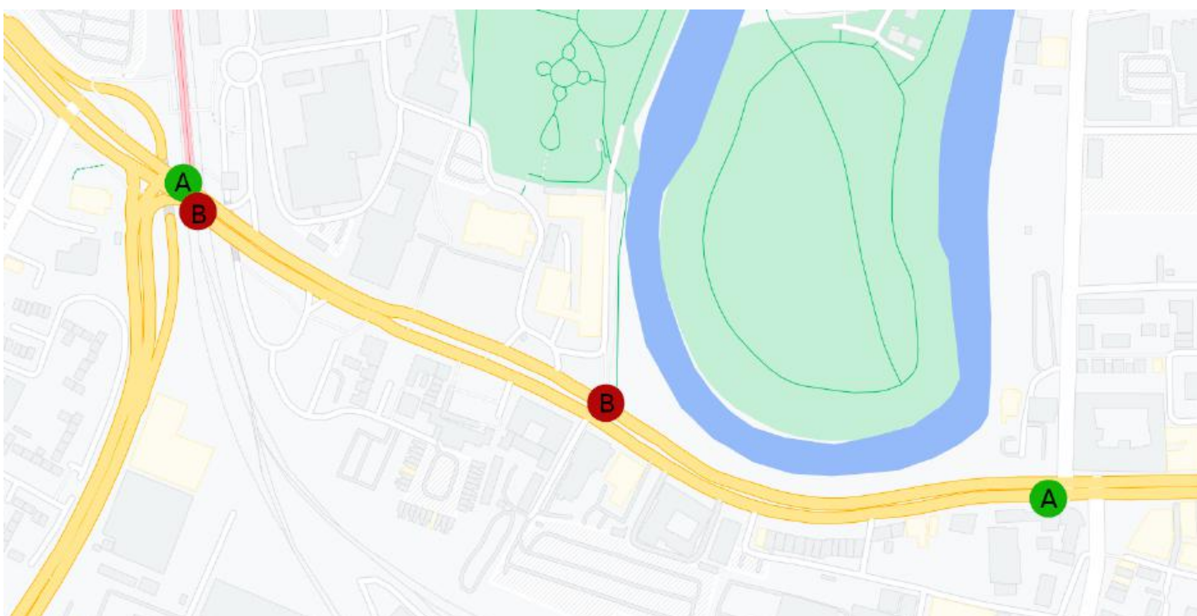

Figure 12: Detection locations for 834 analysis. A = upstream site, B= downstream site

Latency Impact Testing

Assessment of 4G Comms Performance

Latency

The graph below shows the typical 4G uplink latency for the VivaCity UDP traffic from edge devices to cloud servers, over a 1 week period. Note the log scale on the y axis. Also note that all latency figures in this document are measured:

- From the time of frame capture by the onboard camera module
- To the point that the resulting UDP datagram is received at the VivaCity cloud message receiver.

Thus the times include both the onboard vision processing time, as well as in-flight time of the cellular network.

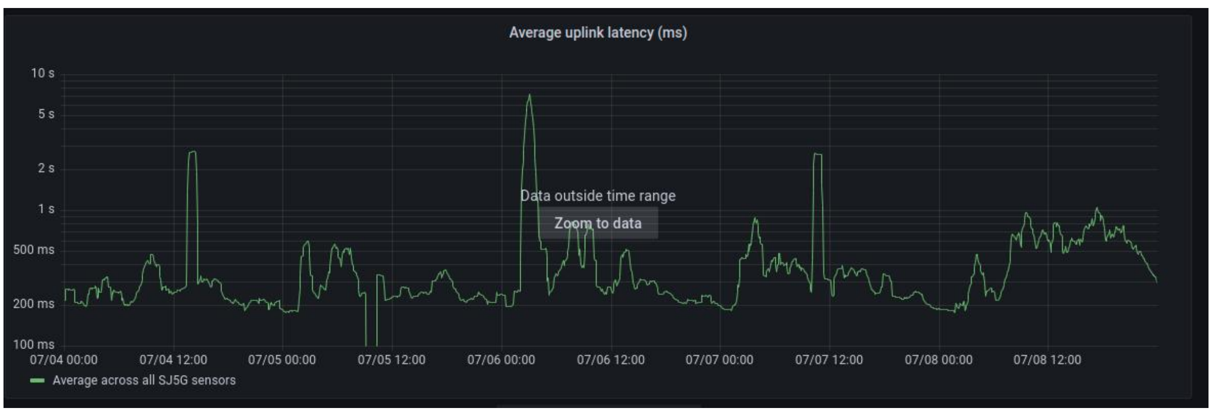

Figure 13: Graph showing typical 4G uplink latency for VivaCity UDP traffic over 1 week

It is possible to distinguish several key features from this graph:

- There is no obvious spike in latency during what might be considered “peak periods” of usage e.g. during rush hour.
- Latency is generally around 200-300 ms, with occasional periods of up to 500ms.
- 2 periods of around 30 minutes where average latency across the entire sensor estate spiked to over 2 seconds. These spikes occurred on all devices across all junctions at the same time. It’s not clear what the cause of this was - and was potentially caused by congestion on the public 4G infrastructure or the APN being used.

The same graph for a typical weekend is shown below. Latencies are generally fairly similar on the weekend, between 200 and 300ms, with occasional spikes up to 500ms - 1s.

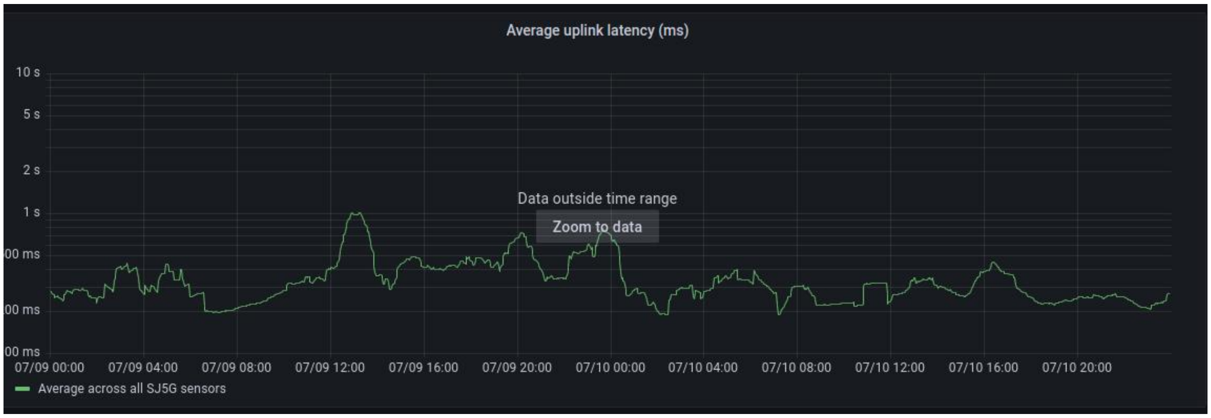

Figure 14: Graph showing typical 4G uplink latency for VivaCity UDP traffic over a typical weekend

Uptime

The following images are screenshots taken from VivaCity's live monitoring/historical performance analysis dashboard.

The following 2 images show the key performance indicators for junctions 810 and 830, under 1 week of VivaCity SmartJunctions control, with all sensors running on 4G

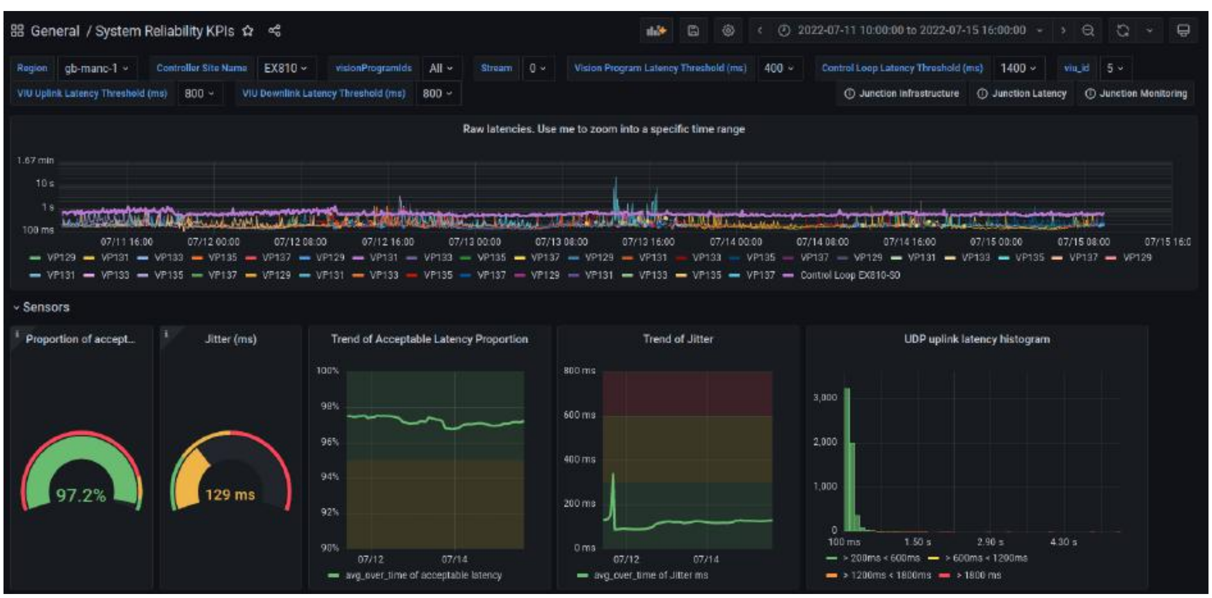

Figure 15: VivaCity Smart Junctions dashboard displaying KPI's for junction 810 on 4G

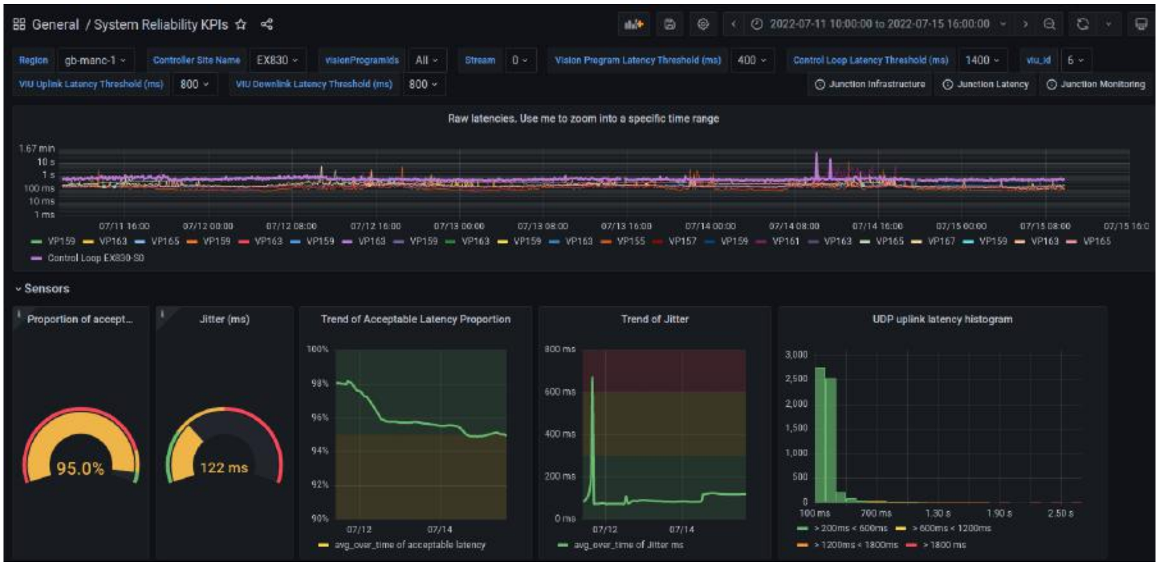

Figure 16: VivaCity Smart Junctions dashboard displaying KPI's for junction 830 on 4G

The key metrics are the left-most circular gauge (Proportion of acceptable latency) and the Trend of acceptable latency over time. This metric indicates the proportion of time that the selected devices are both online, and experiencing latency low enough to be "acceptable".

The graph below shows a typical "zoomed in" control period during peak time (16:00 - 19:00) for junction 810.

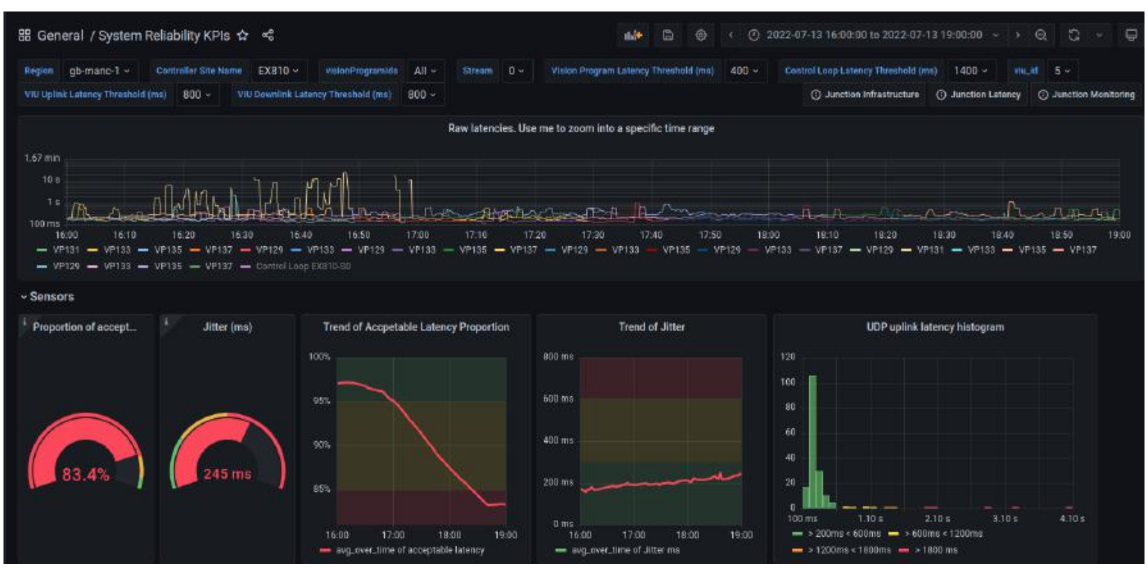

Figure 17:VivaCity Smart Junctions dashboard displaying KPI's for junction 810 during peak period on 4G

Impact of Communication Method when in control

The graph below shows a zoomed-in trace of the raw uplink latency via 4G from around 12:00 to 13:00 at junction 810 during a control period.

One of the sensors (VP131 on the legend) experiences several spikes in latency above 1s, and as high as 20s. Under these circumstances control performance may be impacted.

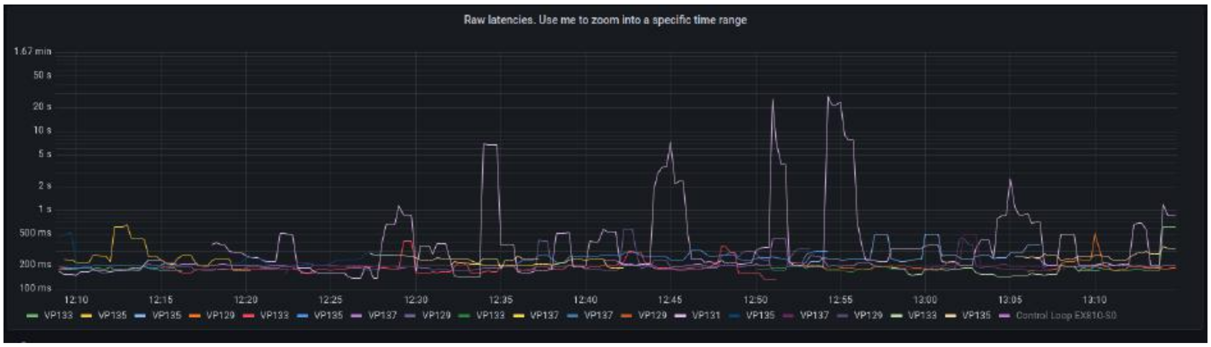

Figure 18: Site 810 zoomed in 1 hour trace of the raw uplink latency on 4G

Assessment of 5G Comms Performance

The following graph is for junction 834 during the same week, showing the statistics for the 3 sensors which were connected to the 5G small cell.

Figure 19: VivaCity Smart Junctions dashboard displaying KPI's for junction 834 on 5G

The graph below shows a typical "zoomed in" control period during peak time (16:00 - 19:00) for junction 834.

Figure 20:VivaCity Smart Junctions dashboard displaying KPI's for junction 834 during peak period on 5G

Smart Junctions Journey Time Analysis

The following graphs display the impacts on journey times through the various junctions tested under both 4G and 5G control and against the incumbent SCOOT system.

Comparative Journey time analysis VivaCity vs SCOOT

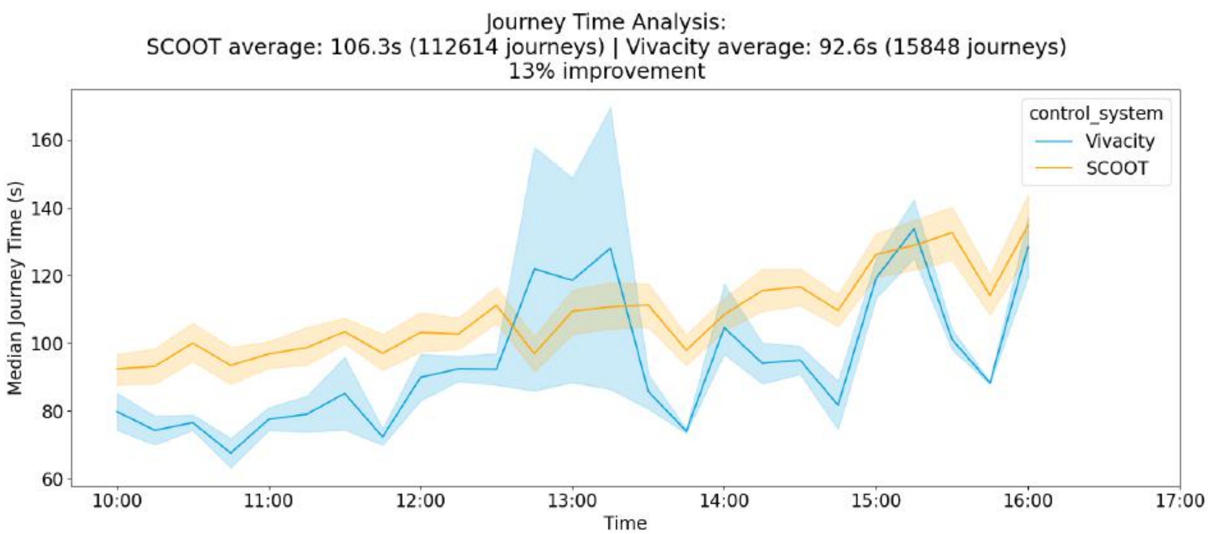

Figure 21: 830-810 Smart Junction 4G vs SCOOT

In the period of VivaCity control, journey times were reduced by 13% compared to the incumbent system's average over the data period on the same days of the week. A total of 2.2 days of person-time were saved through this reduction in vehicle delay.

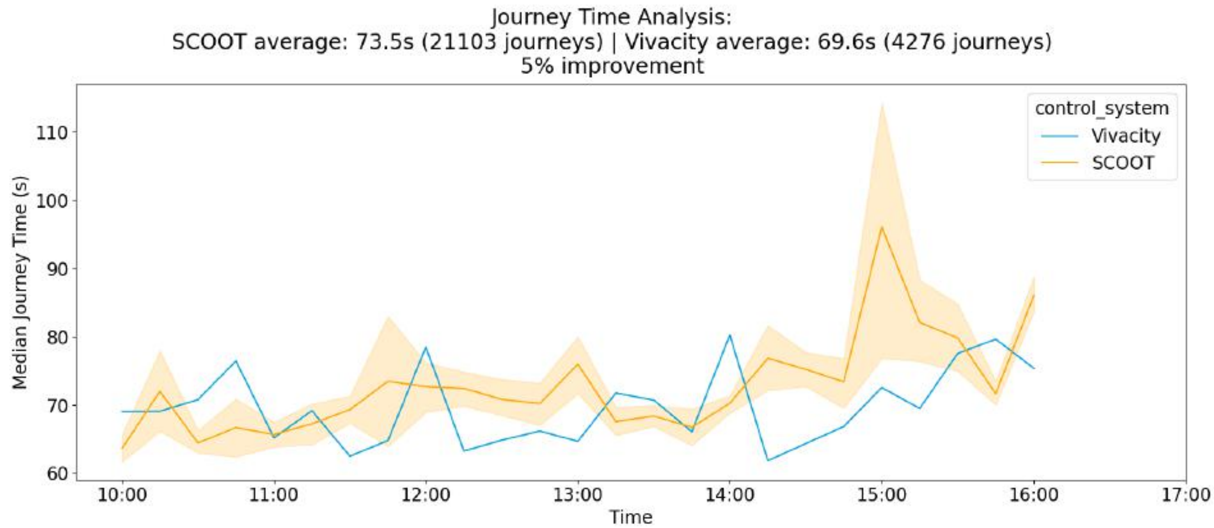

Figure 22: 834 Smart Junction 4G vs. SCOOT

In this period of VivaCity control, journey times were reduced by 5% compared to the incumbent system's average over the data period on the same days of the week.

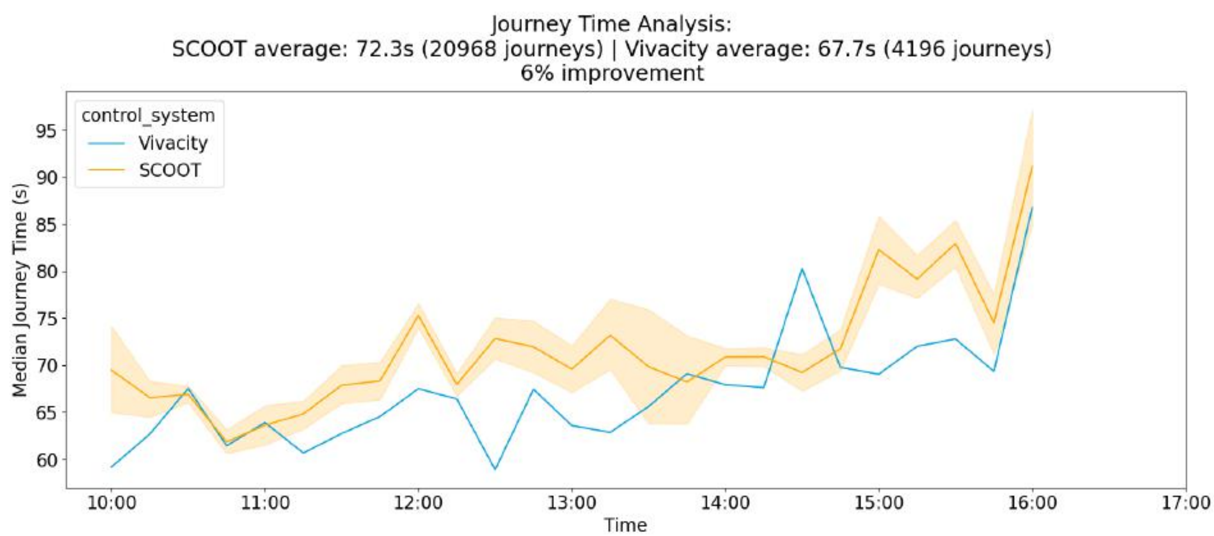

Figure 23: 834 Smart Junction 5G vs. SCOOT

In the period of VivaCity control, journey times were reduced by 6% compared to the incumbent system's average over the data period on the same days of the week.

Comparative Journey Time Analysis Smart Junctions 4G vs 5G

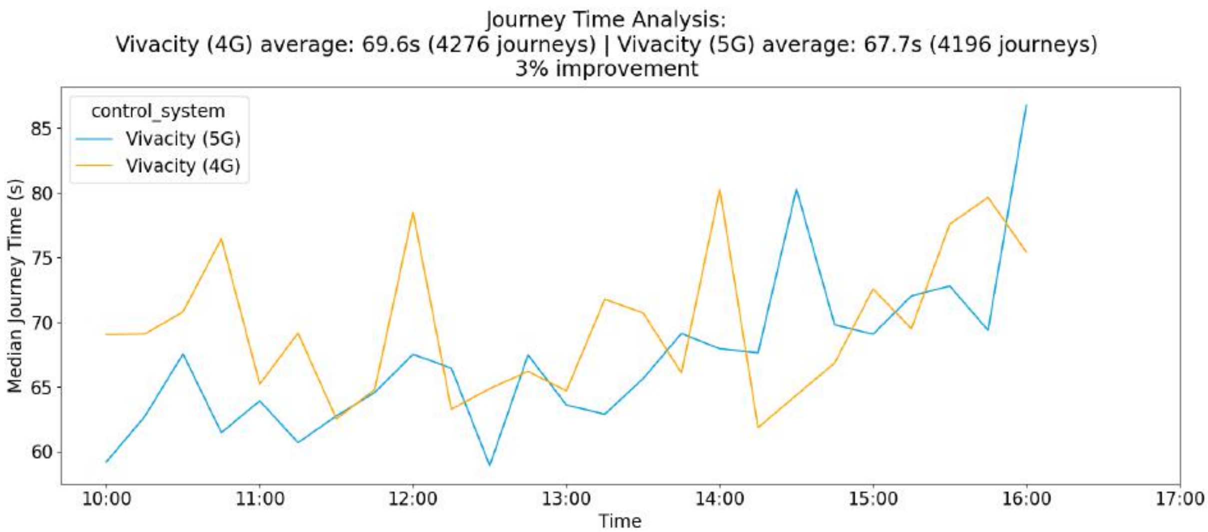

Figure 24: 834 Smart Junction 5G vs. Smart Junction 4G

Journey times through the junction whilst under VivaCity control using 5G comms were 3% less than journey times whilst under VivaCity control using 4G comms. This value was tested at site 834.

Comparison of performance 4G vs. 5G

Latency

Due to the frequent down time of the 5G small cells, it was quite challenging to extract statistically meaningful figures on its latency performance. So the figures and analysis presented here are based on relatively small sample sizes.

There is evidence that, when the 5G small cell is working well, devices which connect to it experience a lower average latency than devices on 4G. The graphs in the Assessment of 5G Comms Performance chapter show a baseline of around 100ms for sensors on 5G (if the somewhat erratic connection behaviour of VP490 is excluded). This is highlighted most clearly on the “zoomed in” plot of 834 during peak time, where the UDP uplink latency histogram has the majority of latency samples below 100ms, and none above 400ms.

Both systems experience spikes in latency during some periods. However, the spikes on the 5G system reduced dramatically over the commissioning period leading up to the control period - as software updates to the 5G core were rolled out and bugs were fixed. Given that the system was still not fully stable, there are promising signs that further improvements could reduce the latency variability further.

Uptime

The uptime of the devices connected via the private 5G small cell is generally much worse than the uptime of the devices connected to the public 4G network. This is demonstrated when comparing the “Proportion of Acceptable Latency” gauges between the plots for junction 834 during the week of control (60.8%) against the equivalent plots for junction 810 (97.2%) and 830 (95%).

The majority of the reduction from 100% for junction 834 is due to the long periods of down-time of the 5G small cell to which the VivaCity devices were attempting to connect during the period of control. These are highlighted in red on the diagram below.

During these periods the VivaCity devices could not connect (or did connect, but were almost immediately disconnected) - and the 5G core had to be manually restarted in order to restore connectivity.

Figure 25: VivaCity Smart Junctions dashboard highlighting connectivity downtime

However, as with the latency analysis - over the commissioning period large improvements were made to the overall stability of the system. Early in the commissioning process, it was not possible to have more than 1 or 2 devices for any length of time. As software and configuration updates were applied and issues were resolved, the stability did generally improve. At the time of the VivaCity Smart Junctions control period, there were still several known issues to be resolved. So there is evidence to suggest that stability could eventually be improved further.

Journey Times

Unfortunately, due to the challenges faced with network integration and stability, the time for testing was heavily impacted. This resulted in a very small subset of data that could be used for comparative journey time analysis between 4G and 5G connectivity and as such caveats the results presented. Due to an insufficient number of UE's supported as required by the smart junction sites on the small cells at junctions 830 and 810, alongside other factors of readiness of the cells, junction control on 5G was only tested at site 834.

Running the various junctions in Manchester under VivaCity Smart Junctions control overall showed positive results of up to 13% improvements in journey times over SCOOT control. This was most apparent on a 4 arm junction that provided more scope for improvement due to its layout and more complicated stage structuring. This also takes into consideration multi-modal aspects of pedestrians and cyclists where the infrastructure for these modes is built into the stage structuring.

Smaller improvements are seen on a smaller dual stream pedestrian crossing site, however the VivaCity system was able to outperform SCOOT during control here. The results also show the impacts of traffic patterns on different days where the peaks in journey time are not always consistent at particular parts of the day.

Furthermore, comparing the journey time results of VivaCity junction control on 4G against 5G at site 834 shows improvements in journey times of 3%. This is attributed to the improved acceptable latency measures, particularly in peak periods, by 5% when the 5G system is more stable. However, this result is caveated by the small number of journeys that have been compared on a fairly simple junction setup. As can be seen from the acceptable latency measurements, on average the performance of the 5G network is worse which we would expect to impact the results of junction control. It is worth noting that this test was undertaken towards the end of this period of testing, when further fixes were introduced and improvements seen. In order to be more conclusive, further days of control should be measured and compared.

Impact of Communication Method When in Control

Given the instability of the 5G system, and the presence of known issues that are to still be resolved, it's challenging to draw robust conclusions on the impact of 5G versus 4G for the VivaCity Smart Junctions control application. In order to provide more insight and draw more conclusive results, a larger data set comparing the same days of the week over a longer duration under 4G and 5G control is required.

When working well, the 5G system provides the VivaCity devices with a lower latency (down to around 100ms or less - which includes the on-device video processing time).

Given that VivaCity devices on a 4G network typically achieve >95% on the KPI of "acceptable latency and uptime", changing to a new 5G cellular network would need to exceed that value to be attractive. The 5G small cell used for this project experienced frequent periods of downtime, which greatly reduced the value of this KPI.

Downtime is worse than high latency, so arguably the KPI overweights the importance of reducing latency to less than 400ms versus just providing any kind of connectivity even if it's a heavily delayed one.

Every time a sensor loses connectivity, the control system must in-fill the missing data with a fail-safe value - which, whilst maintaining the safety of the system, greatly reduces the performance of the control algorithm because the system effectively cannot detect any vehicles or pedestrians.

It is worth noting that WebTag analysis attributes just a 1% journey time improvement to a £45k yearly total road user cost saving at a single junction when also considering further data points gathered around average journey times and number of journeys through the junction. As such, even further small improvements utilising 5G can translate to large cost savings as well as further beneficial environmental impacts.

Therefore, if the 5G system could be relied upon to provide high uptime (approx >95%) to VivaCity devices then the overall performance KPI would make it a very attractive proposition over a public 4G system - at least on a technical level.

Impact and Benefits of Results

The results presented in this report showcase a use case utilising a Private 5G OpenRAN network. These results show the reality of the current developments in Open RAN 5G technologies and the impacts that the current advancements have in the real world on a use case application that requires real time control. It also highlights the impacts that the project hypothesised current technology developments would have within the project timelines, as outlined in the aims and objectives, vs the reality of real world development and testing.

On the other hand, these results highlight the lack of maturity in the current technology for Open Ran 5G to roll this solution out at scale and offer up all of the benefits outlined in the aims and objectives. However, the project was able to show the importance of continued development within the industry in order to accelerate this development and create a production ready system. This also includes the need for larger organisations to take this development on to further improve the technology readiness before being able to further progress with any use case testing. Focussing on the potential use cases that can utilise such a network has been imperative to showcase why such technology can provide added benefits over current solutions to begin building the business case for this development.

The benefits of the results gathered throughout the duration of this project are highlighted below:

Benefits of a cloud based network using a diverse supply chain

A core objective of this project was to deliver a cloud-native network that used software based products from different vendors. This was to reduce deployment and procurement costs and reduce the lock-in of the equipment vendors. Findings in this area are:

1. The project delivered a network that is 70% cheaper compared to a similar deployment using a large vendor.
2. There is a large dependency on the systems integrator to make this work, which increases the complexity of the network delivery and operational work needed
3. 5G is not critical to the deployment of a multi-vendor network, critical components are in fact infrastructure based: good management tool for all network components, innovative cloud design that can be used in the context of OpenRAN
4. This piece of work has been critical to the development of Cell-Stack, before this project we hadn't considered the use of Bare Metal Infrastructure management, which now is central to the orchestration platform

Benefits of 5G to traffic Signal control

1. Reduction in upfront costs of deploying a Smart Junction by moving systems to the cloud due to improved connectivity resulting in a 48% reduction in controller hardware costs This statement is also true for any reliable wireless connection and so it is plausible a private 4G connection would have the same benefit, and as such not entirely 5G reliant.
2. Removal of costs associated with pulling ethernet to all sensors and reduction in deployment lead times
3. £1200 yearly data saving cost per site with a Local Authority owning and managing the network
4. Journey time reduction of 6% over incumbent and 3% over 4G
5. Lower average latency, particularly during peak periods, has the potential to improve overall performance, reducing waiting time at junctions (although this relies on overall improved reliability of the connection)

Benefits towards Smart Junctions Product Resilience

1. Creating a single network performance KPI that accounts for both latency and uptime is extremely valuable for rapid understanding of connectivity resilience.
2. Adapting the control system to deal with frequent downtime when using the nascent 5G cellular system has driven further development within the VivaCity Smart Junctions system in the areas of:
    a. Data fallbacks
    b. Fail-safe system design
    c. AI control system training under imperfect data conditions.

Benefits of a business case for 5G

A large component of this project has been to develop a business case for the public sector to invest in telecoms infrastructure. Working on an integrated 5G strategy has benefited the project in multiple areas:

1. Increase awareness of the need for adopting technology from a public sector perspective. Cities are required to implement an integrated model that addresses cross-sector infrastructure strategy and gives the public sector more control and power to drive long-term strategic goals. This includes the benefits of use case stacking.
2. Development of work of the project with GMCA which has fed into the Advanced Wireless Program.

The impact this has generated in the consortium has been:

1. Both SMEs, Weaver Labs and VivaCity to develop processes with regards to 5G strategy internally that can benefit our commercial processes when working with other local authorities
2. Weaver Labs has fine tuned the Network as a Service model with public sector, including areas like passive assets which are of interest for this market

Challenges and Lessons Learned

Building a cloud base network with OpenRAN

1. OpenRAN components cannot be virtualised, which makes it more difficult to create management interfaces for the infrastructure. We developed bare metal tools to overcome this in the orchestration layer, and successfully deliver an edge-cloud based network.
2. Delivering a 5G private network using more than 1 equipment/software vendor presents challenges on:
    a. Task demarcation: as a customer it's difficult to understand who delivers what, and sometimes the supplier has similar questions with regards to integration, support and delivery
    b. Communication challenges: as a customer we must be on top of all communications across the entire supply chain, we can do that because we have domain expertise, but is a clear limiting aspect of 5G moving forward. It's still too complicated compared to other telecoms technologies, i.e., WiFi
    c. Alignment of all stakeholders to deliver a single product

3. Availability of backhaul limiting the design and the timeline of delivery. As TfGM responsibility within the project to provide the backhaul, with initial project design to utilise the GM LFFN. Due to the change to the delivery timeframe of the LFFN programme, utilising this backhaul wasn't possible. This raised key challenges in regards to what equipment to implement as part of the 5G component of the project:
    a. Network providers high charges to deliver fibre to the cabinets
    b. High charges to deliver a mmWave network for backhaul
4. Readiness of the 5G software stack. The technology is still not mature enough for a production ready system that can be rolled out at scale. Contractual agreement of a software under development, not yet ready for general release, resulting in items missed to deliver a product based on the minimum requirements of the project, requiring additional funding to cover:
    a. Extra support was requested to deliver basic systems integration
    b. The project has finished, the licenses have expired and we still don't have a functioning network

Procurement and deployment of assets

Deploying infrastructure using existing assets, such as publicly owned street furniture or ducting raises difficulties because of the lack of consistent information. It was very time consuming to collect all the information required to deliver the network using the existing assets on the street. Specific challenges around:

1. Street cabinets:
    a. No single repository of information about the existing occupancy of the cabinets, sizes, power, temperature control
    b. Costly surveys from third party companies to consolidate information and draw CAD diagrams
    c. Third party companies maintaining street cabinets control information flow and delay obtaining information in a timely manner
2. Ducting:
    a. No consolidated information about public/privately owned ducting that can be used to interconnect the cabinets
    b. Difficult to access information about Openreach existing ducting
3. Traffic Signal Poles: -
    a. Third party company managing extension poles delayed the timeline to survey the structural requirements and obtain permission for radios to be placed in the traffic signals

Long procurement processes resulted in a knock on effect across multiple work packages, delaying the deployment significantly. Furthermore, timelines have been difficult to predict and delays have been evident in installing the network backhaul. This has had knock on effects for deployment of other aspects such as installing cabinets and deploying the AI algorithm to control the junctions. In order to improve and mitigate against these risks, automation and streamlining of processes is required.

It was also evident that utilising existing street assets to deploy any infrastructure posed the following challenges during the installation phase:

1. Installing Smart Junctions and 5G radio equipment within existing traffic signal controller cabinets - it was established that in most cases the controller cabinets were overcrowded with existing equipment and new cabinets would be required to house SJ5G equipment.
2. Installing 5G radio equipment of existing traffic signal poles - this presented some difficulties with existing signal equipment being mounted on the signal poles. Also the size and weight of the radio units did create some concern. Design of brackets and ensuring wind load calculations compiled with regulations ensured that installation could still be completed safely.
3. Installation locations on signal assets located in busy, congested, city areas, causing issues with speed of maintenance. In-ability to quickly perform maintenance in a location that has a high footfall and congestion which links assets together through underground ducting across the road space. Where the asset needs to be accessed at height and is located in a difficult to reach location with the sole use of a ladder, causes issues with speed of maintenance and debugging causing longer downtimes.
4. Lack of skill set in the public sector to be able to deploy and maintain network hardware on the street using assets such as traffic signal poles and roadside cabinets, including fibre connections. Lack of skill sets within the Local authority team and public sector maintenance contractors to install and maintain more complex network hardware systems required of a private open RAN 5G network. This led to lots of wasted time and effort to successfully install and commission the network hardware as well as difficulties in troubleshooting issues end to end in order to pinpoint problems and allocate the correct resource.

5G Integration challenges for Smart Junction Control

There were numerous delays to the original project timelines, leading to an extended project end date, and reduced scope from the original aims.

The 5G small cells were first brought online in May 2022 - leaving only a few weeks to fully commission them before attempting to deploy VivaCity's Smart Junctions control system using the new 5G network.

The 5G cells required significant commissioning, testing and debugging in order for the VivaCity devices to connect, remain connected for extended periods, and achieve reasonable bandwidth and latency.

In order to validate the functionality of the 5G system during this period, VivaCity devices were required to be switched over from 4G to 5G. This meant that they were unavailable for Smart Junctions control purposes during this phase - which significantly reduced the time available for running the Smart Junctions control system.

- The scope of the 5G control deployment was reduced down to a single junction, whose local 5G cell was prioritised during the bring-up
- This was chosen based on the readiness of the cells, which in turn was based on the readiness of the fibre backhaul - which was also severely delayed.
- Unfortunately this meant that the only junction that was available for a 5G test deployment of the Smart Junction was junction 834 - which is a relatively simple set of pedestrian crossings. This left very little scope for optimisation or exploring the potential of the improvements that a well-functioning 5G system could provide.

1. Installing brand new comms backhaul to remote sites is logistically challenging and knock-on delays to other deliverables should not be underestimated.
2. The core technology stack for private 5G small cells is still nascent, and cannot yet function as an off-the-shelf drop-in replacement for a public 4G cell network.
3. It was a good decision to provide the VivaCity devices with both a 4G connection and a 5G connection - not only as a means of comparison, but also so that the devices could still be accessed remotely when the 5G connectivity was not functioning. However, managing these multiple network connections and custom routing of traffic across dozens of remote devices is labour-intensive.
4. The instability of the 5G system during the commissioning phase made it very challenging to both complete the baseline control period under 4G, and also provide sufficient time to stress test the 5G system using the same VivaCity devices.
5. The 5G system underwent numerous and frequent updates and configuration changes. This was both difficult to keep track of (especially given the large number of suppliers and subcontractors), but also makes it very challenging to interrogate historical performance data for the system, when the system itself is constantly undergoing changes.
6. When data does not flow seamlessly across a network, diagnosing the exact location of the fault is challenging - especially when a core part of the backhaul is novel, and administered by several other parties.

In order to address the above challenges, with the benefit of hindsight several approaches could be taken:

1. Provide the administrators and developers of the 5G cell system with samples of the intended user equipment as soon as possible for testing (ie: the same 5G routers that the VivaCity devices were using).
2. Focus on a smaller rollout of devices and number of small cells - to achieve acceptable quality of service prior to scaling to a whole region. Ie: complete a much geographically smaller pilot project to build system resilience first. This ultimately comes down to further development required for the 5G network to successfully operate as a production system and further time required for bench testing prior to rolling out tests in the real world.

Delivering a cybersecurity strategy

1. The approach to cybersecurity in these types of projects should expand beyond the security technical architecture and include organisational postures. When drafting the project and thinking about the best way to approach cybersecurity in the project, Weaver Labs proposed to work on the security technical architecture, adding a strong cryptographic layer on top. When going through the initial research on how to map the necessary cybersecurity policies with the technical requirements and resulting technical design, the team quickly realised there was a great challenge to translate the cybersecurity design principles into specific policies which were correctly mapped to the NCSC Zero Trust posture.
2. Challenges in aggregating multiple standards bodies policy pools and the Telecom Security Requirements in Cybersecurity Framework. Despite the benefits of the unification of underlying policy pools using the score-card methodology, to include the TSRs into the developed framework we had to closely examine the relationship between the TSRs and the NIST 5 Core Functions. As we mapped the TSRs principles and requirements to the NIST 5 Core Functions, we attempted to be as objective as possible and maintain the grouping and consistency of the TSRs. Integrated policy pools should remain backwards compatible once they are included in the larger set of policy pools. This is something that should be taken into consideration when further developing security requirements, as most of the cybersecurity frameworks and principles will follow the NIST 5 Core Functions

Security Learnings

The main learnings on cybersecurity are around the challenges identified to start developing strategies around certain standards. To overcome this challenge, Weaver Labs created an organisational risk assessment/analysis tool, that can address the gap between the existing policies and providing a means to any organisation to adopt a posture relevant to their business scope. The result of this work is a tool that consists of:

1. A unified view of cyber policies and risks.
2. Selection sheet containing NIST Core functions for an organisation
3. It automates the selection of organisation policies
4. Allows the benchmarking of current and desired posture
5. It outputs a Current Profile, Future Profile, Gap analysis and an action plan

The creation of this tool has provided an initial piece of work that can lead into the creation of a product that can serve as a risk assessment tool for a diverse supply chain.

Conclusion

There is still further development required within open RAN 5G networks in order to achieve the goals set out. In its current state, the network is too unreliable to run a use case successfully, particularly one in real time. The main reasons for this was due to downtime of the network requiring manual intervention to reboot different components of the network throughout the day when things sporadically went offline. Furthermore, there is currently an insufficient number of UE's that can be supported by a single cell, a maximum of 8, that would allow the network to be rolled out into a fully productionised system that can be utilised for use case stacking. The number currently supported does not cover a sufficient number of sensors for a single smart junction site in some instances.

However, some of the results showed promise for the network to achieve its goals given further development. In periods of stability, as shown during some peak periods of control, the network was able to achieve acceptable latency measurements greater than a 4G network. These peak periods in particular are of importance to real time traffic control where the 4G network usually falls over due to higher traffic.

In order to build the business case for a private 5G Open Ran network, further development is required to achieve uptime close to the 99.9% set out in the original target. Alongside this the latency and latency variability need to be reduced closer to the targeted 50ms value in order for more consistent results over a full day. The number of attachable devices requires a significant increase to be able to support not only one use case, but many, without any negative effects of scaling. If this can be achieved, and easily replicated from site to site, this creates a much more scalable and attractive solution.

Coming back to this particular use case, the perception around latency and reliability changed as the project went on. Initially latency was headlined as the important metric for Smart Junctions control, however, it became apparent through testing that the reliability and consistency of the network were the most important factors. Due to the small amount of data being transmitted through the network, a similar improvement could theoretically be achieved using any private network and does not necessarily require 5G. Such a solution is more readily available and as such could be rolled out faster at scale, and at a reduced cost.

However, a private 5G network presents a more appealing solution for a local authority to future-proof their network for use with public authority use cases alongside a potential revenue stream from the private sector. The costs associated with an Open Ran solution create a compelling business case over a single vendor approach and present a much greater opportunity to gain from a revenue stream, particularly at scale. A private 5G solution of this approach and once fully developed and productionised, offers a huge potential for use case stacking to run critical systems that require real time and big data streams. This is particularly critical for sectors such as healthcare, logistics and transport. It also presents an opportunity for the public sector to reduce their ongoing costs for data provision whilst improving the overall security of their network.

Further Use Case Development

In order to develop the business case for further private 5G rollout, the opportunities and potential for investment needs to be realised. This includes use case stacking and developments that show indications of a shift in the telecoms market to realise the opportunities.

For this to be realised, comms stability is critical in order to present a solid opportunity for use cases to utilise a portion of the network availability. In order for this to be realised, further conversations will help to advance the adoption of this testbed into other areas of the city, taking healthcare as an example and building on the testbed in Liverpool.

Due to its close proximity to the corridor, Salford University presents a good opportunity to initially explore further use cases and as such conversations have been underway throughout the duration of the project. These use cases are likely not revenue generating but will aid to provide further testing of the network's capability. Conversations with Salford so far have resulted in interest to provide backhaul connectivity to social workers and housing in areas of deprivation as well exploring opportunities within their robotics and automation faculty, telecommunications and Connected vehicles.

Throughout the project we have showcased the ‘connected corridor’ to DfT who are keen to see how the transport use case can be expanded on. Smart Junctions offers a real step change in traffic signal optimisation and the opportunity for data driven control. Looking at how we use new and emerging technologies, data and connectivity when considering the way roads are designed, built, managed and used offers up real opportunities to scale up SJ5G.

TfGM is looking at how it can build into its Bus Service Improvement Plan and Quality Bus Corridors to ensure the benefits of bus priority can be maxmised. Opportunities with Active Travel also exist to target cycle priority.

Also with the DfT's Connected Vehicle Data Research Project there is a focus on connected services to improve customer information and efficiency of operations. SJ5G and the 'connected corridor' present an opportunity to provide a communication network between vehicles, user devices, and transport infrastructure which will allow TfGM traffic management systems to provide a better, more seamless user experience, operating more efficiently with access to better data, and less reliance on physical infrastructure.

Next Steps and Suggestions for Future Deployments

The project consortium plans to continue development of both the Smart Junctions solution as well as working to create a productised 5G network that can be easily deployed at scale. Part of this ongoing work includes further building of the Business Case for both Smart Junctions and future 5G rollouts. Details of the next steps can be found below:

- Further real-world testing of VivaCity Reinforcement learning junction control within Manchetser, including further refinement of the algorithm and tools to productionise the system.
- 6 months of controlled testing of the network with dedicated devices where we can monitor and control the network as well as troubleshoot any operational issue
- Migration, testing and monitoring of a small subset of the sensors into the 5G OpenRAN network with further migration pending results of this testing
- Prepare the network for multiple use cases to be onboarded during Q1/Q2 2023
- Further building of a business case for both Smart Junctions and a local authority owned private OpenRAN 5G network to promote further rollout
- Based on evidence of Smart Junction benefits, further build the business case for future deployment.
- Incorporate deployment within TfGM strategy and Intelligent Transport Systems Road Map.

In order to realise these next steps, there is a requirement to alter the perception of funding models to increase scope towards ongoing operational costs to allow for ongoing updates, support and maintenance. This is imperative to create an adaptable and future-proofed network and traffic control solution that changes with the world around it.