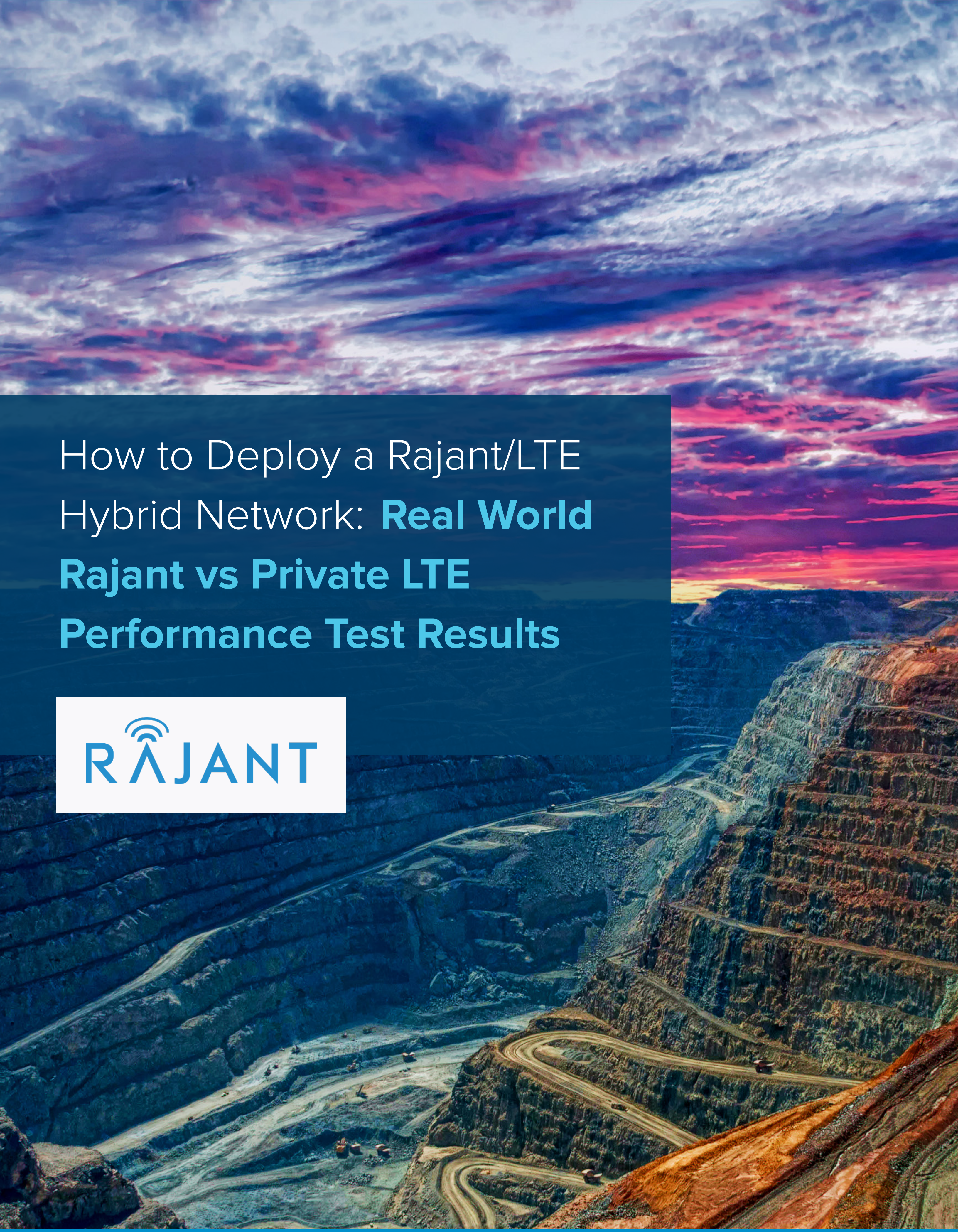

How to Deploy a Rajant/LTE Hybrid Network: **Real World Rajant vs Private LTE Performance Test Results**

RAJANT

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Introduction

LTE is the standard defined to communicate with cell phones in a wide area network, while Wi-Fi is the standard designed for local area networks, and we use both daily. Both are deployed in mines for different applications, and physics defines the limitations of each. LTE uses lower frequencies to cover a more extended range but with lower throughput, while Wi-Fi uses higher frequencies to obtain higher throughput at shorter distances Rajant integrates both technologies into its radios and has enabled machine-to-machine communication since the company's creation in 2001 to extend the range and throughput past the limitations of fixed infrastructure.

In this document, we test Rajant's latest LTE radio integration with Rajant Kinetic Mesh® at different mining locations to demonstrate seamless roaming between Rajant Kinetic Mesh and LTE, along with documenting actual throughput and latency achieved. Conducted tests were run over private and public LTE networks. This document, however, primarily covers the Rajant testing over private LTE networks as public networks are less prevalent in mining, and test results showed a lot of variabilities, so maintaining consistent backhaul throughput was not possible.

In this document, one of the available networks supported a channel bandwidth of 10Mhz of LTE RF spectrum, resulting in a 20Mbps download speed and 10Mbps upload speed. An additional private network was provided at another site with 5Mhz of LTE Spectrum with a 10Mbps download speed and less than 5Mbps upload speed.

During the testing, Rajant achieved 99.5Mbps throughput over Kinetic Mesh with 1.786ms latency and 19.1 Mbps throughput over private LTE with 38.701ms latency.

Utilization of Rajant's Remote Protocol Tunneling (RPT) is required to mesh over a Layer3 LTE connection.

Note: The goal of implementing an RPT connection over Public LTE was to determine what was required to avoid Carrier Grade Network Address Translation to establish Remote Protocol Tunnels over the infrastructure routes with some connectivity over a public network. Throughput testing revealed an excessive variance in latency and cost. Public LTE networks for reliable and required application throughput should be avoided as public LTE saw latencies between 125-133 msec with route costs greater than 28,000.

The purpose of the testing was:

- Integrate with the private LTE network at multiple mine sites
- Confirm SIM card validation on the private mine site and the public LTE networks
- Establish Remote Protocol Tunnels and confirmation of functionality
- Confirm latency over the RPT link
- Confirm RPT could route traffic when it was the best path cost
- Confirm mesh links could route traffic when mesh link cost bettered RPT costs
- Integrate with public LTE and determine best practice to deal with CGNAT

Rajant equipment deployed over the mine:

- Peregrine FE1-2255B
- Peregrine 2455LW with LTE interface running 11.25.1 firmware
- Slipstream 2 running 11.25.1 firmware

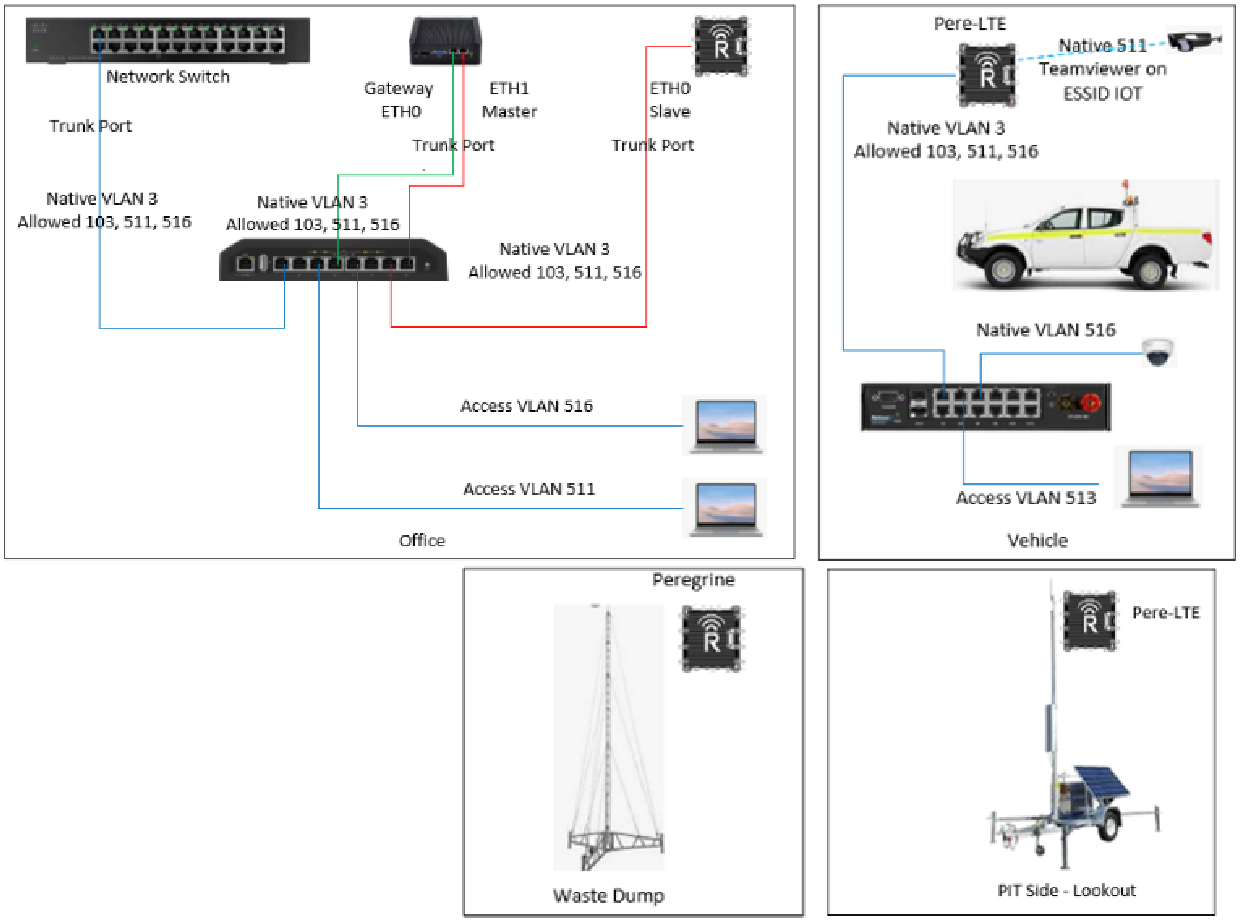
Establish Remote Protocol Tunnels and Confirm Functionality

Remote Protocol Tunnelling was established over UDP. To enable the remote protocol tunnel to function, the following node configurations were applied.

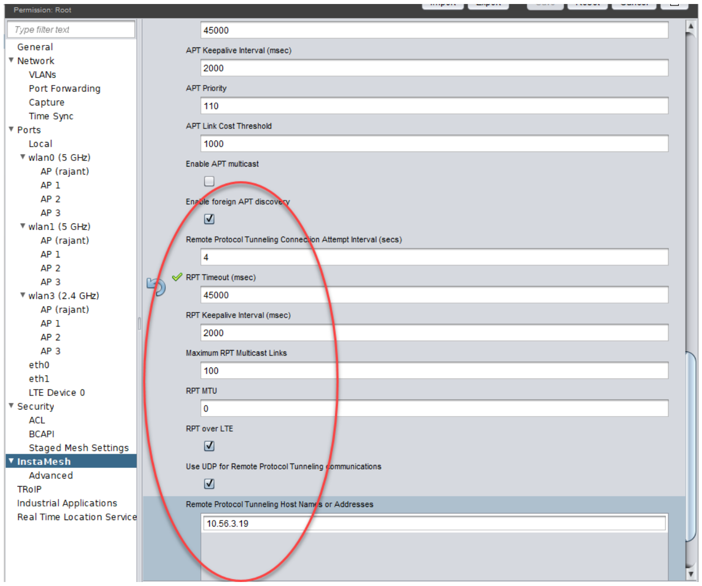
SlipStream RPT Configuration

SlipStream connected via Eth0 to the network switch. The SlipStream network was configured with a static IP address based on its computed V11 address. The SlipStream ETH0 port was configured in gateway mode – with gateway IP address details established via DHCP. ETH 1 was connected to the network switch port.

The figure below shows a block diagram of the mine site test network configuration.



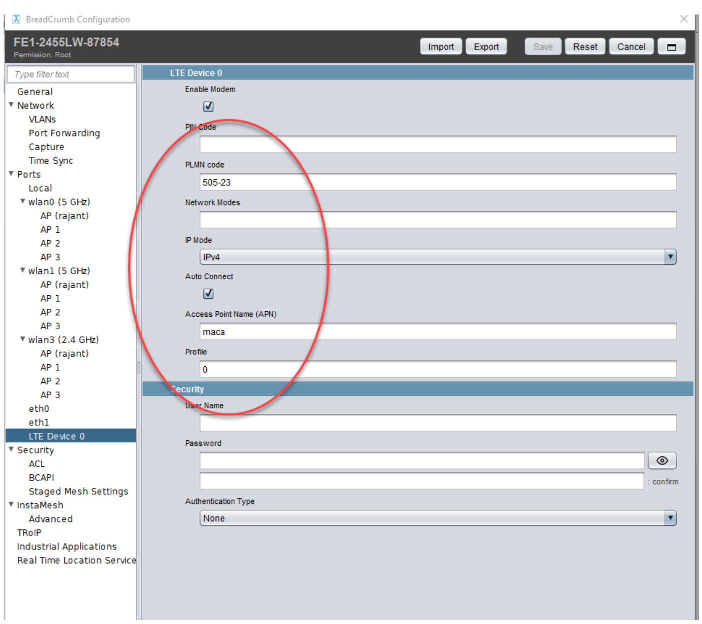
The following was applied on the SlipStream in InstaMesh® (No changes were enabled on the advanced InstaMesh tab). RPT configs are necessary as the Rajant BreadCrumbs® need Remote Protocol Tunneling in order to mesh over LTE. InstaMesh on the Peregrines were configured for RPT using the DHCP assigned gateway IP as the RPT tunnelling address.



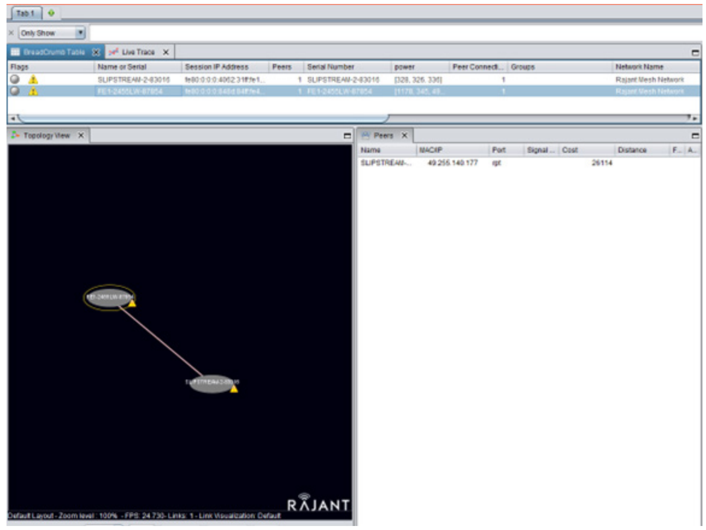
Node Configurations on Peregrine LTE

Network address was established as per the SlipStream - Manually assigned based on computed V11, but in a /24 subnet.

The LTE interface was enabled with the following credentials applied:



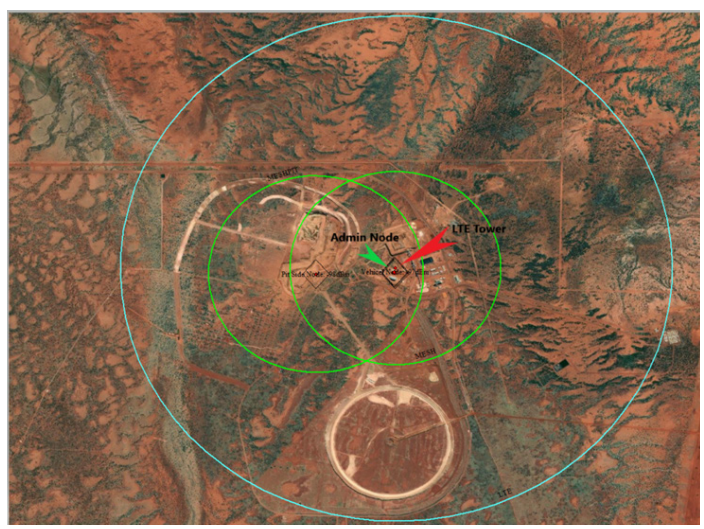
This image shows RPT tunnels established over LTE between each node and the SlipStream.



LTE Coverage Depiction

Green circles represent Rajant preferred over LTE. Higher bandwidth and lower latency – shows pit-side node meshing with admin node. Blue circles represent LTE coverage.

NOTE - During the trial, we deliberately ensured the pit-side node could NOT mesh with the admin node so we would use the LTE backhaul.



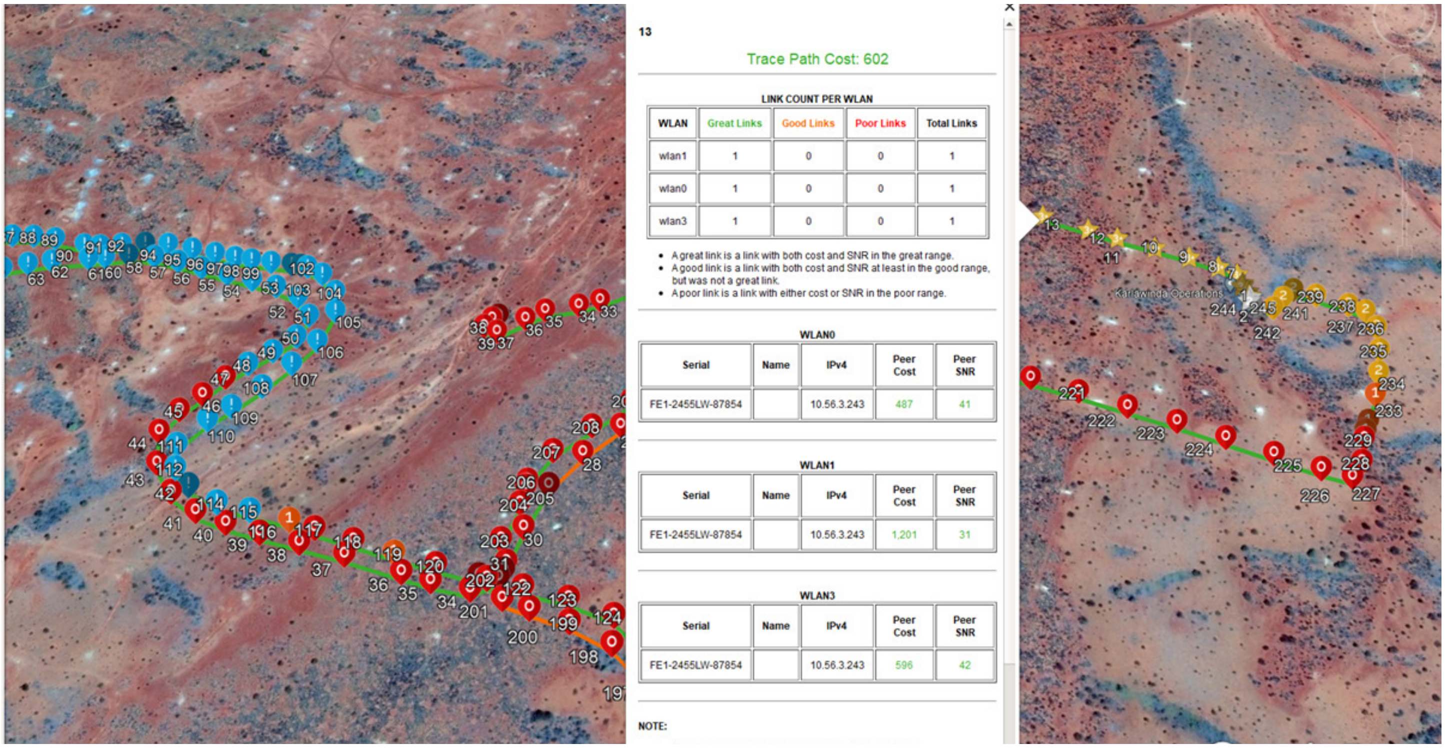
In the image below, the LTE tower is on the left. The admin node is mounted to the roof of the building on the right. The pit-side node is behind the dirt pile directly ahead of the vehicle. The pit-side node was in an LTE coverage area, so it could mesh from the admin building to the pit -side node to switch to LTE. See the video link below which shows mobile roaming between mesh backhaul and LTE. **In a real world deployment , we would have allowed the pit-side node to mesh with the admin node as that provides a 5-6x increase in throughput.**

Test Results

Standard Rajant BreadCrumb nodes (non-LTE) are also able to use the 4G/LTE connections of the hybrid Rajant nodes via the wireless Kinetic Mesh when LTE has the best cost.

The Rajant hybrid BreadCrumbs could seamlessly switch between wireless Kinetic Mesh and 4G/LTE connections. Peer routes are switched without dropping packets.

Watch video. https://youtu.be/7a3avMBPL-A



Using MeshMapper, we can track the progress of the mobile node within the Kinetic Mesh Infrastructure and then switch to LTE. As shown in this picture, the mobile node was in full mesh coverage as noted by excellent peer costs on all three WLANs.

Iperf3 Mast -> Mobile Vehicle/FE1-2255B-82237 | BreadCrumb Table | Live Trace | Topology View

Starting Iperf3 Performance Test
Client: Mast/FE1-2255B-82236
Server: Mobile Vehicle/FE1-2255B-82237
Test Direction: Client->Server
Test Mode: UDP
Bitrate: 100.0 Mbits/sec
Duration: 10 seconds
Buffer Length: Automatic
Test started: 05/08/2021 14:46:28.406
Downloading Iperf3 results.

Latency: 1.786 ms.
BreadCrumb CPU Utilization: 13%
Buffer Length: 1448 bytes

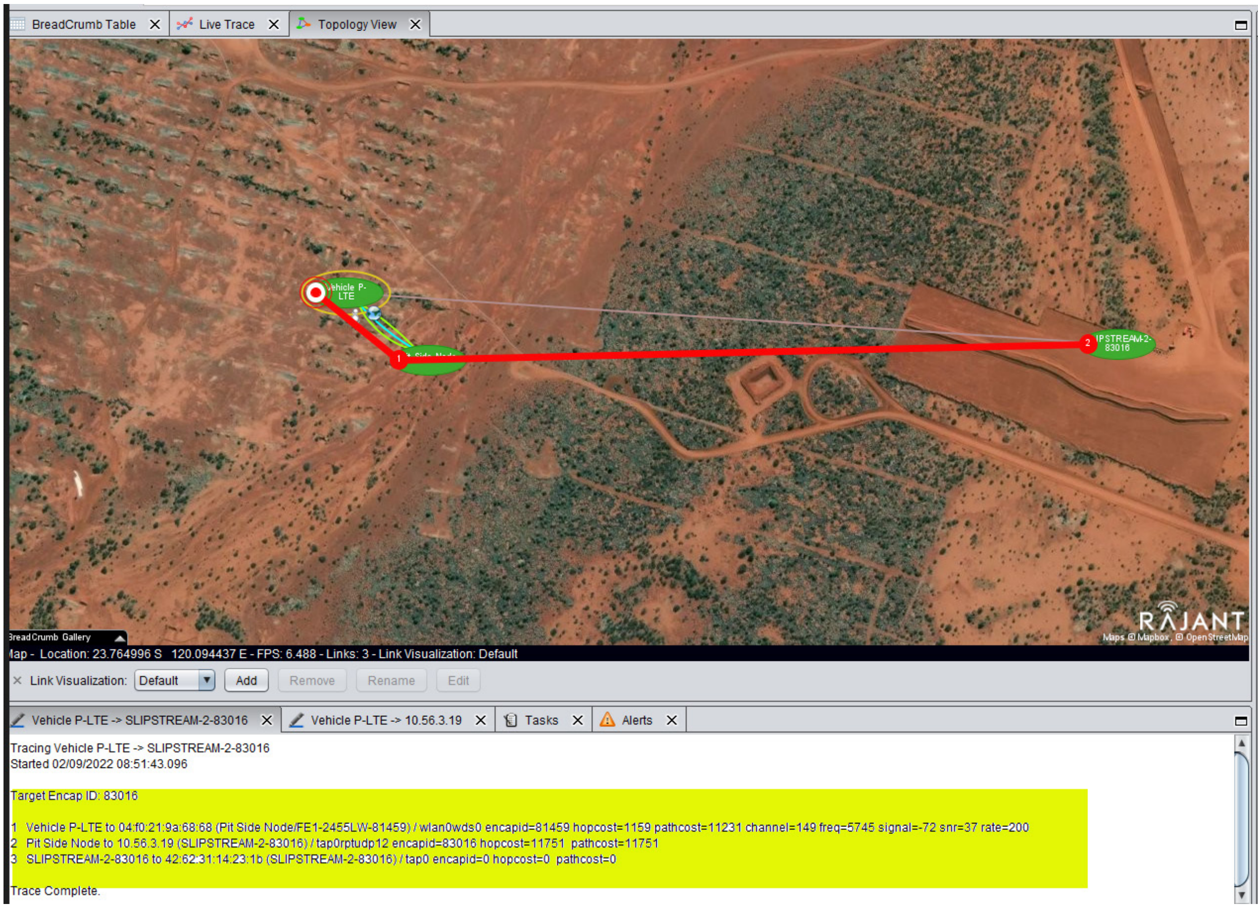
Sender: 10.65.60.1
Bitrate: 100.0 Mbits/sec
CPU Utilization: 8%

Receiver: 10.65.61.1
Bitrate: 99.5 Mbits/sec
Jitter: 0.257 ms
Packet Loss: 0.0%
CPU Utilization: 1%

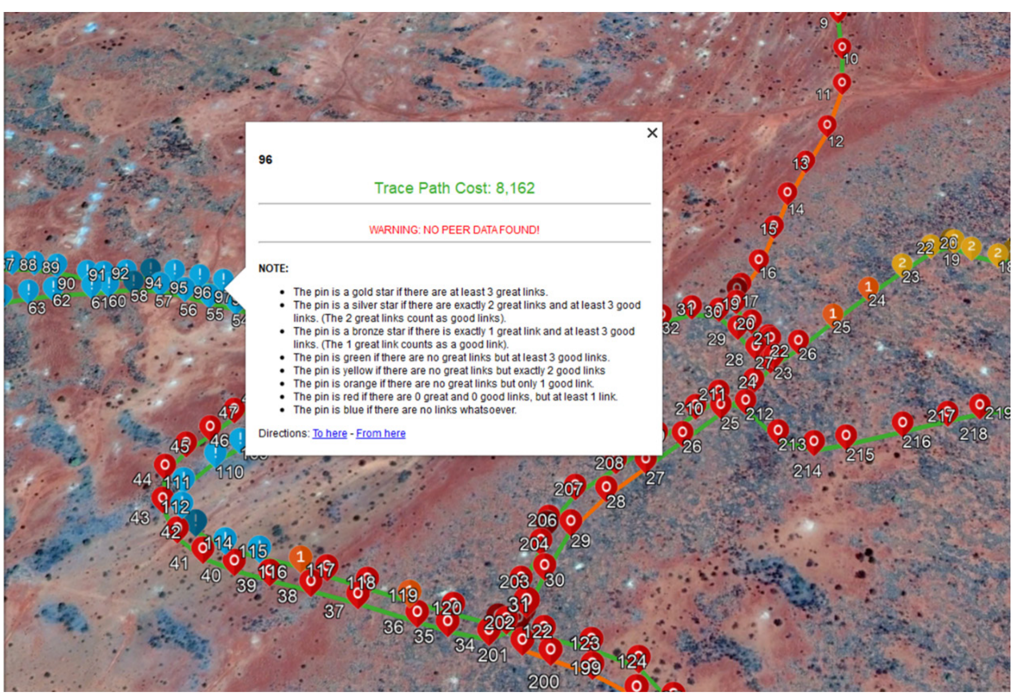
Test ended: 05/08/2021 14:46:46.039

100MBPS UDP throughput over the Kinetic Mesh is shown here.

In this InstaMesh trace during the testing, we can see the vehicle node offloading via Kinetic Mesh to the pit-side node and then using LTE to get from the pit-side node to the LTE tower. The solid lines depict the path for data.



Once the vehicle drives out of Kinetic Mesh coverage, LTE takes over. Data still flows without Kinetic Mesh coverage seamlessly over LTE.



Starting Iperf3 Performance Test
Client: FE1-2455LW-81459
Server: SLIPSTREAM-2-83016
Test Direction: Client->Server
Test Mode: AUTO_UDP
Buffer Length: Automatic
Test started: 01/26/2022 14:07:40.144
Downloading Iperf3 results.

Latency: 38.701 ms.
BreadCrumb CPU Utilization: 0%
Buffer Length: 1428 bytes

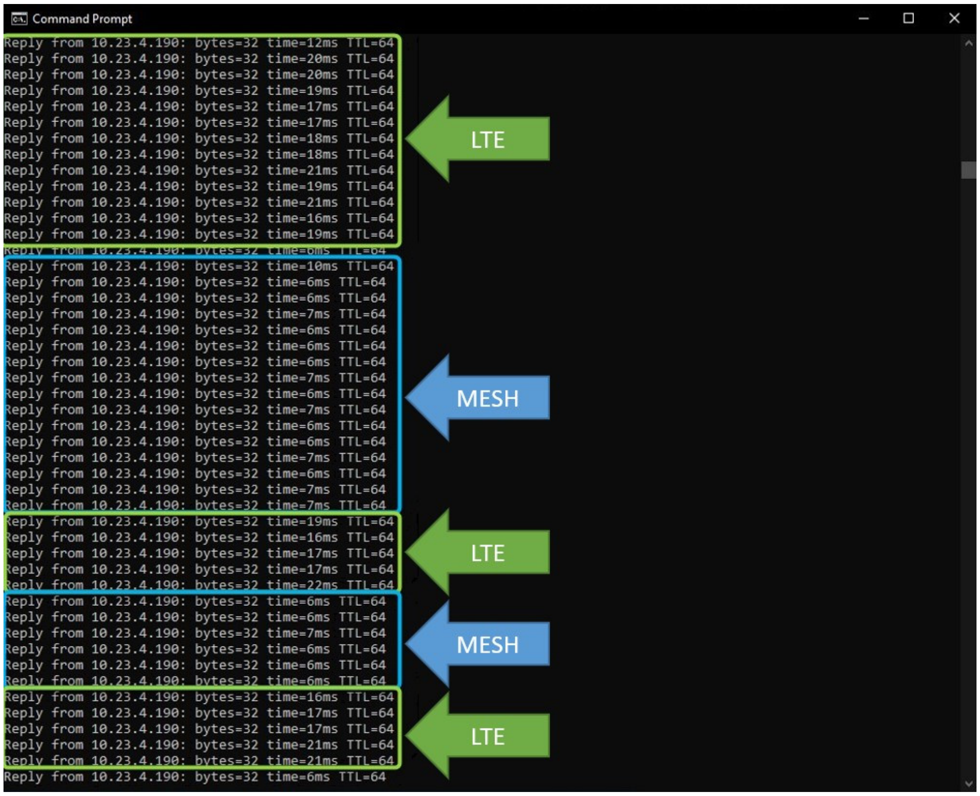
Sender: fe80::13:95ff:fe3c:e1ec
Bitrate: 20.0 Mbits/sec
CPU Utilization: 2%

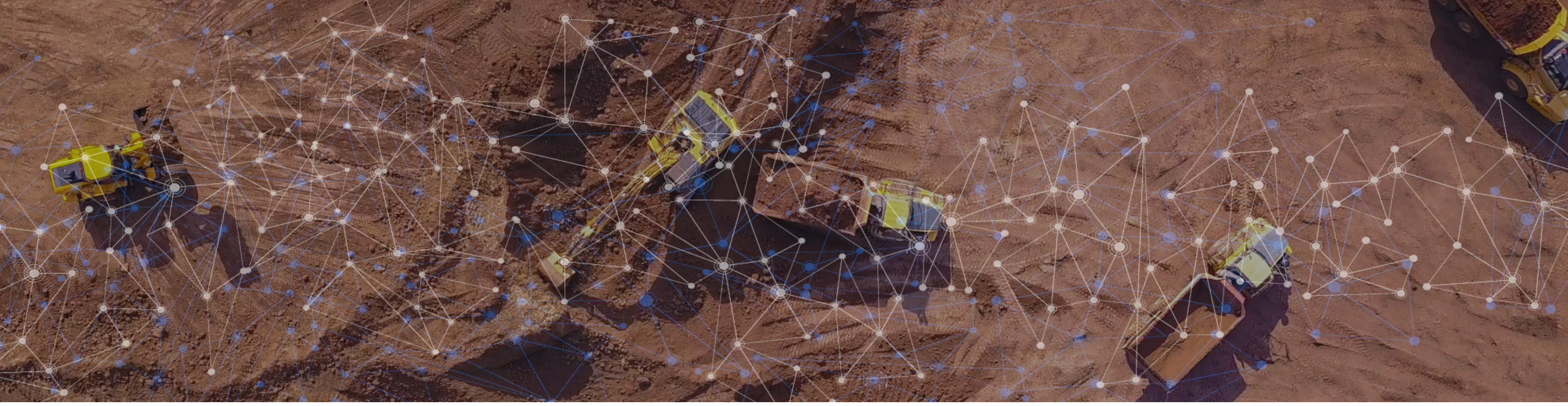
Receiver: fe80::4062:31ff:fe14:231b
Bitrate: 19.1 Mbits/sec
Jitter: 0.959 ms
Packet Loss: 1.1%
CPU Utilization: 2%

Test ended: 01/26/2022 14:08:50.187

With 20MBPS download and 10MBPS upload, we see 19.1MBPS throughput over LTE and no dropped

Roaming back and forth between LTE and Kinetic Mesh shows no ping loss below:





Requirements to Utilize Public LTE

- LTE providers typically implement Network Address Translation (NAT) on post-paid and pre-paid 4G/LTE SIM cards
- The FE1-2455LW will still get an IP address for the SIM card, however this NAT prevents the RPT tunnel from being established.

For successful implementation of RPT over public LTE, ***ensure APN supports a dynamic public IP address without NAT.***

Below is an example of public LTE dynamic IP Address using NAT. Note, no port bonding and no connectivity with NATing, Public LTE cannot work.

```
2069:instaMesh.cpp:1228:Failed to send keepalive to port 9, tap0rptudp9, 49.255.140.177 with error 89, Destination address required
2069:instaMesh.cpp:974:Failed to send periodic keepalive to rpt link 9, tap0rptudp9, 49.255.140.177,aptIsReady=0, handshakeDone=0
2069:instaMesh.cpp:1027:sendRptKeepAlives deleting port 9, tap0rptudp9, 49.255.140.177
2069:packet.cpp:439:Deleting port 9, tap0rptudp9, 49.255.140.177
2069:instaMesh.cpp:1228:Failed to send keepalive to port 10, tap0rptudp10, 49.255.140.177 with error 89, Destination address required
```

Below is an example of public LTE dynamic IP address without NAT. Note, port Bonding process completed.

```
):439:Deleting port 178, tap0rptudp178, 49.255.140.177
: 2069:instaMesh.cpp:12606:Found crumb with encapid of 83016 from port 9, tap0rptudp9, 49.255.140.177
: 2069:packet.cpp:1097:Finished handling response on port 9, tap0rptudp9, 49.255.140.177
: 2069:instaMesh.cpp:12316:Setting encapid of port 9, tap0rptudp9, 83016 after completing handshake, progress is 2
: 2069:instaMesh.cpp:12322:Enabling port 9, tap0rptudp9, 83016 after completing handshake, progress is 2
: 2069:packet.cpp:1097:Finished handling response on port 9, tap0rptudp9, 83016
: 2069:instaMesh.cpp:12670:ack response on port 9, tap0rptudp9, 83016 of 0.125919 seconds with 0 packets lost out of 2 packets sent
: 2069:instaMesh.cpp:12670:ack response on port 9, tap0rptudp9, 83016 of 0.133966 seconds with 0 packets lost out of 1 packets sent
: 2069:instaMesh.cpp:12670:ack response on port 9, tap0rptudp9, 83016 of 0.135771 seconds with 0 packets lost out of 1 packets sent
: 2069:instaMesh.cpp:12670:ack response on port 9, tap0rptudp9, 83016 of 0.125752 seconds with 0 packets lost out of 1 packets sent
```

SCTP over public LTE - successful creation of SCTP tunnel. ACK response on tunnel - ***Note:*** in the acknowledgement response, the substantially high latency across the tunnels.

```
Feb 18 07:37:30 instamesh[2069]: 2069:portInfo.cpp:1080:port 0, tap0 set srto_initial to 45000, srto_min to 7, srto_max to 45000, a
Feb 18 07:37:30 instamesh[2069]: 2069:packet.cpp:1132:Finished handling response on port 10, tap0sctp10, 49.255.140.177
Feb 18 07:37:30 instamesh[2069]: 2069:packet.cpp:1132:Finished handling response on port 10, tap0sctp10, 49.255.140.177
Feb 18 07:37:30 instamesh[2069]: 2069:instaMesh.cpp:12316:Setting encapid of port 10, tap0sctp10, 83016 after completing handshake,
Feb 18 07:37:30 instamesh[2069]: 2069:instaMesh.cpp:12322:Enabling port 10, tap0sctp10, 83016 after completing handshake, progress
Feb 18 07:37:30 instamesh[2069]: 2069:packet.cpp:1132:Finished handling response on port 10, tap0sctp10, 83016
Feb 18 07:37:36 instamesh[2069]: 2069:instaMesh.cpp:12670:ack response on port 10, tap0sctp10, 83016 of 0.114972 seconds with 0 pac
```

Testing Summary

Industrial applications, like mines, require more than LTE and Wi-Fi alone. Both are deployed for different applications, and physics defines the limitations of each. When deploying a Rajant Kinetic Mesh utilizing the FE1-2455LW, with Rajant's InstaMesh protocol routing over LTE, one can see that robust connectivity remains seamless when switching between Rajant Kinetic Mesh and LTE. Kinetic Mesh achieves much lower latency and much higher throughput while leveraging a mines LTE investment.

Rajant Peregrine LTE BreadCrumb

The Peregrine LTE is interoperable with all Rajant BreadCrumb nodes. It is part of Rajant's initiative to develop deeply integrated solutions that securely combine data from connected people, vehicles, machines, and sensors, with machine learning (ML). This new high-performance industrial-grade BreadCrumb platform provides secure connections to back-end networks using Rajant's APT and RPT tunneling while actively using multiple frequencies to avoid interference and network congestion.

The Peregrine LTE uses real-time, automated packet routing to always select the best path for each packet. This data combination unlocks the benefits of process optimization, digital twins, predictive analytics, AR, VR, and more, while improving worker safety. Capable of providing a reliable connection in highly obstructed, cluttered, or shadowed areas, the Peregrine LTE is ideal to expand market capabilities for industries like rail, shipping ports, military, mining, and heavy construction.

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