Final Report

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1 Industrial Report

In this program, I had the privilege of contributing as a research partner in a collaboration between IP Tel Solution, an international logistics distributor, and Innovation Central Canberra (ICC). Our client, one of the world's largest supply chain providers, offers an end-to-end supply chain through a network of terminals across 60 countries, spanning all six continents. They provide global transportation services via rail, air, and sea, with a strong presence in Australia supported by ports in major cities. Renowned for services like direct shipments, contract logistics, port and terminal operations, and marine services, the company emphasises technology-driven solutions and sustainable principles. Its goal is to deliver affordable logistics while minimising environmental impact and mitigating climate change, aiming for zero carbon emissions within the next 25 years. The company is committed to strategic international distribution and expanding into next-generation, sustainable mechanisms. To achieve this, they employ strategies such as reducing diesel use, exploring low-carbon technologies, maximising renewable energy, producing low-carbon fuels, and implementing carbon offset methods. These efforts align with the mission of IP Tel and ICC to provide innovative technical solutions that turn challenges into opportunities for profitable and sustainable business growth.

IP Tel Solutions is a well-established provider of network system solutions for businesses of various sizes. They offer comprehensive designs incorporating technologies from Cisco, Aruba, and Meraki, supporting both wired and wireless networks. As a market leader, IP Tel specializes in Enterprise LAN, Wireless LAN, Cisco system design and implementation, and automated network configuration.

ICC is an innovative organisation within the University of Canberra, and was formed through a partnership with Cisco. It focuses on delivering advanced solutions to industries undergoing rapid technological and business changes. This initiative involves students and academics from diverse backgrounds, providing them with valuable hands-on experience in real-world projects. ICC's collaborative spaces are located in universities across Australia to address industry challenges in sectors such as health, education, private business, and government.

To achieve a sustainable operational system, the first step is to develop automated port services, which will initiate the reduction of fuel consumption at operational sites. Strengthening network connections across these sites is essential for this automation. Consequently, our client established a partnership with IP Tel for consultation, resulting in the creation of an initial process system that provides dual connectivity through private 5G technology and fast Wi-Fi roaming, as shown in Figure 1. The objective is to maintain a reliable network connection that consistently links critical infrastructure deployed on-site to the nearby data centre or control room.

2 Learning Outcomes

Through this internship, I was able to achieve the following learning outcomes:

2.1 Professional Application of Knowledge

I applied some of the knowledge I gained during my studies. I used concepts from the Unit, such as:

- Workflow and Process Management provides guidance on implementing Kanban and managing all tasks and processes throughout the project.
- Technology Engineering Management provides guidance on how to lead the project.
- Information Research and Methodology involves conducting a literature review of all devices deployed in the project.
- Engineering Work Experience offers guidance on how to conduct the project in a professional environment.
- Internet of Things helps in understanding how edge computing devices can create a robust and integrated network in critical infrastructure sites.
- Network Architecture develops an understanding of the conceptual design of the deployed network devices.
- Introduction to Network Engineering serves as the fundamental principle for configuring network devices.

2.2 Professional Skill Development

I gained a deeper understanding of the project development lifecycle. I was introduced to tools such as:

- Kanban for managing boards.
- Microsoft SharePoint and Google Drive serve as a professional platform to share my findings.
- Webex and Microsoft Teams for conducting professional meetings.

In addition to the project assistance tools mentioned above, I was able to develop my technical skills. I provided a literature review on some of the hardware and software involved in this program. This introduced me to various Cisco hardware devices, such as:

- Cisco Catalyst IR1835.
- Cisco Catalyst IW9165.
- Cisco Catalyst 9800.
- Cisco Air 3802i–z–k9.
- Cisco catalyst 8000v.

I also learned to perform initial configuration, understand system architecture, licensing, and configuration. I also performed virtual deployment, such as the Cisco 9800 and Cisco 8000v, which are deployed virtually in our dedicated desktop computer and Azure cloud environment.

2.3 Networking and Mentorship

This project has also given me the opportunity to connect with people from various professional fields. I worked directly with other Network Engineers from IP Tel Solutions, who shared their insights and knowledge on how to approach this project and the technical skills needed to build the network setup. I built connections with well-known Cisco engineers, whom I often seek for technical advice. They shared their experience on tackling challenges I encountered and how these relate to similar projects they have completed. I also collaborated with our academic partners from UC and ICC to provide suitable solutions to the project's requirements. They demonstrated how to manage and guide the project from the initial planning stages through to the complete setup. I was also actively involved in weekly progress meetings with IP Tel and our academic partners. During these meetings, I presented my findings, discussed the necessary hardware and software for the project, provided reports on additional costs, and identified challenges along with estimates of how long it might take to resolve them. In general, I am confident that this project has offered me valuable professional insight into a real-world initiative that could potentially benefit our industrial partner by maximising their business profits.

2.4 Workplace Culture and Expectation

I also gained practical experience that significantly improved my communication skills. It also enhanced my productivity, as I am committed to making quick yet thoughtful decisions to tackle some of the project's challenges. During this decision-making process, I was motivated to collaborate professionally with other academics to foster a high-performance work culture. Additionally, this work environment has laid the groundwork for other vital aspects, such as maintaining a professional attitude in meetings and reporting, proper documentation, and transparency, all of which are essential. I also learned to be accountable for the results I delivered and the issues I raised, as well as to be flexible and adaptable when required.

2.5 Career Exploration and Refinement

This internship has also sparked my interest in exploring real-world applications that are profitable for industrial sectors. I was motivated to focus my career interests on technology-related areas, such as public and private 5G deployment, edge computing, network automation, and sustainability solutions in industrial sites. In short, this program could offer an opportunity to pursue a career in industrial network systems, sustainable solutions for the industrial sector, and technical consulting and innovation management.

2.6 Increase Self-Confident

I was able to develop my confidence to be presentable during a technical meeting, in which I was able to perform:

- Providing professional recommendations in technical discussions.
- Providing reliability and assurance when describing a technical concept.
- Self-reliance during the implementation of academic theory when tackling a specific issue.
- The self believes in providing valuable insights and contributing to the project team.

Overall, this internship has given me confidence that my contributions are valuable and useful in real-world projects and issues, potentially leading to profitable business outcomes.

2.7 Enhanced Employability

I am confident that this program is beneficial for career opportunities. It significantly improves my technical network engineering skills, which I can showcase through my professional portfolio and resume. I was directly involved in a 16 week real-life project, where the deliverables will be used in an actual industrial environment and for broader research opportunities. I believe that I am at least qualified for the next challenge and job opportunity based on some of the things I have done throughout this project, such as:

- Hands-on experience in real-world study cases and real network setups covers the latest Cisco technology.
- Documentation and reporting according to the industry standard.
- Gaining experience in actual project management, where I defined some required technical tasks under time constraints.
- Demonstrate the ability to present findings and results in a professional environment.

These general results are shaping my academic skills to a professional level that I can present in job applications and interviews.

2.8 Reflection and Self-awareness

However, despite all the positive results that I have gained from this program, I also reflect on some aspects that I need to improve, such as the following.

- Research in the broader network engineering field, staying up-to-date on the latest network innovations, exploring related case studies that yield similar results, and enhancing my technical skills using various online resources.
- I also reflect on how important the work environment is, as it plays a crucial role in determining the project's outcome.
- I was also able to reflect on how I respond professionally by acting under pressure, ambiguity, and feedback.

As a result, this project has improved my self-awareness in a team role and demonstrated how responsibility and determination are vital despite ongoing challenges. I also became more proactive in approaching tasks and taking the initiative to provide updates and findings on the project's progress.

2.9 Project Management Skills

This program also improves my management skills, enabling me to contribute effectively to the technical deployment. For this, I used some of the following tools.

- Using a Kanban board to add, manage, modify, update, prioritise, and track task progress.
- Coordinating meetings via Outlook and running a professional schedule using Outlook calendar search to book appointments according to other academic' schedules.

- Reporting and updating progress according to requirements and formatting professionally.

In general, it has helped me manage project development, understand milestones, carefully allocate helpful resources, and complete tasks on time alongside other priorities outside of the project.

2.10 Technical Skills Development

Key takeaways from my internship include developing valuable technical skills, working with widely-used Cisco devices across various industries, and gaining insights into key technical aspects.

- Successfully learned and configured all Cisco devices involved in this project.
- Completed a genuine network deployment using these devices in both WAN and LAN configurations.
- Able to troubleshoot wired and wireless connections.
- Understand the different modes in which the devices operate, such as Work Group Bridge (WGB), Universal Work Group Bridge (uWGB), Control and Provision Wireless Access Point (CAPWAP), Flex Connect, Bridge, Flex Mobility Express, Autonomous, and Control-Managed.
- study the system architecture of the Cisco operating system, such as IOS XE.
- The importance of the ISO layer was taken into account, especially layer two and layer three connections.
- Understand the type and model of Cisco devices and their designated regions in which they can be operated.
- Set up virtual deployment using VMware Workstation Pro to host Cisco devices.
- The interfaces of wireless connections were investigated, including 4G, 5G, and understanding the range over which these signals operate and the use of Access Point Name (APN) for cellular connections.
- Use and implement a variety of protocols such as SSH, HTTP/S, DHCP, TLS, DTLS, FTP, TCP, UDP, and ICMP.
- Measurement of signal strength using tools such as Ping and Iperf3.
- Server deployment using the Linux operating system.
- Cloud deployment of Cat8k on Azure.
- Understanding network security involves using firewalls, secure tunnels such as IPsec, VPN, and possibly deploying SD-WAN.
- Able to professionally provide documentation of network topologies, analysis, and architecture.

In general, this project provides a practical overview of industrial technologies, including edge computing, industrial networking systems, and an introduction to remote management through SD-WAN functionality.

3 Task Undertaken

Our industrial partner is actively seeking innovative solutions to enhance network connections within critical infrastructure, thereby improving security, reliability, and privacy. This initiative is driven by the rapid expansion of the global economy, which has increased demand for robust, end-to-end supply chain solutions across various sectors. Consequently, our industrial partners have approached IP Tel and ICC to verify this transformation and collaborate on developing a comprehensive testbed environment. As a result, key hardware used in this testbed was fully funded through this partnership. This testbed will serve as a platform for building and testing similar network connections, ensuring the successful realisation of this transformation and supporting the evolving needs of critical infrastructure.

3.1 Task and Responsibilities

The initial plan was to establish two separate connections: one via private 5G and another using a high-speed Wi-Fi roaming connection, employing Cisco Catalyst Industrial Wireless 9165. These connections would be supported by an edge device, specifically a Cisco Catalyst Industrial Router 1835, connecting to a dummy server that could be deployed either locally on-site or in a cloud environment. To start this project, a simple initiation task was outlined, detailing the necessary steps and responsibilities involved in establishing this system as part of the core duties. Some of these responsibilities are listed below.

- Carrying out literature review and technical evaluation of Key Cisco Devices used in this project. This inludes:
  - Ensuring that all funded hardware is listed and present.
  - Verifying that there are no faults in each item.
  - Providing hardware descriptions and functionalities.
  - Analysing the key components, such as the IR1835's 5G/4G/Wi-Fi modem, the LAN and WAN port, storage capacity, power adapter, power options, system architecture of IOS XE, a Suitable working mode for IW9165 AP bridge, Configuration option via console port, web interface, or SSH. For more information on equipment used in this project, see 3.3.2.
- Performing the initial configuration and network setup to mimic the same network connection intended for this project, such as shown in Figure 2. To achieve this task, the following are required:

  Local Deployment

  Cisco AIR AP 3802i - Z - K9

  - Ensuring that Cisco AP 3802i is the regulated device in the Australian and New Zealand region, as indicated by the Z in the device model. More details of AIR AP can be seen in 3.3.2.
  - Powering the AIR AP with an Ethernet cable RJ45 - 8 pin as in Figure 11, by connecting directly to the green Ethernet socket for accessing the testbed LAN.
  - Using a USB-RJ45 console cable in Figure 12 to access the CLI of the AP.
  - Ensuring that AP is operated in Control and Provisioning Wireless Access Point or CAPWAP mode. In this mode, the AP will automatically search for a nearby wireless LAN controller (Cisco Catalyst 9800v WLC) within the subnet. AP deployment can be seen in Figure 3.

Desktop Computer

- Setting up a dedicated desktop computer in the testbed environment such as shown in Figure 25.
- Connecting the computer to the LAN network of the testbed environment via an RJ45 Ethernet cable.
- Downloading and installing Putty. If it is not installed.
- Downloading and installing the VCP driver to enable Putty to access the console port.
- Downloading and installing VMware Workstation Pro.
- Downloading the OVA file of Cisco v9800 WLC.
- Running the file in VMware Workstation Pro to create a virtual 9800 wireless LAN controller.
- Performing day 0 configuration, such as setting the username, password, enable password, static IP (in the same subnet as the testbed LAN), and the IP routing
- Configuring v9800 wlc to be connected with Cisco AIR 3802i (If v9800 wlc is deployed in the same subnet as AIR AP 3802i then AIR AP will automatically assign to v9800 wlc via CAPWAP mode)
- Creating WAN profile. This includes: onboarding AIR AP 3802i.
- Accessing the Web UI of v9800 WLC through the configured static AP and confirming that the AIR AP is registered in the WAN dashboard.
- Creating the AIR AP profile (This can be done via CLI on a desktop computer or in the WEB UI)
- Through the WAN dashboard in the WEB UI, define the SSID name and SSID key to enable the AIR AP to provide Wi-Fi coverage around the testbed environment, which will be used as the parent AP for IW9165 that bridges traffic from IR1835.

Cisco IR1835 Router

- Performing initial installation for the IR1835, such as powering the router with a power adapter, since the router is not directly deployed in a fleet vehicle as intended with the OBD2 cable for CANBUS plus power combo. Information about OBD2 - CANBUS can be seen in 3.3.2.
- Installing an Appropriate SIM card for the 5G modem. In this case, we utilise a Telstra SIM as the Cisco-supported cellular service within the Australian region. Installing guide and modem details can be seen in 3.3.2. *(NOTE: Current private 5G deployments are in progress; therefore, the validation process is carried out by employing a public mobile operator)*
- Installing 9 in 1 Antenna for IR1835 Router as shown in Figure 3. More information about the antenna overview and installation guide can be seen in 3.3.2.
- Accessing router CLI via console port with USB-micro B console cable while using Putty in Windows OS or Minicom in Ubuntu Linux OS, with 9600 baud rate for IR1835.

- Performing the day 0 deployment or initial configuration, such as verifying the right IOS XE version, configuring username, password, and web interface management details.
- Configuring layer 3 GigabitEthernet 0/0/0 interface, to receive an IP address from our LAN DHCP server.
- Configuring cellular interface 0/5/0 to receive an IP address through Telstra Access Point Name(APN) to maintain a direct cellular connection as shown in Figure 6.
- Configuring the IP routing for Router IR1835 so that the layer three interface can direct traffic into the internet through the GigabitEthernet 0/0/0.

Cisco IW9165 Access Point

- Conducting initial installation of the access point by removing the antenna cover used for Wi-Fi transmission.
- Powering up the access point with an Ethernet Cable 8-pin RJ45 that is connected directly to the Wired 0 interface, which functions as Power over Ethernet (PoE). This is also reflected in the requirements, where the access point will be powered from IR1835's LAN port, indicating these two devices are on the same platform, and IW9165 is in WGB mode.
- Connecting GigabitEthernet 0/0/0 of IR1835 to wired 1 of IW9165 via an 8 pin Ethernet Cable RJ45
- Accessing the CLI of the access point via USB-RJ45 console cable through the Ethernet console port.
- Performing day 0 configuration, such as checking the right IOS XE version of the AP, setting the username, password, enable password.
- Checking the right software image that runs in the AP, ensuring that the AP runs the Unified Industrial Wireless (UIW) image, which supports the intended AP mode use in this setup, WGB/uWGB.
- Setting the static IP to be an unroutable IP address. For example, if the DHCP pool of the LAN is 10.0.0.* Then the unrouteable IP is set to 10.10.1.1.
- Disabling the Wi-Fi 6/IEEE.802x, and just enable Wi-Fi 5/IEEE.802ac. *NOTE: The WGB is only working with the 5 GHz Wi-Fi band and not the 2.5 GHz band. Also, the AIR AP 3802i does not support Wi-Fi 6.*
- Creating the SSID profile. This includes defining the SSID profile name, assigning this profile to the SSID name of AIR AP 3802i, including the SSID key, and defining the authentication type used in the AIR AP 3802i SSID.
- Configuring the AP mode into Work Group Bridge by assigning the SSID profile to one of the three Wi-Fi antennas of IW9165 AP to establish a Wi-Fi bridge connection between AIR AP and IW9165 AP. The WGB configuration can be seen in Figure 5.
- Ensuring that the bridge connections are established between the two APs. To confirm this, check the CLI message on IW9165 or through the WAN dashboard of v9800 wlc that shows a client with GigabitEthernet 0/0/0 MAC address has been registered. *NOTE: If the connection is established correctly, then the interface GigabitEthernet 0/0/0 will receive an IP address from*

the testbed LAN DHCP server as presented in Figure 7.

Cloud Deployment

Azure Cloud

- Creating an Azure account with the staff ID to obtain the $300 credit.
- Using the credit to obtain the Cisco Catalyst 8000v from the Azure Marketplace.
- Performing initial installation by deploying the Cat8k in Azure and selecting the appropriate subscription method, which in this case, uses a pay-as-you-go (PAYG) subscription, from which the $300 credit is deducted.

Cisco Catayst 8000v

- Performing the initial configuration, such as setting up the virtual device name, key management, enabling public IP address, enabling SSH protocol for remote access, defining other protocols used, defining device storage and capacity, defining the size of the Network Interface Card needed (by default, two NICs are automatically assigned to the virtual Cat8k), and creatting the username, password, and enable password.
- Accessing the console port through Azure or SSH with remote access to check the current image version that is running. NOTE: For this project, the SD-WAN license is in progress to be finalised; hence, it is currently running in autonomous mode. To enable SD-WAN capability, the Cat8k needs to be configured in Controll-managed mode.
- Ensuring that Gigabit-Ethernet 1 is receiving an IP address from Azure DHCP by default. NOTE: This local IP is directly translated in Azure Network Address Translation (NAT) to receive outside traffic via a public IP.
- Creating a different subnet that faces inside the Cat8k by defining a static route to the Gigabit-Ethernet 2. This is where the dummy server will be deployed.

Ubuntu Linux

- Deploying a virtual Linux OS in the cloud, ensuring that the capacity is within the appropriate cost for the $300 credit.
- Performing the initial configuration, such as defining device name, management key, protocols, and public IP address.
- Defining the network interface by giving the static IP to the device, and it needs to be in the same IP pool as GigabitEthernet 2 of Cat8k.
- Defining the IP route for the virtual machine where the last resort of the traffic is the GigabitEthernet 2 as its gateway.
- Ensuring the connection has been established by pinging the gateway from the server and vice versa.

NOTE: The Cat8k is reachable from outside traffic; however, it can not pass the traffic to see the content that is deployed in the Linux server behind it. Therefore, an additional Linux virtual machine *is deployed outside the above-configured subnet for temporary testing.*

  - Deploying another Ubuntu Linux with minimal storage that fits with $300 credit.
  - Allowing the server to receive a public IP address
  - Configuring device name, management key, SSH protocol for remote access, and defining the required protocol.
  - Ensuring the connection is established by SSH into the device from the local machine.

  If the deployment is correct, there will be three virtual machines deployed as shown in Figure 4.

- Testing the connection of the testbed network, ensuring that the end device IR1835 can reach the stand alone server deployed in Azure.
- Documenting, updating, and reporting each milestone as the project progresses through weekly meetings.

3.2 Tools and Application Utilised

- VMware Workstation Pro. It was used as the host for some of the virtual images that are essential for this project.
- Microsoft Teams and Webex for a professional meeting and chat platform.
- Microsoft Outlook for emailing and scheduling.
- Microsoft SharePoint and Google Drive for a file sharing, version control, and storage platform.
- Microsoft Visio to draw and illustrate the network topology and to carry out system models.
- Kanban via Azure DevOps to display project management, task initiation, and track workflow.
- Virtual Cisco Catalyst 9800. It was used as a replacement for the actual Cisco 9800. It functions as a wireless LAN controller to manage lightweight Cisco APs, such as Cisco AIR AP 3802i, that was used in this setup. This was achieved by obtaining the OVA file from the official Cisco website, and the deployment was made on VMware Workstation Pro.
- Virtual Cisco Catalyst 8000. This was used to provide SD-WAN capability, which will be deployed in the next phase of this project.
- Virtual Ubuntu Linux for a dummy server, to which data is sent.
- Azure cloud environment to host both Catalyst 8000v and the dummy server.
- Putty for Windows OS and Minicom for Ubuntu Linux were utilized to gain access to Cinco devices' command line interface (CLI) via the console cable.

3.3 Data, Research Materials, and Work Outputs

3.3.1 Data

Figure 1: Sytem Approach

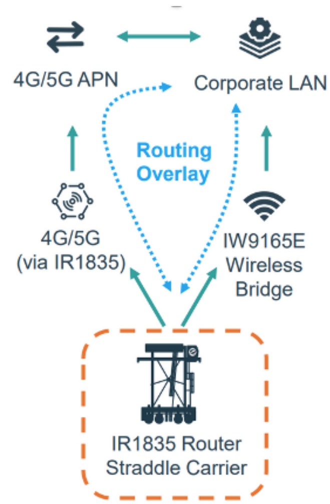


Figure 2: Testbed Implementation Network

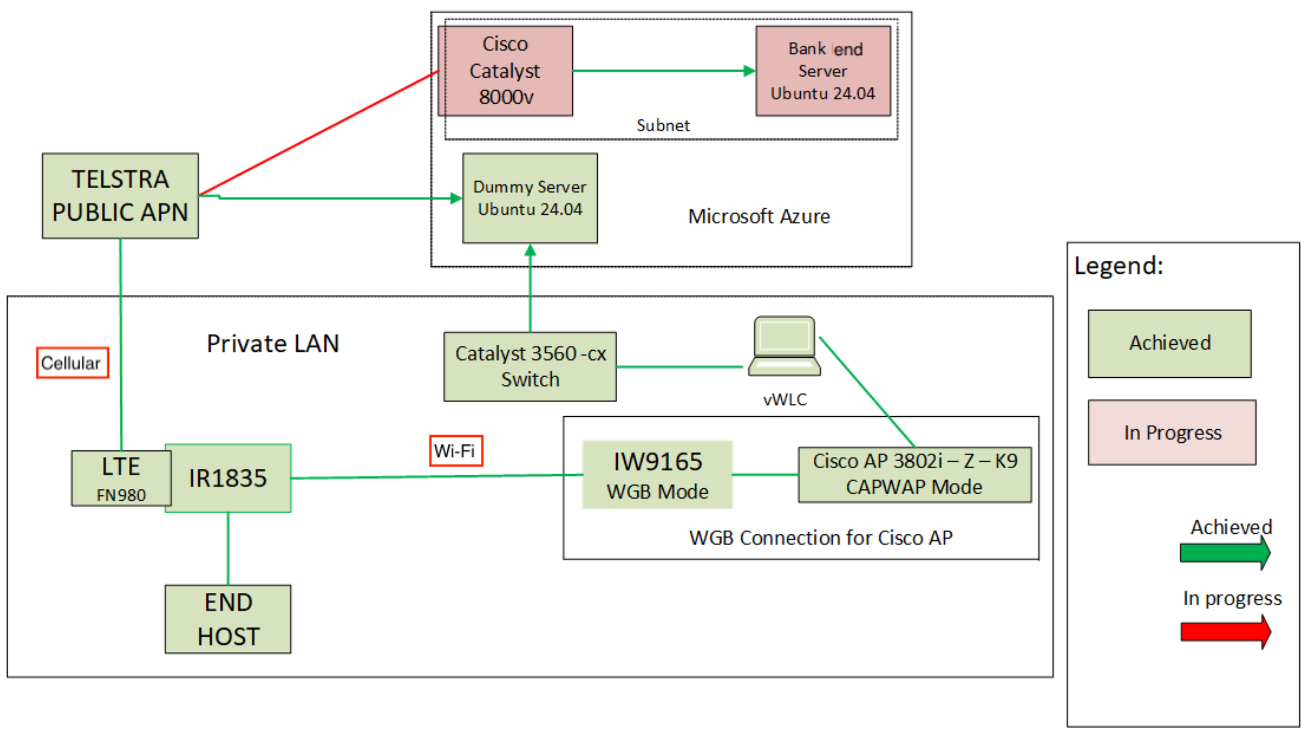


Figure 3: Local deployment within a private LAN according to the testbed network

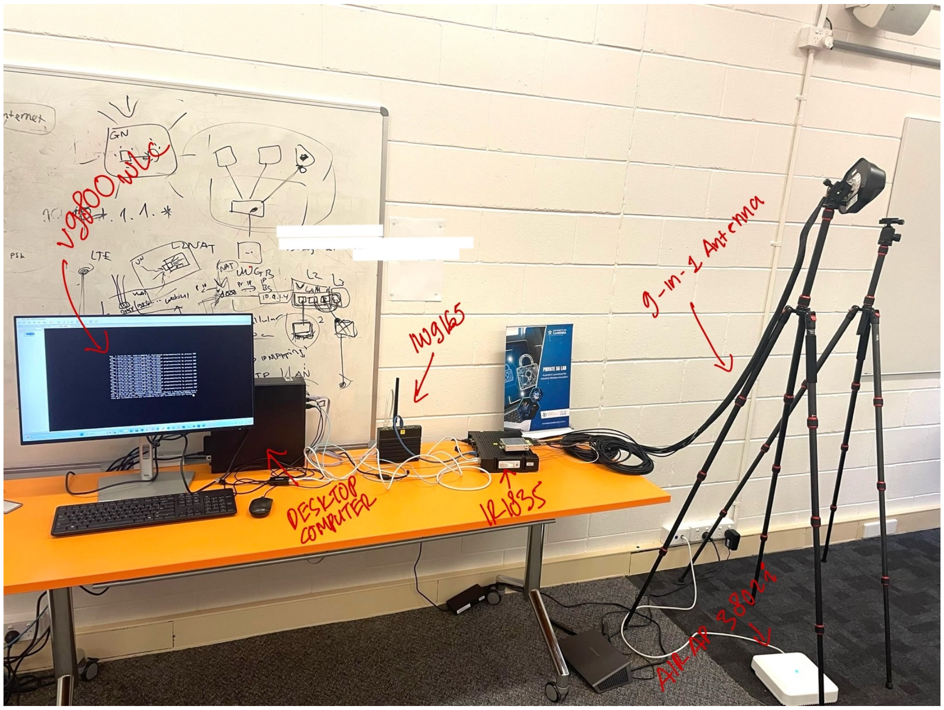


Figure 4: Cloud deployment for Cat8k, backend server via cat8k, and stand alone server

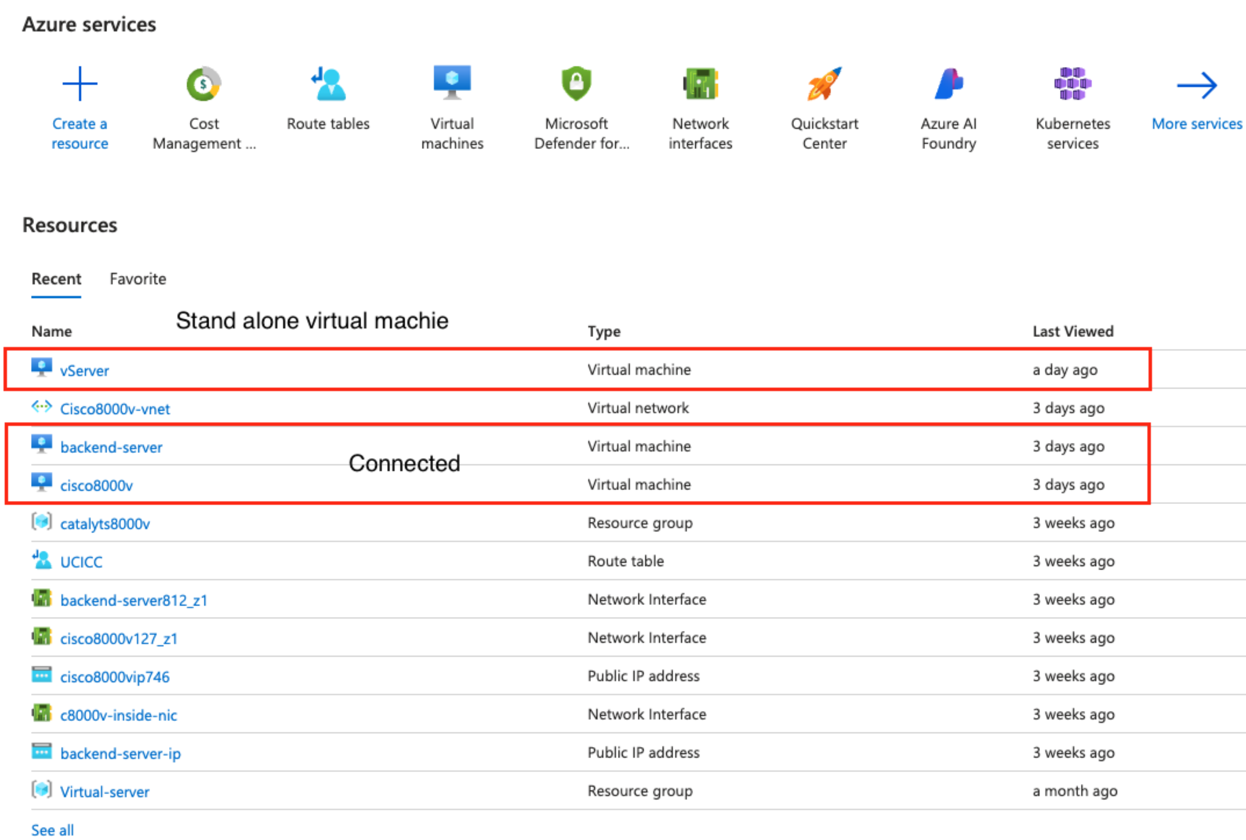


Figure 5: WGB Configuration for Cisco IW9165 AP

```
### WGB Running config - Hostname: Router-IW9165 ###

configure ap management add username UCICC password $1$$e0C6lzD.33KSjvp1mod/K. s
ecret $1$$e0C6lzD.33KSjvp1mod/K.
configure ap hostname Router-IW9165
configure ap address ipv4 static 10.0.1.10 255.255.255.0 10.0.1.245
configure ssid-profile UCICC-PROFILE ssid UCICC-WIFI authentication psk U2FsdGVk
X19zcVmOKp9uyXkKKeXUiMGzK7KbMAQX8xc= key-management wpa2
configure dot11Radio 1 mode wgb ssid-profile UCICC-PROFILE
configure dot11Radio 1 enable
configure wgb uclient timeout 300
configure wgb mobile station interface dot11Radio 1 scan 36 add
configure l2nat default-vlan 1
configure wgb ethport 0 native-vlan id 1
configure dot11Radio 1 802.11ax disable
configure dot11Radio 1 profile customized-wmm enable


*** End of WBridge configurations ***
```

Figure 6: Cellular Configuration with an active APN profile

```
Router-IR1835#show cellular 0/5/0 all
Hardware Information
====================
Modem Firmware Version = M0H.030202
Host Firmware Version = A0H.000302
Device Model ID =  FN980
International Mobile Subscriber Identity (IMSI) = 505012000505581
International Mobile Equipment Identity (IMEI) = 351533923292937
Integrated Circuit Card ID (ICCID) = 89610180004292541341
Mobile Subscriber Integrated Services
Digital Network-Number (MSISDN) = +61497445858
Modem Status = Modem Online
Current Modem Temperature = 39 deg C
PRI version = 1080-115, Carrier = Telstra
OEM PRI version = 1080-115

Profile Information
====================

Profile 1 = ACTIVE* **
--------
PDP Type = IPv4
PDP address = 100.90.214.145
IPv4 PDP Connection is successful
Access Point Name (APN) = telstra.internet
Authentication = None
        Primary DNS address = 10.3.41.226
        Secondary DNS address = 10.3.24.11
```

Figure 7: Gigabit Ethernet Configuration

```
Router-IR1835#show ip interface brief
Interface              IP-Address      OK? Method Status                Protocol
GigabitEthernet0/0/0   10.0.0.182      YES DHCP   up                    up
GigabitEthernet0/1/0   unassigned      YES unset  up                    up
GigabitEthernet0/1/1   unassigned      YES unset  administratively down down
GigabitEthernet0/1/2   unassigned      YES unset  down                  down
GigabitEthernet0/1/3   unassigned      YES unset  down                  down
Wl0/1/4                unassigned      YES unset  up                    up
Cellular0/4/0          unassigned      YES NVRAM  administratively down down
Cellular0/4/1          unassigned      YES NVRAM  administratively down down
Cellular0/5/0          10.242.16.64    YES IPCP   up                    up
Cellular0/5/1          unassigned      YES NVRAM  down                  down
Async0/2/0             unassigned      YES unset  up                    down
Async0/2/1             unassigned      YES unset  up                    down
VirtualPortGroup0      192.168.0.1     YES NVRAM  up                    up
Vlan1                  unassigned      YES unset  up                    up
Vlan4                  unassigned      YES DHCP   administratively down down
Router-IR1835#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, m - OMP
       n - NAT, Ni - NAT inside, No - NAT outside, Nd - NAT DIA
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       H - NHRP, G - NHRP registered, g - NHRP registration summary
       o - ODR, P - periodic downloaded static route, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR
       & - replicated local route overrides by connected

Gateway of last resort is 10.0.0.1 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 10.0.0.1
      10.0.0.0/8 is variably subnetted, 3 subnets, 2 masks
C        10.0.0.0/24 is directly connected, GigabitEthernet0/0/0
L        10.0.0.182/32 is directly connected, GigabitEthernet0/0/0
C        10.242.16.64/32 is directly connected, Cellular0/5/0
      192.168.0.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.0.0/24 is directly connected, VirtualPortGroup0
L        192.168.0.1/32 is directly connected, VirtualPortGroup0
```

3.3.2 Research Materials

- IR1835-K9 refers to a highly modular rugged series router designed to maximise IoT features in industrial areas, with key functions such as 5G, 4G LTE, Wi-Fi 6, Gigabit Ethernet, CAN BUS, dead reckoning and Global Navigation Satellite System (GNSS). It is also powered by Cisco IOS XE, an advanced operating system to enhance its performance. Installation and initial configuration were

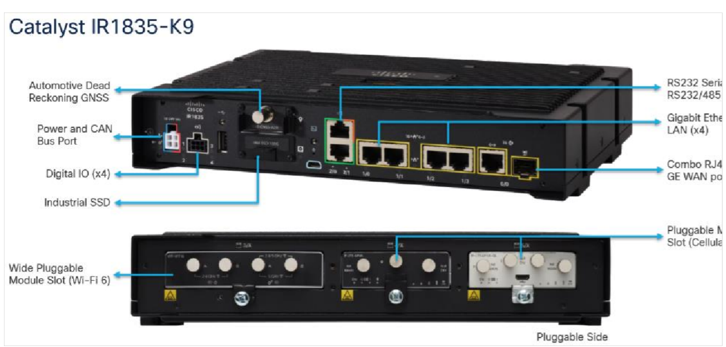


Figure 8: Cisco Catalyst IR1835-k9

  based on the following Cisco manuals: Router IR1800 Overview, Router IR1835-K9 installation guide, IOS XE Configuration for IR1800.

- OBD2-J1962YA-MF4 is an OBD-II (J1962) Type A to IR1800 cable wired; OBD $\rightarrow$ On Board Diagnostic, used to transfer data between the vehicle's OBD2 system and external devices, such as diagnostic tools or computers. It is also compatible with the CAN BUS connector with its Mini Fit 4 (MF4) Connector.

Figure 9: OBD2-J1962YA-MF4 cable

For more details, see the following: Cable Overview (NOT THE ACTUAL ITEMS FROM CISCO OFFICIAL WEBSITE), and Digital Input Output, Ignition, and CAN Bus Connectivity.

- USB Type A to USB Micro-B (2m) cable used to connect the router IR1835 through its USB micro-B port to a USB Type A in an external device, such as a user computer, for initial configuration or troubleshooting. However, User computers are required to have a VCP (Virtual COM Port) drive to enable communication with the CP210x USB to UART.

Figure 10: USB Type A to USB Micro-B (2m)

This cable requires the installation of a VCP driver. The use of this cable was based on the following Cisco manual: IR1800 Connecting Process and VCP Driver installation link for those who do not have VCP installed in their devices.

- 8-pin RJ45 Ethernet Cable Connector with PoE capability. This is used to connect devices to the green Ethernet socket wall in the test bed environment. It was also used to provide a connection between the edge devices IR1835 and IW9165.

Figure 11: Ethernet Cable RJ45 - 8 pin

- RJ45 - USB console cable, which provides access to perform initial configuration on Cisco Catalyst IW9165 and Cisco air AP 3802i - Z - K9. The baud rate is 115200, which is according to the IW9165 configuration guideline.

Figure 12: URJ45 - USB console cable

This cable requires the installation of a VCP driver. The use of this cable was based on the following Cisco manual: IW9165 Connector and Ports and USB-RJ45 Console Cable Overview

- IR1800-DINRAIL is a DIN RAIL kit for IR1800. It was used to mount IR1835 in the preferred mount position according to the project's requirements.

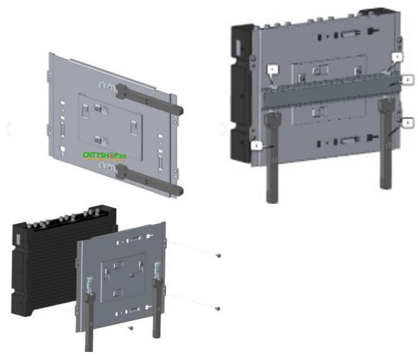


Figure 13: IR1800-DINRAIL

However, the router is not mounted in a specific position but is placed in a safe working space to provide mobility during the configuration process. For more information on the DIN RAIL Kit, see the following: IR1800 Rugged Series Din Rail Installation Guide.

- P-LTEAP18-GL is a plug-in modem with CAT18 LTE Advanced PRO. As a Cisco LTE Advanced Pro

Figure 14: P-LTEAP18-GL

CAT 18 pluggable Interface Module (PIM), it is designed to offer high-speed cellular 4G LTE connectivity for the Cisco IR1800 router. The installation guide was based on the following Cisco manual: P-LTEA18-GL PIM Overview and Installing SIM card into PIM.

- P-5GS6-GL is an interface module for IoT Routers, particularly the IR1800, which is a pluggable interface module (PIM) designed for Cisco routers, including the IR1800 series. Key features include 5G connectivity, global coverage, and enhanced performance, providing reliable and high-quality wireless WAN connectivity. However, to maximize connection to the 5G band signal range, such as in n77 or n78, the modem model must be in EM9293 and not in FN980.

Figure 15: P-5GS6-GL

During deployment, this PIM connects to a 5GANTM 0-4-B antenna to initiate its operation, with configuration accessible through the Cisco IOS XE operating system. The installation guide was based on the following Cisco manual: 5G pluggable Interface Module Overview and Installing SIM card into PIM.

- A Telstra SIM card is required to enable the modem to work properly, since Telstra is the only mobile network operator that supports the above Cisco modems within the Australian region. For information on SIM card installation, use the SIM card to PIM installation link above from the P-5GS6-GL section.

Figure 16: Telstra SIM card

- WiFi6 pluggable modem for IoT routers such as the IR1800 model. This module improves the ability of the router to provide robust and reliable wireless connectivity in various industrial and mobile environments. However, this Wi-Fi modem is not used in this setup, as the IW9165 AP is used to provide a Wi-Fi bridge to a nearby parent AP.

Figure 17: WP-WIFI6-Z

Installation and configuration can be found in the following, Wireless Interface Module overview

- IRM-GNSS-ADR is an Automotive Dead Reckoning GNSS Module. It is used to provide an accurate location during the disturbance of the satellite signal in the GPS system.

Figure 18: IRM-GNSS-ADR

It uses previously recorded data to estimate the exact location of the object by measuring speeds, time, and directions. To enable this feature, manual configurations are required through the Cisco IOS XE software/operating system. The installation guide was based on the following Cisco manual: IRM-GNSS-ADR installation and GNSS configuration with Cisco IOS XE software.

- IRM-SSD-100GB is a 100 GB SSD storage module designed for industrial environments.

Figure 19: IRM-SSD-100GB

It provides mainly an extra 100GB of flash memory for the router and is also used for application data in the Cisco IOS XE operating system. The installation was performed in the following Cisco manual: SSD module overview.

- PWR-MF4-125W-AC is a power supply adapter that converts AC to DC for IR1800.

Figure 20: PWR-MF4-125W-AC

It has a sleek industrial design and provides 125 watts of power. The adapter supports multi-voltage input from 12 to 14 V DC and can be adjusted from 9 to 36 V DC. It effectively transforms power from a standard outlet. The overview of the adapter can be found as follows Adapter Overview.

- The 5G-ANTM-O-4-B is a 9-in-1 outdoor black antenna 5G Sub-6GHz / 4G LTE. This omnidirectional 5G antenna is designed for Cisco industrial routers, such as the IR1800 model.

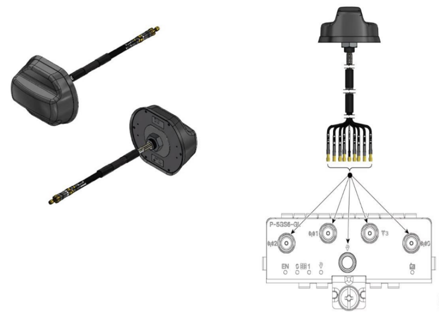


Figure 21: 5G-ANTM-O-4-B

It offers high-performance 5G and LTE cellular connectivity, dual-band Wi-Fi, and GNSS (GPS). During deployment, the antenna connects to a plug-in module interface, as shown in Figure 21. The installation was carried out according to the following Antenna Overview and Installation Guide.

- The IW9165E-Z-WGB, also known as an IW9165, 11ax 6E, with 4 RF ports and a Z domain W, refers to the IW9165E Cisco Catalyst access point supporting IEEE 802.11ax (Wi-Fi 6), as shown in the description as 11ax 6e.

Figure 22: IW9165E-Z-WGB

It features four removable radio frequency ports for external antennas (4 RF ports) and is used to deploy wireless infrastructure for system automation through a wireless network. The installation and configuration were made according to the following, Router IW9165 Overview, Installation Guide, Cisco IW9165E access point configuration.

- IW-PWRADPT-MFT4P is a Power Adapter AC-DC Micro-Fit 4 Pin connector.

Figure 23: IW-PWRADPT-MFT4P

IW-PWRADPT-MFT4P is a power supply adapter that provides an option to generate power for the Cisco IW9165 access point in addition to Power over Ethernet (PoE) capability. The overview of the device can be found in the following, IW-PWRADPT-MFT4P Adapter Overview.

- The Cisco AIR 3802i-Z-K9 was used to connect to IW9165 via Wi-Fi.

Figure 24: Cisco AIR AP 3802i - Z - k9

As a lightweight access point, it must operate in CAPWAP mode so that IW9165 can be used in the Work Group Bridge to connect IR1835 to a dummy server. The configuration and general configuration of the Aironet 3800 were performed according to the following Cisco manual: Cisco 3800 Overview.

- A dedicated desktop computer to host VMware Workstation Pro as a virtual platform running Cisco v9800 WLC. This desktop is equipped with a keyboard, a monitor, and a mouse, as shown in the figure below.

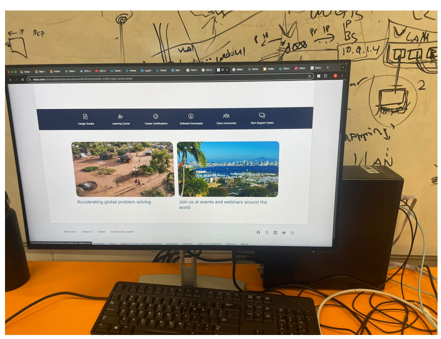


Figure 25: Dedicated desktop

3.3.3 Licensing and Agreement

- CON-L1NBD-IR1835RK or known as CX LEVEL 1 8X5XNBD Cisco Catalyst IR1835 is licensed to receive the right to Cisco customer service level 1 for 8 hours a day in 5 business days, for equipment support on the Cisco IR1835 router when the device was purchased.

- SL-1800-NA / PRF-K9 or known as the Network Advantage License for Cisco IR1800 is intended as a license that gives permission to the router IR1800 and its software capability and security during the deployment stage.

- CON-L1NBD-IW9165BG or known as CX LEVEL 1 8X5XNBD IW9165, 11ax 6E, 4 RF. It refers to Cisco customer care level 1, which provides technical support for the IW9165 router if it is not working properly or experiencing a technical issue.

3.3.4 Works Output

Test Plan

To check the stability of the connection according to Figure 2, the following set of tests was established.

- Confirming that both of the interfaces are receiving an IP address.
- Confirming that the IR1835 can reach outside traffic by pinging the Google DNS server IP: 8.8.8.8.
- Running a lightweight Iperf docker in the IR1835. *(NOTE: Due to the NDA, these steps can not be presented)*
- Testing the cellular connection via P5GS6- GL modem that directly connected to the Telstra APN. During this testing, the GigabitEthernet 0/0/0 is shutdown mode.
  - Sending an ICMP packet by pinging the cloud-deployed server from the Docker.
  - Testing TCP and UDP with Iperf3 from the Docker.
- Testing the Wi-Fi connection via gigabitethernet 0/0/0 that directly connected to IW9165, which bridges traffic to the parent AP, Cisco AIR AP 3802i. During this testing, the cellular 0/5/0 is in shutdown mode.
  - Sending an ICMP packet by pinging the cloud-deployed server from the Docker.
  - Testing TCP and UDP with Iperf3 from the Docker.

Result

- Both interfaces are assigned an IP address, and the IR1835 can reach the outside network as shown in the Figures below.

Figure 26: Cellular Configuration

```
Router-IR1835#show running-config interface cellular 0/5/0
Building configuration...

Current configuration : 185 bytes
!
interface Cellular0/5/0
 mtu 1456
 ip address 100.90.225.9 255.255.255.0
 ip tcp adjust-mss 1416
 dialer in-band
 dialer watch-group 1
 dialer-group 1
 ipv6 enable
 pulse-time 1
end

Router-IR1835#
```

Figure 27: GigabitEthernet Configuration

```
Router-IR1835#show running-config interface gigabitethernet 0/0/0
Building configuration...

Current configuration : 156 bytes
!
interface GigabitEthernet0/0/0
 ip dhcp client update dns server both
 ip address 10.0.0.177 255.255.255.0
 negotiation auto
 spanning-tree portfast
end

Router-IR1835#
```

Figure 28: IR1835 as an end host is able to reach Google DNS server

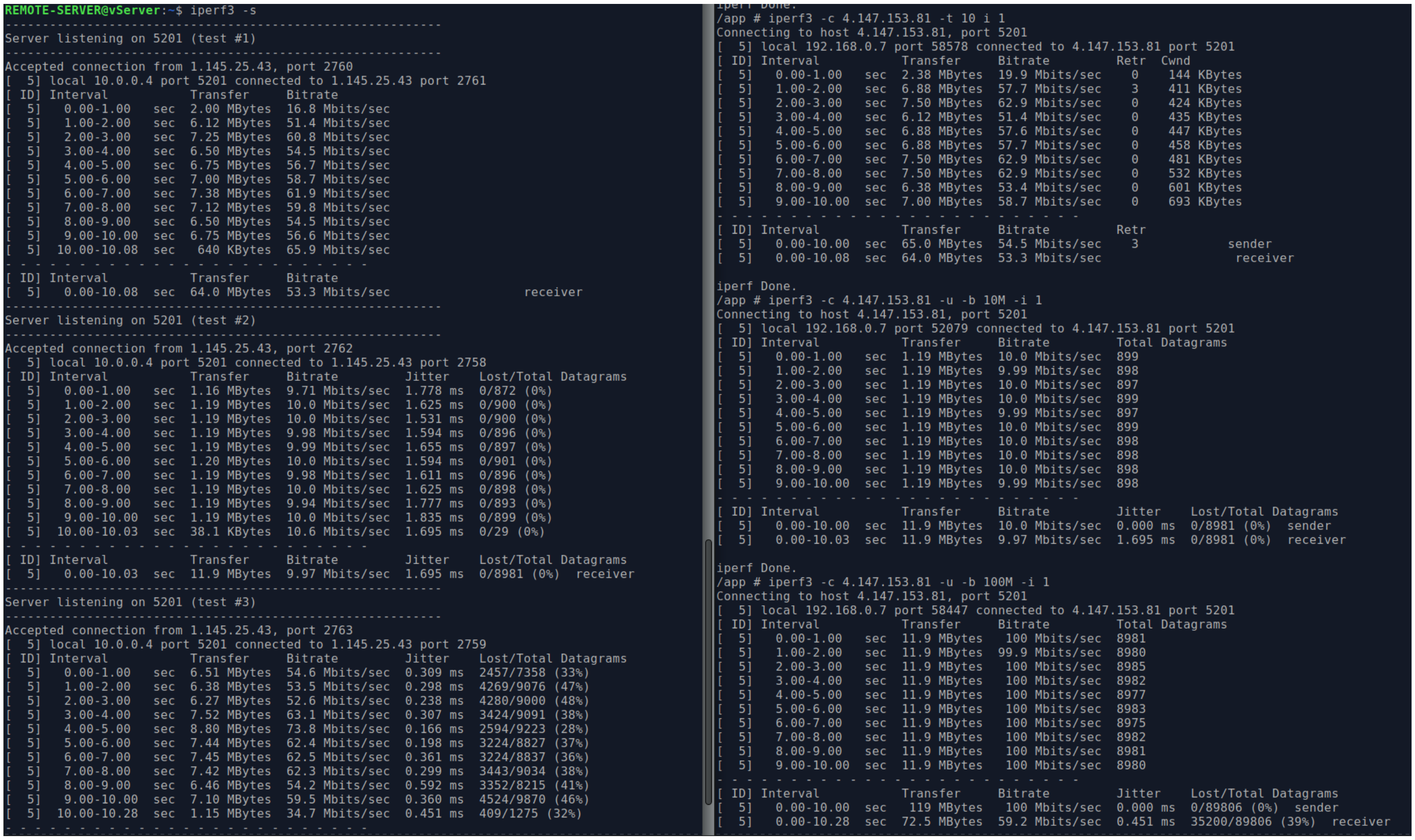
```
Router-IR1835#ping 8.8.8.8
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 8.8.8.8, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 16/96/280 ms
Router-IR1835#ping www.gooogle.com
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.3.26.60, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 36/38/44 ms
Router-IR1835#
```

- The network Connection via the cellular interface 0/5/0 with the P5GS6-GL modem and Telstra APN is properly established, indicating that data can be transferred to the server via the Cellular pathway. This proves that the system approach in Figure 1 and Figure 2 has been achieved.
  - ICMP testing.

```
/app # ping 4.147.153.81
PING 4.147.153.81 (4.147.153.81): 56 data bytes
64 bytes from 4.147.153.81: seq=0 ttl=50 time=31.234 ms
64 bytes from 4.147.153.81: seq=1 ttl=50 time=40.336 ms
64 bytes from 4.147.153.81: seq=2 ttl=50 time=39.868 ms
64 bytes from 4.147.153.81: seq=3 ttl=50 time=39.531 ms
64 bytes from 4.147.153.81: seq=4 ttl=50 time=29.805 ms
64 bytes from 4.147.153.81: seq=5 ttl=50 time=39.495 ms
64 bytes from 4.147.153.81: seq=6 ttl=50 time=39.365 ms
64 bytes from 4.147.153.81: seq=7 ttl=50 time=39.112 ms
64 bytes from 4.147.153.81: seq=8 ttl=50 time=38.912 ms
64 bytes from 4.147.153.81: seq=9 ttl=50 time=39.170 ms
64 bytes from 4.147.153.81: seq=10 ttl=50 time=37.947 ms
64 bytes from 4.147.153.81: seq=11 ttl=50 time=38.236 ms
64 bytes from 4.147.153.81: seq=12 ttl=50 time=28.509 ms
^C
--- 4.147.153.81 ping statistics ---
13 packets transmitted, 13 packets received, 0% packet loss
round-trip min/avg/max = 28.509/37.040/40.336 ms
```

Figure 29: Ping result for cellular connection

- TCP and UDP testing.



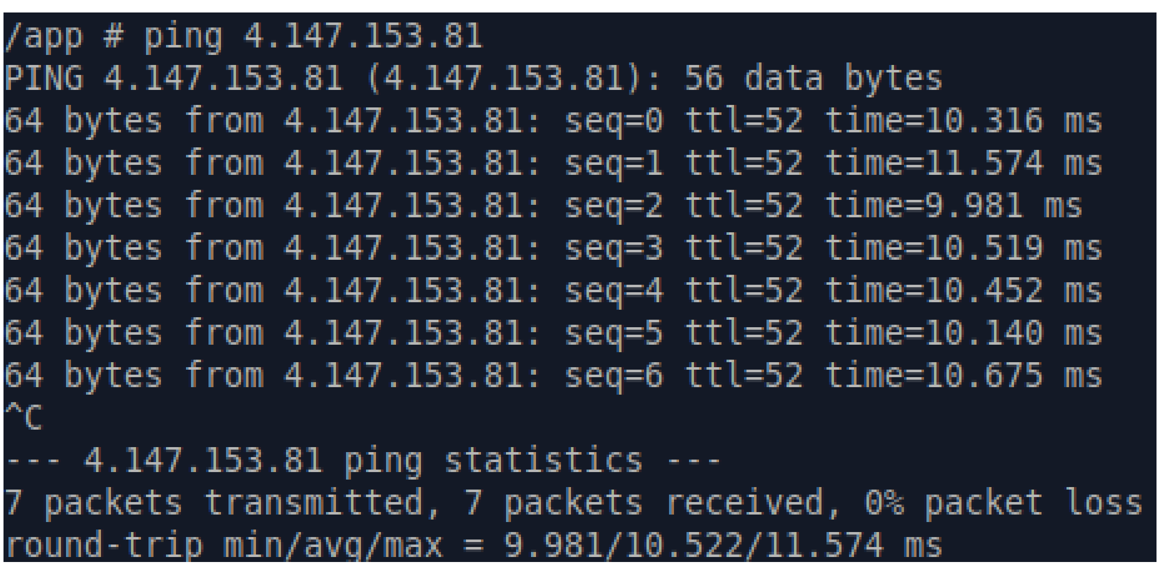
```
REMOTE-SERVER@vServer:~$ iperf3 -s
-----------------------------------------------------------
Server listening on 5201 (test #1)
-----------------------------------------------------------
Accepted connection from 1.145.25.43, port 2760
[  5] local 10.0.0.4 port 5201 connected to 1.145.25.43 port 2761
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-1.00   sec  2.00 MBytes  16.8 Mbits/sec
[  5]   1.00-2.00   sec  6.12 MBytes  51.4 Mbits/sec
[  5]   2.00-3.00   sec  7.25 MBytes  60.8 Mbits/sec
[  5]   3.00-4.00   sec  6.50 MBytes  54.5 Mbits/sec
[  5]   4.00-5.00   sec  6.75 MBytes  56.7 Mbits/sec
[  5]   5.00-6.00   sec  7.00 MBytes  58.7 Mbits/sec
[  5]   6.00-7.00   sec  7.38 MBytes  61.9 Mbits/sec
[  5]   7.00-8.00   sec  7.12 MBytes  59.8 Mbits/sec
[  5]   8.00-9.00   sec  6.50 MBytes  54.5 Mbits/sec
[  5]   9.00-10.00  sec  6.75 MBytes  56.6 Mbits/sec
[  5]  10.00-10.08  sec   640 KBytes  65.9 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-10.08  sec  64.0 MBytes  53.3 Mbits/sec                  receiver
-----------------------------------------------------------
Server listening on 5201 (test #2)
-----------------------------------------------------------
Accepted connection from 1.145.25.43, port 2762
[  5] local 10.0.0.4 port 5201 connected to 1.145.25.43 port 2758
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  1.16 MBytes  9.71 Mbits/sec  1.778 ms  0/872 (0%)
[  5]   1.00-2.00   sec  1.19 MBytes  10.0 Mbits/sec  1.625 ms  0/900 (0%)
[  5]   2.00-3.00   sec  1.19 MBytes  10.0 Mbits/sec  1.531 ms  0/900 (0%)
[  5]   3.00-4.00   sec  1.19 MBytes  9.98 Mbits/sec  1.594 ms  0/896 (0%)
[  5]   4.00-5.00   sec  1.19 MBytes  9.99 Mbits/sec  1.655 ms  0/897 (0%)
[  5]   5.00-6.00   sec  1.20 MBytes  10.0 Mbits/sec  1.594 ms  0/901 (0%)
[  5]   6.00-7.00   sec  1.19 MBytes  9.98 Mbits/sec  1.611 ms  0/896 (0%)
[  5]   7.00-8.00   sec  1.19 MBytes  10.0 Mbits/sec  1.625 ms  0/898 (0%)
[  5]   8.00-9.00   sec  1.19 MBytes  9.94 Mbits/sec  1.777 ms  0/893 (0%)
[  5]   9.00-10.00  sec  1.19 MBytes  10.0 Mbits/sec  1.835 ms  0/899 (0%)
[  5]  10.00-10.03  sec  38.1 KBytes  10.6 Mbits/sec  1.695 ms  0/29 (0%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-10.03  sec  11.9 MBytes  9.97 Mbits/sec  1.695 ms  0/8981 (0%)  receiver
-----------------------------------------------------------
Server listening on 5201 (test #3)
-----------------------------------------------------------
Accepted connection from 1.145.25.43, port 2763
[  5] local 10.0.0.4 port 5201 connected to 1.145.25.43 port 2759
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  6.51 MBytes  54.6 Mbits/sec  0.309 ms  2457/7358 (33%)
[  5]   1.00-2.00   sec  6.38 MBytes  53.5 Mbits/sec  0.298 ms  4269/9076 (47%)
[  5]   2.00-3.00   sec  6.27 MBytes  52.6 Mbits/sec  0.238 ms  4280/9000 (48%)
[  5]   3.00-4.00   sec  7.52 MBytes  63.1 Mbits/sec  0.307 ms  3424/9091 (38%)
[  5]   4.00-5.00   sec  8.80 MBytes  73.8 Mbits/sec  0.166 ms  2594/9223 (28%)
[  5]   5.00-6.00   sec  7.44 MBytes  62.4 Mbits/sec  0.198 ms  3224/8827 (37%)
[  5]   6.00-7.00   sec  7.45 MBytes  62.5 Mbits/sec  0.361 ms  3224/8837 (36%)
[  5]   7.00-8.00   sec  7.42 MBytes  62.3 Mbits/sec  0.299 ms  3443/9034 (38%)
[  5]   8.00-9.00   sec  6.46 MBytes  54.2 Mbits/sec  0.592 ms  3352/8215 (41%)
[  5]   9.00-10.00  sec  7.10 MBytes  59.5 Mbits/sec  0.360 ms  4524/9870 (46%)
[  5]  10.00-10.28  sec  1.15 MBytes  34.7 Mbits/sec  0.451 ms  409/1275 (32%)
- - - - - - - - - - - - - - - - - - - - - - - - -
```

```
iperf Done.
/app # iperf3 -c 4.147.153.81 -t 10 i 1
Connecting to host 4.147.153.81, port 5201
[  5] local 192.168.0.7 port 58578 connected to 4.147.153.81 port 5201
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  5]   0.00-1.00   sec  2.38 MBytes  19.9 Mbits/sec    0    144 KBytes
[  5]   1.00-2.00   sec  6.88 MBytes  57.7 Mbits/sec    3    411 KBytes
[  5]   2.00-3.00   sec  7.50 MBytes  62.9 Mbits/sec    0    424 KBytes
[  5]   3.00-4.00   sec  6.12 MBytes  51.4 Mbits/sec    0    435 KBytes
[  5]   4.00-5.00   sec  6.88 MBytes  57.6 Mbits/sec    0    447 KBytes
[  5]   5.00-6.00   sec  6.88 MBytes  57.7 Mbits/sec    0    458 KBytes
[  5]   6.00-7.00   sec  7.50 MBytes  62.9 Mbits/sec    0    481 KBytes
[  5]   7.00-8.00   sec  7.50 MBytes  62.9 Mbits/sec    0    532 KBytes
[  5]   8.00-9.00   sec  6.38 MBytes  53.4 Mbits/sec    0    601 KBytes
[  5]   9.00-10.00  sec  7.00 MBytes  58.7 Mbits/sec    0    693 KBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  5]   0.00-10.00  sec  65.0 MBytes  54.5 Mbits/sec    3             sender
[  5]   0.00-10.08  sec  64.0 MBytes  53.3 Mbits/sec                  receiver

iperf Done.
/app # iperf3 -c 4.147.153.81 -u -b 10M -i 1
Connecting to host 4.147.153.81, port 5201
[  5] local 192.168.0.7 port 52079 connected to 4.147.153.81 port 5201
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec  1.19 MBytes  10.0 Mbits/sec  899
[  5]   1.00-2.00   sec  1.19 MBytes  9.99 Mbits/sec  898
[  5]   2.00-3.00   sec  1.19 MBytes  10.0 Mbits/sec  897
[  5]   3.00-4.00   sec  1.19 MBytes  10.0 Mbits/sec  899
[  5]   4.00-5.00   sec  1.19 MBytes  9.99 Mbits/sec  897
[  5]   5.00-6.00   sec  1.19 MBytes  10.0 Mbits/sec  899
[  5]   6.00-7.00   sec  1.19 MBytes  10.0 Mbits/sec  898
[  5]   7.00-8.00   sec  1.19 MBytes  10.0 Mbits/sec  898
[  5]   8.00-9.00   sec  1.19 MBytes  10.0 Mbits/sec  898
[  5]   9.00-10.00  sec  1.19 MBytes  9.99 Mbits/sec  898
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-10.00  sec  11.9 MBytes  10.0 Mbits/sec  0.000 ms  0/8981 (0%)  sender
[  5]   0.00-10.03  sec  11.9 MBytes  9.97 Mbits/sec  1.695 ms  0/8981 (0%)  receiver

iperf Done.
/app # iperf3 -c 4.147.153.81 -u -b 100M -i 1
Connecting to host 4.147.153.81, port 5201
[  5] local 192.168.0.7 port 58447 connected to 4.147.153.81 port 5201
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec  11.9 MBytes   100 Mbits/sec  8981
[  5]   1.00-2.00   sec  11.9 MBytes  99.9 Mbits/sec  8980
[  5]   2.00-3.00   sec  11.9 MBytes   100 Mbits/sec  8985
[  5]   3.00-4.00   sec  11.9 MBytes   100 Mbits/sec  8982
[  5]   4.00-5.00   sec  11.9 MBytes   100 Mbits/sec  8977
[  5]   5.00-6.00   sec  11.9 MBytes   100 Mbits/sec  8983
[  5]   6.00-7.00   sec  11.9 MBytes   100 Mbits/sec  8975
[  5]   7.00-8.00   sec  11.9 MBytes   100 Mbits/sec  8982
[  5]   8.00-9.00   sec  11.9 MBytes   100 Mbits/sec  8981
[  5]   9.00-10.00  sec  11.9 MBytes   100 Mbits/sec  8980
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-10.00  sec   119 MBytes   100 Mbits/sec  0.000 ms  0/89806 (0%)  sender
[  5]   0.00-10.28  sec  72.5 MBytes  59.2 Mbits/sec  0.451 ms  35200/89806 (39%)  receiver
```

Figure 30: TCP & UDP result for cellular connection

- The network Connection via the Gigabit interface 0/0/0 with Cisco Catalyst IW9165 that bridges traffic via Wi-Fi transference to AIR AP 3802i, as shown in Figure 2, has been achieved. This validates the system approach in Figure 1.

  - ICMP testing.



```
/app # ping 4.147.153.81
PING 4.147.153.81 (4.147.153.81): 56 data bytes
64 bytes from 4.147.153.81: seq=0 ttl=52 time=10.316 ms
64 bytes from 4.147.153.81: seq=1 ttl=52 time=11.574 ms
64 bytes from 4.147.153.81: seq=2 ttl=52 time=9.981 ms
64 bytes from 4.147.153.81: seq=3 ttl=52 time=10.519 ms
64 bytes from 4.147.153.81: seq=4 ttl=52 time=10.452 ms
64 bytes from 4.147.153.81: seq=5 ttl=52 time=10.140 ms
64 bytes from 4.147.153.81: seq=6 ttl=52 time=10.675 ms
^C
--- 4.147.153.81 ping statistics ---
7 packets transmitted, 7 packets received, 0% packet loss
round-trip min/avg/max = 9.981/10.522/11.574 ms
```

Figure 31: Ping result for Gigabit Ethernet for Wi-Fi connection

- TCP and UDP testing.

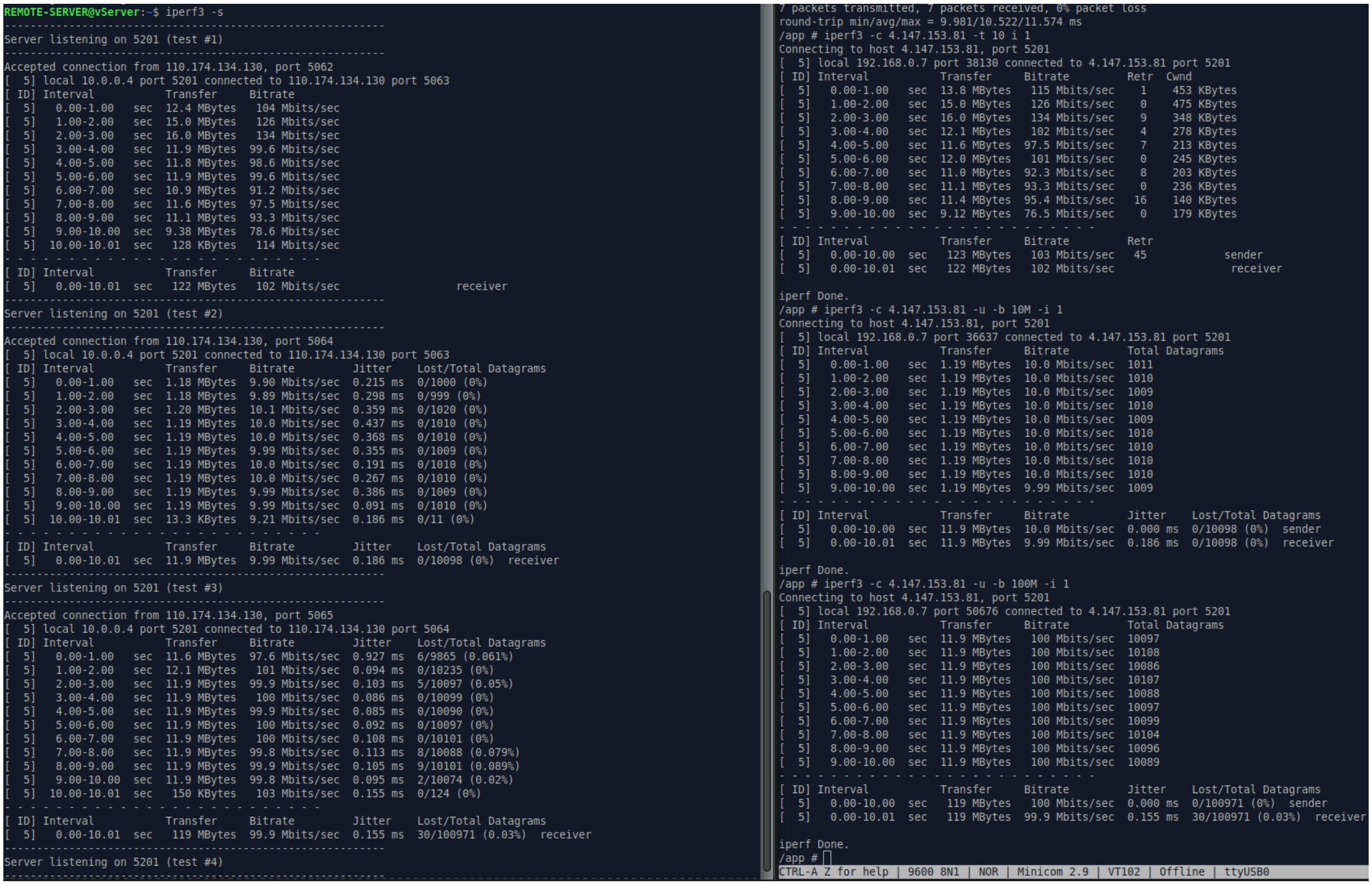


Figure 32: TCP & UDP result for Gigabit Ethernet for Wi-Fi connection

Future Works

The results demonstrate that the initial solution shown in Figure 1 was validated, indicating that a reliable network connection can be achieved using 5G Cellular and Fast Wi-Fi roaming. Therefore, this milestone will be used for further development to maximise network reliability and security in order to meet our industrial partner's sustainable plan. Some of the further developments are listed as follows:

- Implement an end-to-end tunnel for both interfaces from the end device IR1835 to the server by utilising Cat8k.
- Deploying SD-WAN for centralised control and maximising security.
- Deploying private 5G to secure and isolate the network system from public services.
- Test the set-up in the actual environment for real-life data connection, utilising the OBD2 cable in Figure 9 in the actual vehicle.
- Providing a platform for further studies with critical infrastructure research and potential automation process.

3.4 Alignment with Organisation Goals and Impact

This internship project has offered a validation process that an industrial partner could potentially adopt to shape their business approach in the future, which I believe this project's outcome can lead to.

- Transitioning process to zero-emission business operation for the next 25 years.
- Automation process to decrease fuel consumption by employing reliable network models with high-speed connections in a critical infrastructure environment.
- Private operation networks and enhancing network resilience.

In this program, my contribution was directly involved in helping with the following mission:

- Verifying that dual connectivity using Cellular 5G and fast Wi-Fi roaming is achievable.
- Providing an initial process that can strengthen network security to be aligned with the compliance of SOCI (Security of Critical Infrastructure).
- Creating a network foundation for further studies in digital twin implementation.

In conclusion, this validation process is crucial to establishing a scalable pathway for network upgrades that aligns with their primary objective of transforming into sustainable business operations.