UBBA

Utility Broadband Alliance

2024 Plugfest Testing Report

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Report Contents

Thank You to the 2024 UBBA Plugfest Steering Committee:

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- Mike Brozek, Anterix
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2024 UBBA Plugfest Test Report

Executive Summary

The Utility Broadband Alliance (UBBA) is a collaboration of utilities and solution providers dedicated to championing private broadband networks for critical infrastructure industries. Since its inception, UBBA has been at the forefront of exploring and demonstrating utility-centric use cases operating on private LTE cellular networks. These efforts are highlighted through Plugfest, the premier live testing event in the U.S. focused exclusively on private LTE networks. Plugfest facilitates collaboration among solution providers to test the interoperability and connectivity of devices with private LTE infrastructures. The 2024 UBBA Plugfest highlighted the innovation, collaboration, and interoperability of three distinct utility use cases and associated devices on private LTE networks, as selected by UBBA's utility members.

Communication systems must be built to utility-grade standards to serve these critical infrastructure applications. From hardening utility infrastructure against storms and cybersecurity threats to integrating distributed energy resources (DERs) and renewables, high-speed private broadband communication plays an essential role in enabling the innovations driving the utility industry forward.

"The growth of the UBBA Summit & Plugfest over the years has been nothing short of extraordinary, and it's clear that there is great hunger in the industry for more opportunities to collaborate on delivering real-world solutions to industry challenges," said Ameren's Chris Vana, Chairman of UBBA. "Between the highly relevant and applicable technical sessions, expert thought leadership from industry luminaries and regulators and innovative Plugfest presentations, this year's event proved to be our most successful to date. We look forward to working with our members and industry partners as we begin planning to make next year's event even better."

Along with host utility, Evergy, UBBA held the 2024 Summit & Plugfest in Kansas City and welcomed more than 620 attendees, with 32% of attendees coming from utilities. The purpose of annual Plugfest events is to test, evaluate, explore, and discover how utility use cases benefit with the utilization of broadband networks, such as Private LTE. The success of Plugfest is driven by the collaborative efforts of utility and solution provider members across the UBBA community. The UBBA Plugfest Task Force plays a pivotal role in advancing the capabilities of private broadband networks by addressing the challenges utilities encounter when operating critical infrastructure under diverse conditions worldwide. Plugfest not only raises awareness within the industry but also fosters the ongoing enhancement of ideas, technologies, and operational efficiencies. These improvements ultimately benefit all stakeholders who depend on the reliable and secure operation of the electrical grid.

The Process

At the start of each year, the UBBA Plugfest Task Force initiates the planning and brainstorming phase to define the focus of the Plugfest demonstrations for the annual UBBA Summit & Plugfest conference. Comprising UBBA member utilities and solution providers, the task force collaboratively identifies key use cases to be tested, ensuring that these efforts align with the strategic needs of the utility sector. By focusing on relevant and impactful use cases, the task force ensures that the testing process delivers valuable insights and tangible benefits to utilities, fostering innovation and driving progress in the industry.

The 2024 Plugfest Task Force chose to explore, test and evaluate three specific use cases:

1. AMI 2.0
    a. As Advanced Metering Infrastructure (AMI) evolves from a focused revenue use case to a multi-sensor platform, the Plugfest Task Force will explore, educate, and demonstrate what AMI 2.0 is and how AMI 2.0 applications enable operational efficiencies to grid monitoring.
2. Device Routing
    a. As utilities transition to Private LTE networks there will be several thousands of LTE devices deployed for distribution automation. Routing of all these use cases will be critical to ensure regulatory compliance, reliability, safety, and security.
3. Edge Computing & Low Latency
    a. Moving decision making to the edge will be a valuable strategy for critical infrastructure communication. The Plugfest Task Force will explore, educate, and demonstrate how configuring devices and applications to make automated decisions in the field increase operational efficiencies, reduce costs, reduce latency, and increase overall safety. The task force seeks to explore how applications at the edge can remain secure, how they are hosted, how they are managed, and what does “Edge Compute” really mean.

Given UBBA’s emphasis on collaboration, the Plugfest Committee oversaw an extensive review process, considering proposals from many vendor teams, and narrowed the participation down to the following Alliance teams:

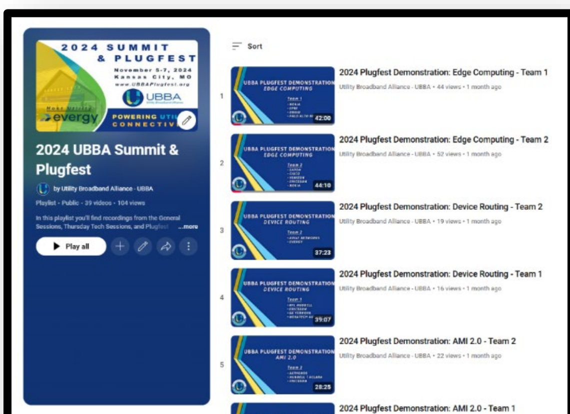
- Use Case 1: AMI 2.0
    - Team 1
        - Itron, PG&E, Xcel, Anterix, Ericsson, Nokia, Ubiik
    - Team 2
        - Ericsson, Hubbell, Aetheros
- Use Case 2: Device Routing
    - Team 1

        - GE, Ericsson, Hubbell, NovaTech
    - Team 2
        - Aviat, Evergy
- Use Case 3: Edge Computing & Low Latency
    - Team 1
        - Nokia, Druid, EPRI
    - Team 2
        - Cisco, Verizon, Ericsson, Nokia, Eaton

Each team worked together for four months developing test plans, defining parameters, and executing tests in various team members' labs. Each team observed and recorded all testing results and compiled the information into a presentation, which was presented during the 2024 UBBA Summit & Plugfest conference.

The value of Plugfest is the ability of the utility and vendor communities to collaborate and push technology forward to benefit the modernization of the electrical grid. By combining resources, such as lab spaces, utilities can evaluate and gain understanding about various technologies that support their missions.

The results in this report are presented in a "raw" state, meaning that the use case teams have compiled these summaries and submitted them to the UBBA leadership to be included in this report. UBBA has not been involved in the writing of the individual reports. Each team's testing report stands alone with respect to any background materials, perspectives and personal conclusions. Recordings of the 2024 Plugfest presentations can be viewed at the official UBBA YouTube portal.



https://www.youtube.com/playlist?list=PLJSdxnFbbbah5rDTteKbAnhnF95FoXELU
Please feel free to reach out to the utilities and solution providers involved in each use case for further explanations.

2024 UBBA Plugfest Testing Results

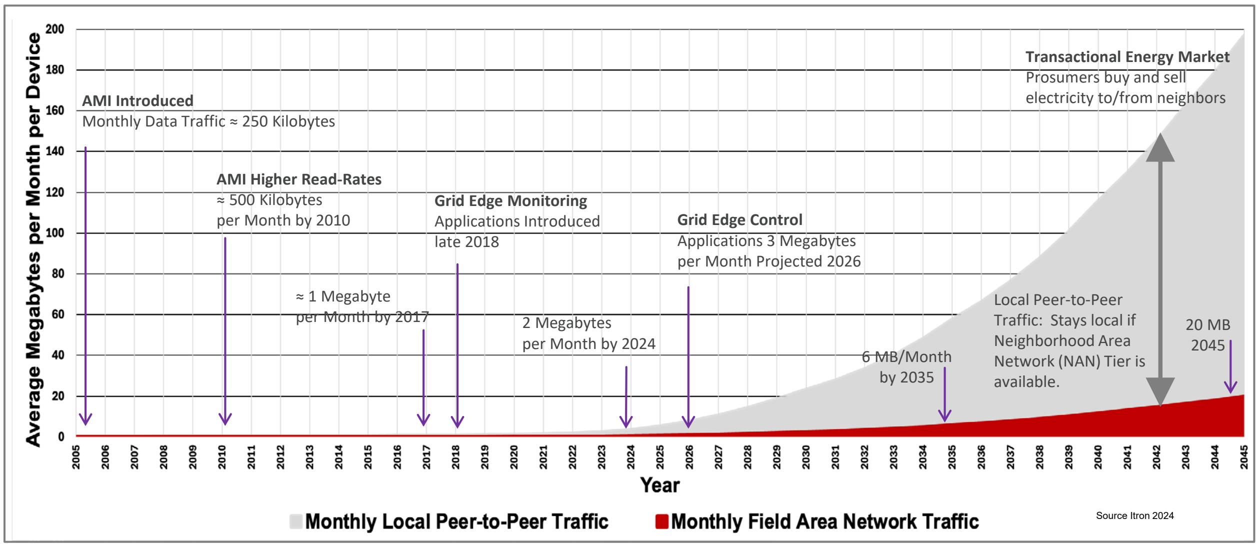
This year's effort focused on three use cases: AMI 2.0, Device Routing, and Edge Computing & Low Latency. The results of these multi-month efforts are detailed in the following sections.

Use Case 1: AMI 2.0

Team 1 – Itron, PG&E, Xcel, Anterix, Ericsson, Nokia, Ubiik

Summary of Findings

Monthly Data Traffic per Electricity Meter

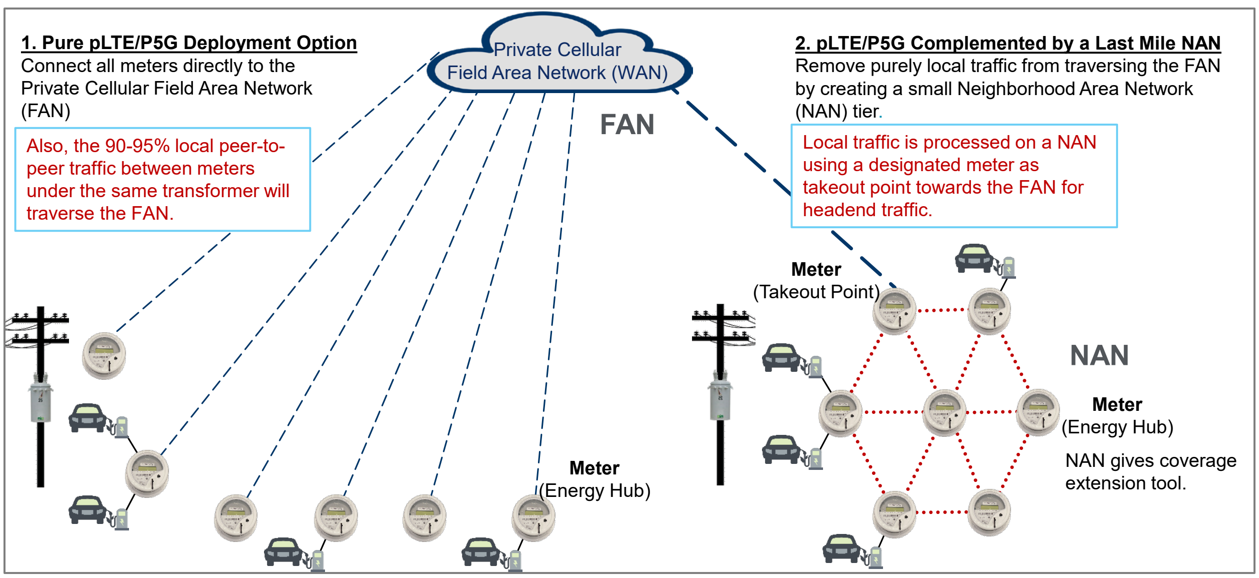


- This graph shows the AVERAGE MB/Month per Electricity Meter over time. It includes historical and predicted data values for 20 years back and 20 years in the future.
- As you can see traffic load has been relatively flat at around 0.5 – 1 MB/month during the first-generation AMI deployments as the dominant meter-to-cash use case stayed the same. All the AMI 1.0 traffic were in a client-server traffic model. This type of traffic is headend traffic and is captured in red in the graph (Monthly Field Area Network Traffic).
- AMI 2.0 has a new traffic component related to coordination at the edge to coordinate monitoring efforts and to take real-time actions. The team calls this local Peer-to-Peer (P2P) traffic, and it is shown in grey in the graph. Among the initial use cases contributing to this traffic class are Location Awareness and Transformer Load Monitoring, both of which were used for testing in this plugfest activity.
- The introduction of control applications adds more load to both P2P and headend traffic data streams, but more importantly applies a new need for more predicable latency headend to meter for load adjustments. The team used Transformer Load Management and Electric Vehicle Supply Equipment (EVSE) Management as two use

cases from this category in the plugfest study. The team expect these types of control applications to start to roll out at scale in the 2026 timeframe.

- Finally, this graph shows a prediction of an increase in traffic over the next 20 years. The increase is related to the fact that the AMI 2.0 meters have an app-delivery model and new use cases can be identified, implemented, and pushed out to the meters in the field over time. Particularly, the team expected to see further growth in the local P2P traffic once the industry enters a transactional energy market, where neighbor prosumers are selling and buying electricity from each other.
- Not all AMI 2.0 use cases generate significant traffic, either head-end or P2P, however most utilities are expected to implement the specific use cases selected for this year's plugfest analysis and testing, so Itron expects these results will be typical for U.S. AMI 2.0 deployments.

Considered AMI 2.0 Connectivity Options

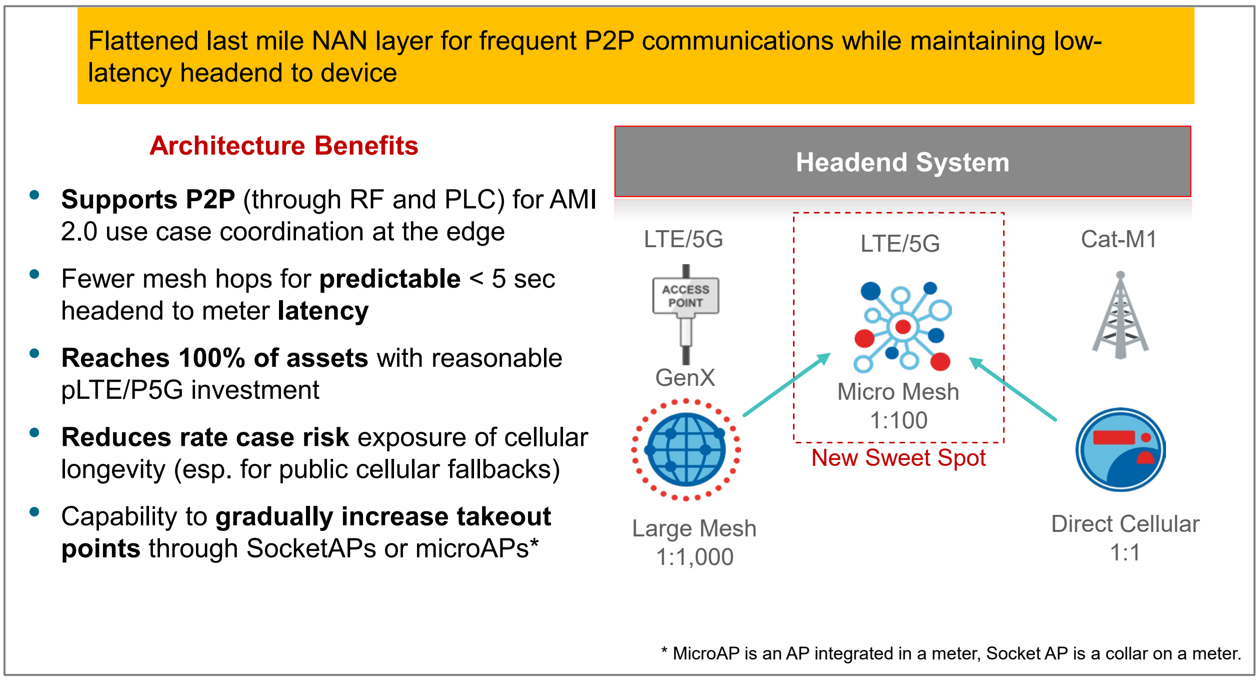


- In the plugfest activities the team studied two network architectures.
- The one to the left is a pLTE-only network architecture where the team connected all meters directly to the Private Cellular Field Area Network (FAN).
- The one on the right side of the slide shows architecture where the FAN is complemented with a small last mile Neighborhood Area Network (NAN).
- In the modeling, the team assumed that for the FAN-only architecture both the headend and the P2P traffic are traversing the FAN.
- For the FAN+NAN architecture, the team assumed that the NAN had capabilities to handle and offload large local P2P traffic (90-95% in the study) and avoid it from entering and loading the FAN unnecessarily.

- The team did the assessment of both user plane (bandwidth) and control plane (signaling) in our study. While both were limiting the FAN-only architecture, the control plane was seen harder to work around due to minute-level connection requests for both the local P2P and meter-to-headend traffic in AMI 2.0. This control plane load is managed better in the FAN+NAN architecture as it can be aggregated into more of a streaming interface at a takeout point even when modest in terms of meters. In the modeling, the team used more frequent takeout points in the form of collar-based Socket APs that the team displayed in our booth or microAP inside a meter and kept the NAN to 1-2 hops to ensure predictable latency for the control applications.

- As an additional benefit, the team also saw that the NAN addition gave a coverage extension tool that allowed us to reduce the number of required eNodeBs by approximately 20%.

Recommended Network Architecture for AMI 2.0



- So, what is the recommended architecture for AMI 2.0? While the team were at two extremes in AMI 1.0 in that the team either applied very large NAN cells as depicted in the left side of the picture or direct-to-cell to each meter as in the right side, the team concluded from the plugfest activities that a more balanced approach (named micro-mesh here) is a likely sweet spot for AMI 2.0.

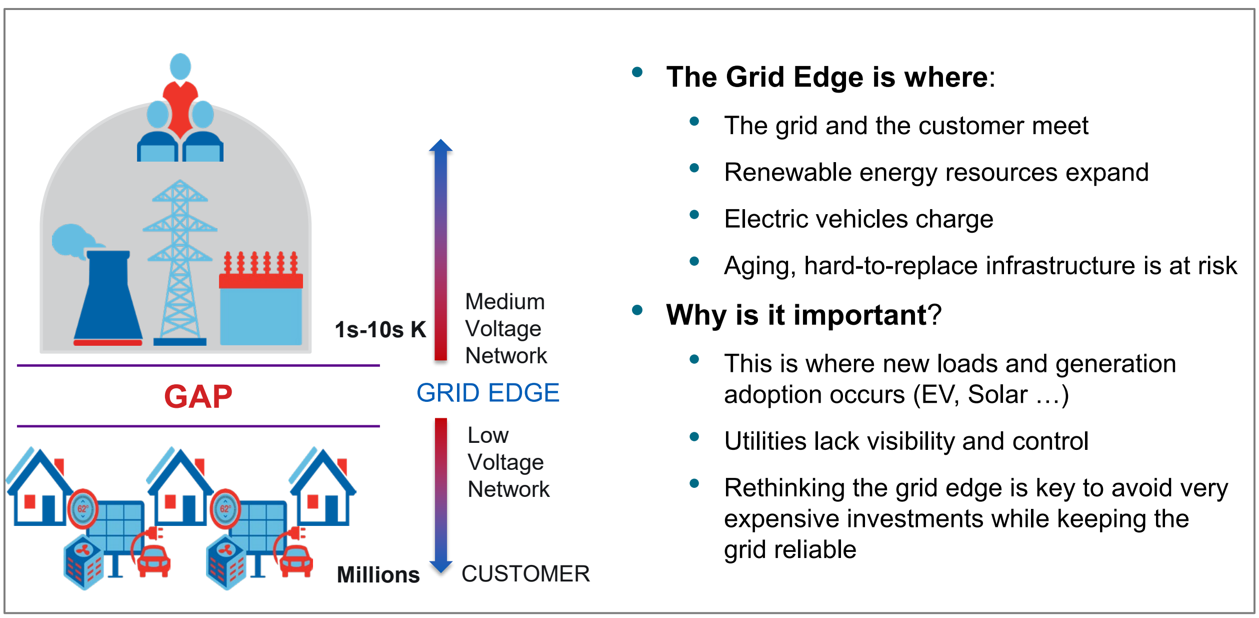
- This micro-mesh would have a flattened last mile NAN layer for handling frequent P2P communications while still maintaining low-latency communications from the headend.

- The architectural benefits of this approach are several:

- It supports P2P (through e.g., RF and PLC) for AMI 2.0 use case coordination at the edge.
- It has fewer mesh hops for predictable < 5 sec headend to meter latency.
- It reaches 100% of assets with reasonable pLTE/P5G investment using the NAN as a coverage extension tool.
- It reduces rate case risk exposure of cellular longevity (e.g., 4G Sunset), when using public cellular for fallback, where the utility does not control the longevity of the implementation. Those takeout points can be replaced once during the 20-year rate case and still achieve rate case targets.
- There is finally an inherent capability to gradually increase the number of takeout points to increase NAN layer capacity using Socket Access Points (SocketAP) and micro–Access Points (microAP) as the number of AMI 2.0 applications and data traffic grows.

- So, this was the quick high-level summary. The next sections will look at the results in more detail starting with the AMI 2.0 applications the team used in the plugfest modeling, simulation, and testing activities.

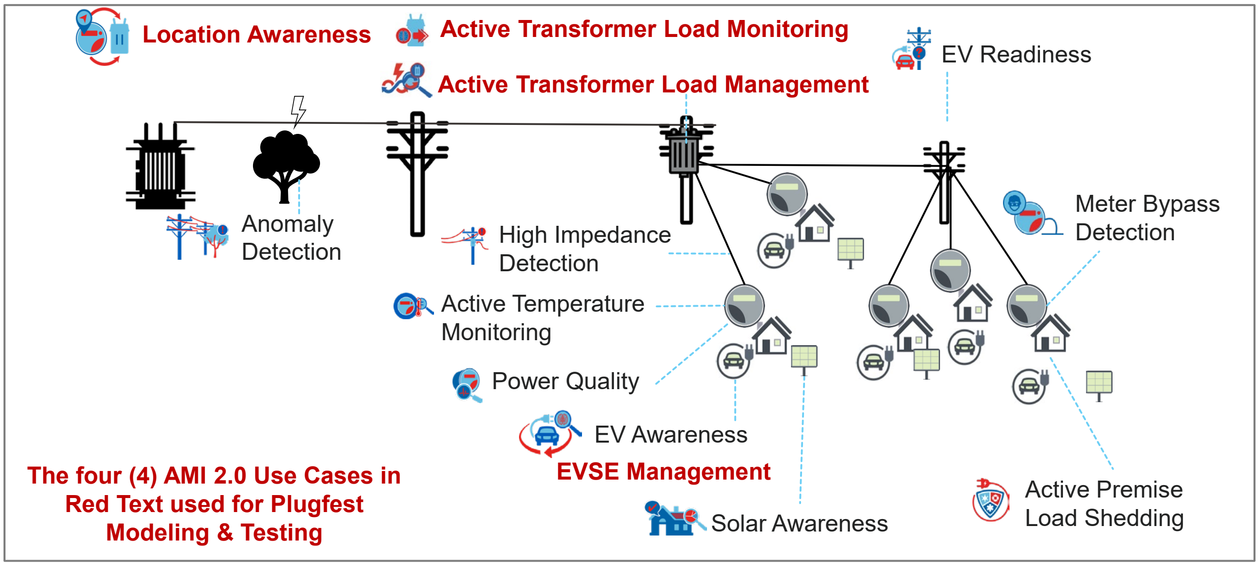
AMI 2.0 Defined: Grid Edge Intelligence



- The next generation of Advanced Metering Infrastructure, AMI 2.0, will continue to support all the traditional meter to headend AMI 1.0 applications, including meter-to-cash, outage management, over-the-air firmware downloads, etc.
- AMI 2.0 brings many new valuable capabilities to help manage the low voltage network under each distribution transformer at the power distribution network edge (Grid Edge).

- The Grid Edge is where the utility meets the customer, where renewable energy resources are expanding, where electric vehicles charge, and where aging utility infrastructure is at risk.
- Utilities need visibility and control of the Grid Edge to manage cost and maintain grid reliability.

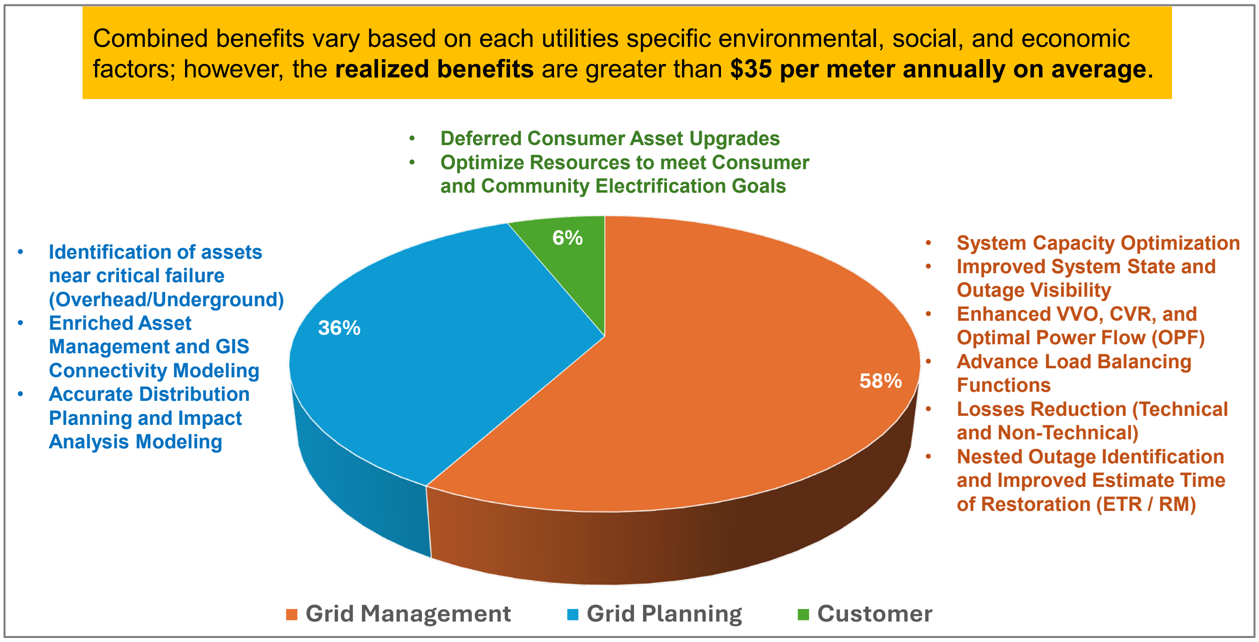
AMI 2.0 Use Cases



- To understand the information gap between the medium and low voltage power distribution networks when going to AMI 2.0 (the left column in our previous slide), the team needed to review what some of the Grid Edge applications are and how they work. This picture shows some of the currently developed and soon-to-be released Grid Edge Intelligence applications.
- While there are some applications like solar and EV awareness that work independently on each meter using ML load disaggregation logic, there are a set of applications that have been deemed very valuable and that are operating truly distributed. These applications leverage the ability to collaborate and communicate extensively between the meters served by the same transformer phase. Examples include those shown in red at the top of the diagram.
- The foundational application Location Awareness is one of those. It is used by GIS to know 100% accurately at any time under which transformer, phase and feeder a meter is electrically located. PLC broadcast is used here as it is an economical way to discover this mapping.
- Active transformer load monitoring is an example of an additional application that relies on a coordinated view. In this case, it is the instantaneous load from each meter under a transformer that needs to be coordinated and shared.

- The key takeaway is that the team now have a new type of traffic pattern that the team did not have before and that the team refer to as local peer-to-peer (local P2P).

Average AMI 2.0 Benefits Among Engaged Utilities



- The realized cost benefits from AMI 2.0, based on a cross-section of applications utilities in the United States envision implementing fall into three (3) primary categories:
    - Grid Management
    - Grid Planning
    - Direct Customer Benefits

- The average realized cost benefit per AMI 2.0 meter is very conservatively projected to be greater than $35 per meter annually, with the savings distributed between each category:
    - **Grid Management** **58%**
    - **Grid Planning** **36%**
    - **Direct Customer Benefits** **6%**

- This diagram also provides a list of examples of some specific benefits in each category.

PG&E EVSE Management Business Case Assigned Value

- **Customer Challenge**
  - **~50% of customers have 100A panels** which need immediate upgrade to 200A to serve Level 2 EV home charging
  - Many of these customers will **trigger service upgrades** which can vary in cost from $3,000 to $50,000/site with 2-to-12-month durations
  - Customers either don't buy or return an EV, charge on Level 1 outlets, or perform unpermitted work **causing transformer failures**
- **Value**
  - ~$9,500/EV-equipped home in **customer value**
  - ~$8,500/EV-equipped home in **grid deferral**

Neighborhood infrastructure can be sufficient *if* coordinated

Month -->	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	25.4	21.8	23.8	19.0	21.4	25.5	25.1	32.0	31.7	17.9	26.9	27.0
1	25.3	21.3	19.9	27.4	25.2	29.4	28.1	31.1	39.1	18.9	24.6	23.3
2	26.2	27.6	25.4	27.8	25.3	30.0	32.9	36.3	36.7	22.5	28.8	22.4
3	26.2	24.7	22.7	25.6	22.4	24.4	30.3	33.5	27.8	30.9	22.5	22.0
4	26.7	20.9	22.2	22.2	14.5	21.4	32.9	23.3	32.7	24.0	30.9	33.5
5	28.7	26.7	26.4	22.5	11.6	21.9	30.1	31.3	39.0	31.5	36.6	33.8
6	28.1	28.5	28.3	23.7	11.5	28.4	33.3	29.8	31.8	29.0	30.7	33.7
7	27.8	25.4	27.4	15.4	14.1	22.3	27.0	18.5	16.4	20.3	23.3	27.8
8	23.5	34.0	28.1	17.3	16.0	15.1	20.5	17.1	17.2	19.9	21.4	33.6
9	30.2	23.9	21.2	20.2	17.7	18.4	18.9	20.4	21.3	18.3	20.8	23.9
10	28.3	25.0	23.5	22.9	23.7	17.5	19.0	24.9	28.6	22.2	24.7	25.4
11	25.3	24.5	29.4	24.9	22.9	23.9	20.5	29.2	33.1	23.6	24.5	26.8
12	25.6	23.9	25.4	27.1	29.1	26.3	23.9	37.4	32.1	29.5	24.6	28.6
13	26.5	24.0	24.4	25.3	37.0	31.7	25.0	38.7	41.3	29.3	28.1	29.7
14	25.7	28.6	27.2	28.5	39.2	36.3	29.6	46.4	54.2	26.8	27.8	26.7
15	27.0	31.1	24.9	32.8	41.6	37.6	33.0	52.2	58.4	33.1	22.3	28.3
16	27.4	30.3	25.5	22.9	41.9	51.9	38.5	53.6	58.8	40.2	22.9	24.6
17	29.0	28.6	29.3	22.1	44.4	49.9	34.1	54.3	60.5	39.0	25.0	28.6
18	34.5	29.6	30.2	23.6	46.1	52.6	36.9	54.4	60.0	40.8	25.5	31.1
19	29.7	28.6	26.4	23.6	43.1	49.7	37.1	55.2	54.0	31.7	27.5	32.2
20	29.0	27.2	28.5	24.7	41.8	45.2	30.7	47.2	51.4	31.0	26.6	29.7
21	30.2	30.5	27.0	28.0	45.6	38.3	26.3	45.2	43.2	30.6	27.5	34.4
22	30.6	28.4	29.7	25.9	39.4	36.8	27.3	40.2	39.1	25.3	28.1	33.2
23	30.5	28.6	24.5	24.4	26.5	36.6	25.2	34.8	34.3	26.8	29.3	27.4
Nightly surplus	307	310	316	325	330	318	313	308	316	325	313	301
Commutes	**26.1**	**26.4**	**26.9**	**27.7**	**28.1**	**27.0**	**26.7**	**26.2**	**26.9**	**27.6**	**26.6**	**25.6**

- As part of exploring ways to modernize its electric meter network, PG&E is working on a customer-focused pilot to develop and test the management of EV charging loads in real-time, with the goal of significantly lowering the cost barrier for customers to charge their EV at home by avoiding the need for costly customer electric panel and service upgrades averaging approximately $18,000 per household (~$9,500 for residential customer panel upgrade and ~$8,500 for utility service upgrade).

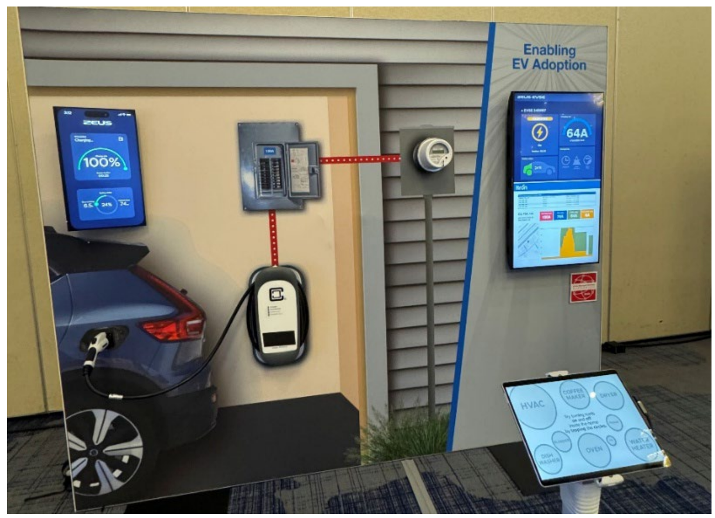
- Currently, about 50% of PG&E residential customers have 100A panels which would otherwise need to be upgraded to 200A panels to accommodate a Level 2 EV charger. A service upgrade can vary in cost from $3,000 to $50,000 per site and take 2 to 12 months to complete.

- PG&E is working to give more of its customers access to faster charging at home through a safe and affordable alternative to panel and service upgrades. This solution makes EV adoption easier because customers can avoid out-of-pocket expenses and get faster Level 2 EV charging immediately, while keeping vehicle charging within safe grid limits.

- Typically, a Level 2 EV charger requires a 200-amp service to the customer's home. A Level 2 charger is up to 15 times faster than plugging into a standard wall outlet and allows drivers to fill an all-electric vehicle from empty overnight. If a customer has 100-amp service, which is the case for about half of the existing homes in PG&E's service area, upgrading to a 200-amp panel and service can cost customers thousands of dollars and take months to complete.

- Unlike typical cloud-only software-based integrations that exchange information only a few times a day, the PG&E EV Connect program is unique in that it uses AMI 2.0 distributed intelligence (DI) edge computing that operates on a customer's electric meter directly. This on-meter application connects to, and coordinates with, the customer's EV charger to keep charging within their panel and utility grid limits. The combined solution enables a customer to avoid the cost and time of panel and service upgrades while still being able to install and operate faster Level 2 EV charging at home.

- The innovative EV Connect program is the first of its kind and combines elements of consumer engagement, advanced edge compute capabilities and broad industry collaboration to provide a cost-effective, consumer-friendly, secure end-to-end solution that increases access to electric vehicle charging for PG&E's customers.
- The initial scope of the EV Connect pilot program will support up to 1,000 residential customers who currently own or are considering purchasing an EV and have panel or service limitations that prevent them from installing a Level 2 EV charger at home. PG&E will replace customers' existing electric SmartMeters™ with Itron Riva meters, enabling them to immediately install and utilize Level 2 chargers available within the program.



- PG&E will launch the new pilot offering in early 2025, with larger availability in the second half of 2025. Depending on learnings and the success of the pilot program, PG&E will evaluate extending the program to be broadly available on an ongoing basis.
- A demonstration of the EV Connect application at PG&E's 2024 Innovation Summit on Nov. 13, 2024 in San Jose is available here: Media Access Site - pCloud

AMI 1.0 Use Cases and Traffic Requirements

Use Cases	Network Needs
• **Meter Data Collection**	• 1 day of interval & total data from **100% every 24 hours**.
◦ Daily, Hourly and lately every 15 minutes	◦ 99% in 4 hours, 99.9% in 24 hours
• **Remote Individual Reads**	• 7 days of interval & total data from **~2% every 24 hours**.
◦ For customer trouble ticketing support	◦ 90% in 30 min, 99% in 1 hour, 99.9% in 6 hours
• **Remote Commands**	• Execute command to **~2% every 24 hours**.
◦ Disconnects	◦ 90% in 10 min, 99% in 1 hour
• **Outage**	• 90% of alarms received within 1 hr (**last-gasp < 75 sec**);
◦ Outage & Restoration Notifications	◦ 90% of restoration received within 1 hour
• **Firmware OTA**	• < **3 weeks for 1 MB** firmware update to 100% of POP

- The team are now going over to the traffic model, and the team start with the AMI 1.0 use cases as these will not go away and need to be modeled as a base traffic volume/load.
- The team used a modern AMI 1.0 deployment with predominantly every 15-minute meter data collection and average packet size of 300 bytes.
- The outage notifications use case is the most stringent and hardest to solve AMI 1.0 use case as it is limited by the supercaps on the meters and as such only allows 60-75 seconds for all impacted meters to send their last gasp. This creates a burst of control signaling and sending of small data packets (PON-Power Outage Notification & PRN-Power Restoration Notification). It also gives a view into what is coming with AMI 2.0 on a continuous basis with its once-per-minute data transmissions that are required for some applications.
- Note also that the team have applied an average of 1 MB for firmware download. For the month when the firmware is downloaded, it is required to take less than 3 weeks to roll out to all the meters. Note that the actual size of the download can vary significantly from small incremental updates to quite large 25 MB updates if the Linux OS needs to be refreshed.

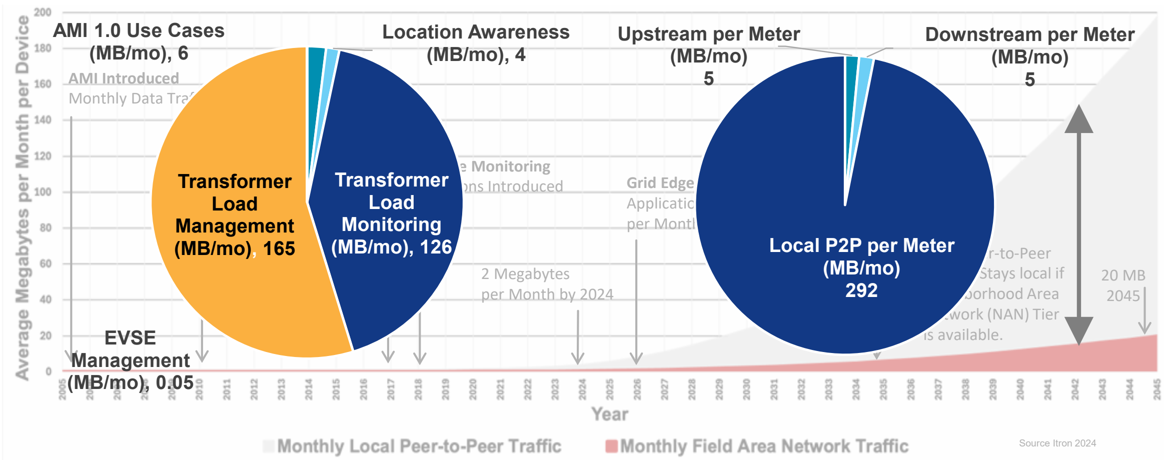
AMI 2.0 Use Cases and Traffic Requirements

Use Cases	Network Needs
LOCATION AWARENESS • Electrical location of every meter, incl. transformer, phase, and feeder. • Used for GIS, improved outage response, feeder phase balancing, etc.	**LOCATION AWARENESS** • **To Other Meters on Transformer**: 100% Every Hour • To Headend: 100% Daily; Latency in Minutes
ACTIVE TRANSFORMER LOAD MONITORING • Monitoring of transformer load statistics, incl, overload, reverse flow and power factor. • Used for preserving transformer life and reduce unplanned interruptions	**ACTIVE TRANSFORMER LOAD MONITORING** • To other Meters on Transformer: **100% Every Minute** • To Headend: 15% Every Minute; Latency < 1 Minute
ACTIVE TRANSFORMER LOAD MANAGEMENT • Power down capability to meter & appliance, incl. to shed load & manage frequency . • Used to moderate capacity build-out and stabilize the service for critical assets	**ACTIVE TRANSFORMER LOAD MANAGEMENT** • To Other Meters on Transformer: 100% Every Minute • From Headend: ~3% Once a Day (Summer/Winter); **Latency 5 Sec**.
EVSE MANAGEMENT • Throttle smart EV chargers to a percentage of their max charge capacities. • Used to optimize host capacities at transformer, secondary bus & household breaker.	**EVSE MANAGEMENT** • To Other Meters on Transformer: Built on top of ATLM • To EV Charger: ~15% of EV Assets Once a Day; **Latency < 1 Sec**. • To Headend: ~15% of EV Assets Once a Day; Latency 1-2 Sec.
APPLICATION OTA	**< 3 weeks for 1 MB** app update to 100% of POP

- Going over to the AMI 2.0 use cases, you can see the use cases this team modeled on the left and then their traffic requirements on the right.
- Particularly worth highlighting is the meter-to-meter communication pattern that already starts with Location Awareness and then is accentuated with Transformer Load Monitoring. There is a once-per-minute default schedule with an average packet size of 500 bytes.
- With the addition of Transformer Load Management, the team are getting the additional requirement of a 5 second level latency from headend to meter for control load shedding commands to be executed.
- The EVSE Management use case is built on top of the others and adds msec-level comms requirement for behind-the-meter connectivity to the EV Charger as well as a 1-2 sec latency requirement for updating the headend and any associated user apps on changes to the charge rate and the time required to full charge.
- Finally, the team added another 1MB for application downloads and set the same 3-week requirement for a complete rollout of those application updates to each meter during the month that it occurs.

Traffic Model Results

Analysis uses an average **meter-to-transformer ratio of 7:1.** No broadcast among transformer group meters is applied as only available on NAN option today.

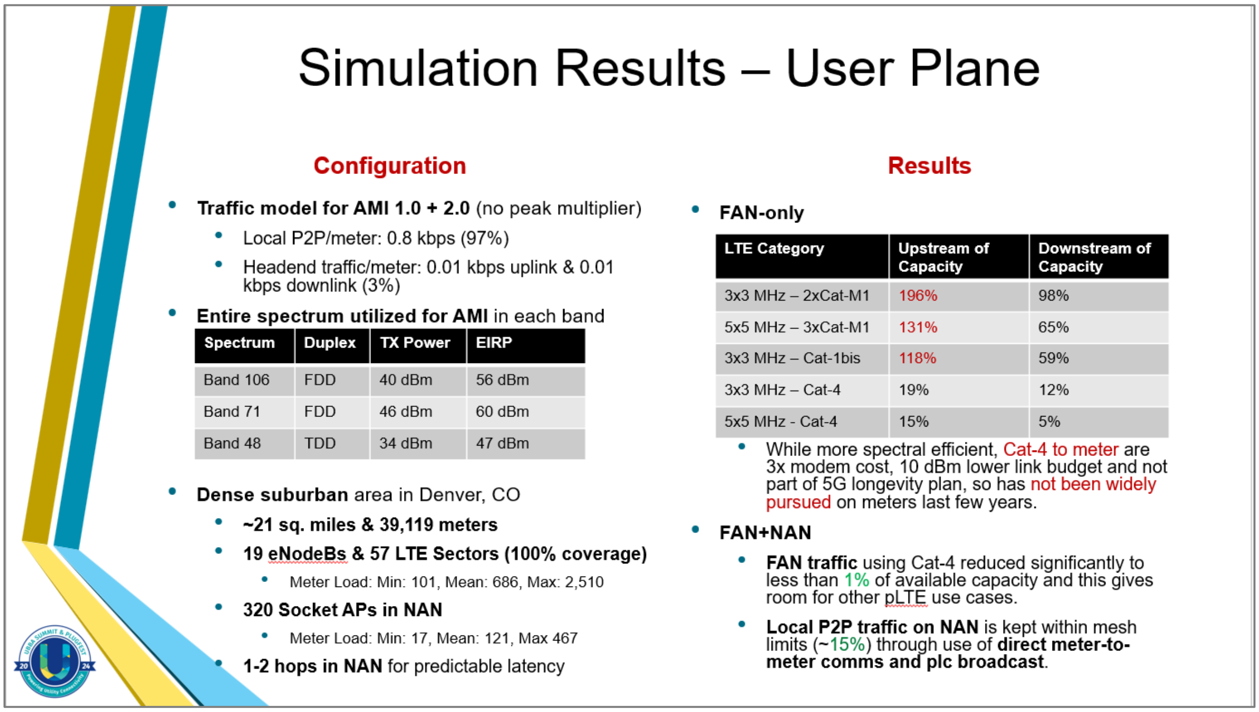


- **AMI 2.0** applications represent **98%**, while AMI 1.0 (incl. FWDL) represent 2% of total traffic.
- AMI 2.0 apps build on each other with **Transformer Load Monitoring and Mgmt. constituting 95%** of total traffic (with unicast).
- **Local P2P** traffic accounts for **97%** of total traffic. Head End System (HES) traffic accounts for only 3% of total traffic.
- **Meter-to-Headend** Traffic load similar **~5 MB/month up- & downstream.**

- In the analysis, the team used an average meter-to-transformer ratio of 7:1. This is very much an average number and can vary significantly.
- The team are also modeling the simpler use case of single transformer load monitoring and not phase-level monitoring that would need traversing multiple transformers for coordination.
- To get comparable results between the two architectures later, the team are not showing any efficiency measures like broadcast among transformer group meters in the NAN. All traffic is modeled as unicast.
- The left-side pie chart shows the overall traffic load split between use cases. As the team can see AMI 2.0 applications represent 98% of the load, while AMI 1.0 (incl. FWDL) represents only 2% of total traffic. While the AMI 2.0 apps are built on each other, the Transformer Load Monitoring and Management are together constituting 95% of total traffic. Again, note that this is modeled as unicast.
- In the right-side pie chart, the team see a split between P2P and headend traffic. In this model, the local P2P traffic accounts for 97% of total traffic, while the Head End System (HES) traffic accounts for only 3% of total traffic. Also worth noting is that Meter-to-Headend Traffic load is approximately symmetric ~5 MB/month up- & downstream. This comes from the fact that the team modeled for a month when firmware and app downloads occurred.

Simulation Results

Simulation Results – User Plane



- The simulations of the user plane were done using EDX Wireless SignalPro software. This is a coverage analysis software which also can track user plane bandwidth usage.
- You will see in the reflection section a model made by Nokia to check the results. The data aligns from both activities when considering that packet load and message sizes were slightly larger in this traffic model than in the Nokia model.
- As part of the configuration column (left side of above table), you can first see the input data taken from the traffic model, i.e., 800 bps in terms of local P2P (97%) and 10 bps uplink and downlink (3%) to the headend, respectively. The team modeled a month in which firmware download occurs. It is important to note that the team didn't add any peak multiplier when going from MB/month to Mbps as this is a network design criteria. However, it does mean that the team have no buffer for traffic peaks as one normally can expect peaks in the range of 200% to 500% or more.
- The second simplification the team made was that the entire cellular spectrum could be used for AMI. Of course, in real life, a significant portion of the spectrum will be used for other use cases such as SCADA, DA, MCPTT, and Video Surveillance.
- The team modeled three bands: B106 in the 900 MHz range, B71 in the 600 MHz range and B48 (CBRS) in the 3 GHz range. The modeling was done at the FCC max EIRP limit and with a 14 dBm antenna gain. – 110 dBm was used as coverage threshold point

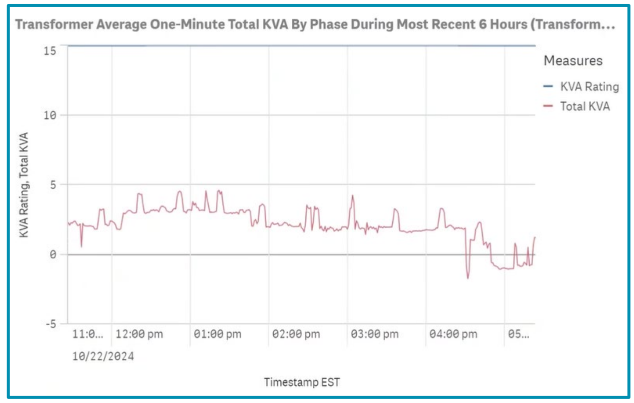
based on experience from existing Cat-M1 meter deployments. Most base station antennas were placed at 65 ft height with a few at 100 ft building height. The main design was based on the B106 900 MHz spectrum and then checked on the others for coverage. While B71 Cat-M1 could remove 1-2 eNodeBs, and B48 CBRS Cat-4 had 234-meters dropout for that design.

- The team modeled a suburban area in Denver, Colorado of about 21 square miles and 40,000 meters. To achieve 100% coverage in the FAN-only model, the team needed to use 57 eNodeB sectors. In the FAN+NAN model, the team used 320 Socket APs located at 5 ft (meter) height (no pole mounted NAN assets) and limited the NAN to 1-2 hops for more predictable latency.
- On the right side of the above table, the team shows the results from the simulation. For the FAN-only alternative the team compared the required bandwidth with typical real-world available sector capacity, e.g., 600 kbps downlink & 300 kbps uplink for 2x1.4 MHz Cat-M1 and 5.1 Mbps downlink & 3.1 Mbps uplink for 3 MHz Cat-4. Note that these standard settings could be tweaked to favor uplink a bit more in a private LTE network deployment, but this was not considered here. As the team can see, the team ran over the available capacity even if using the whole spectrum with Cat-M1. Cat-4 showed to be more spectrum efficient.
- On the other hand, using Cat-4 in Socket APs is more of the norm as these can be replaced once in a 20-year rate case. With this takeout point doing data aggregation and by offloading the P2P traffic on the NAN, the team got down to less than 1% of available FAN capacity on a 3x3 MHz spectrum. This approach leaves 99% of the available FAN capacity for other pLTE use cases, which is desired.

Simulation Results – Control Plane

Clogging the control channel before the data channel on Cat-M1 when there are a lot of small packets even **with one use case** (see below). **Offloading P2P Traffic to a connectionless NAN** and aggregating traffic towards headend using a Socket AP, e.g. Cat-4, **solves this problem**.

- **Instantaneous load gets sent every minute** for Transformer Load Monitoring
  - ~ similar to Outage Notifications but now on a continuous basis every minute.
- **Max 100-150 devices in RRC Connected State** for Cat-M1 1.4 MHz. 10 seconds refresh cycle.
  - Max 1,000 devices/minute at 500B messages.*
- **P2P Traffic:** Max sector size: 2,510. Each meter sends **6 messages in one RCC** to the other transformer group meters.
  - Connection requests: **2,510 > 1,000**
- **Headend Traffic**: Only one meter in the transformer group (**1 in 7**) sends an update:
  - Connection requests: 2,510/7 = **360 < 1,000**



* Comparatively 3x3 MHz Cat-4 will max out at 1,500-2,000 devices per minute and sector. Control plane activities then take 20-30% of the capacity.

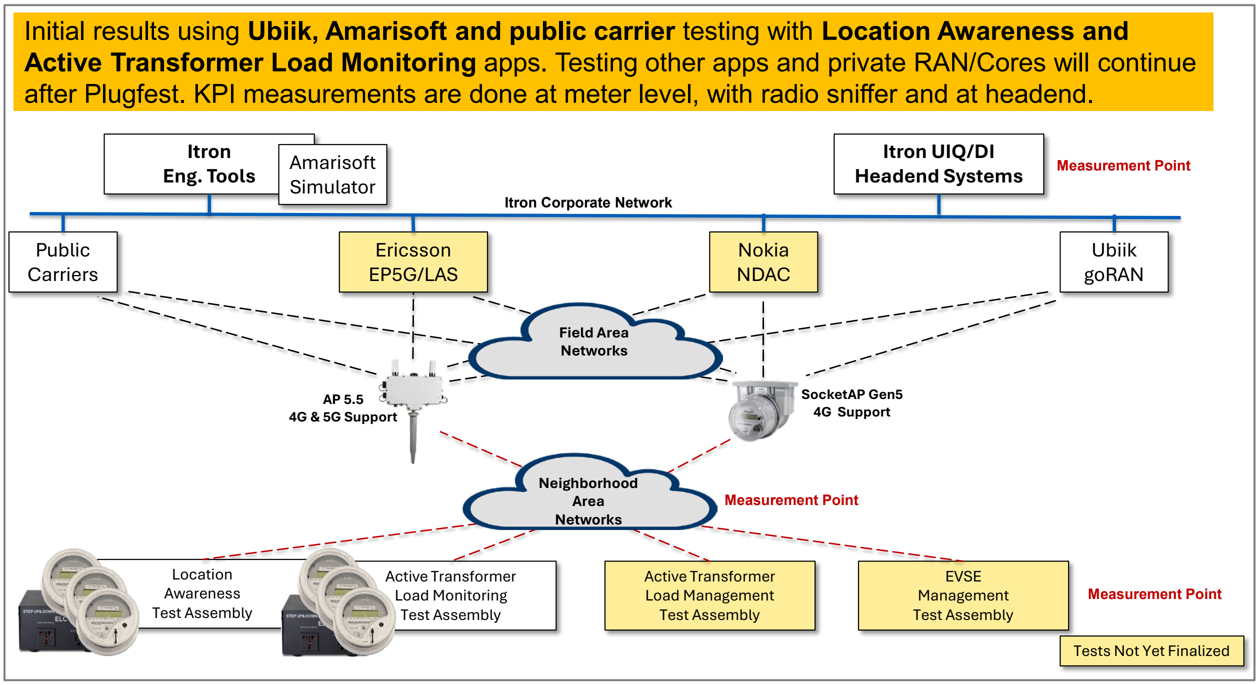
For the FAN-only network architecture model, when it comes to the control plane, the banner at the top of this diagram summarizes the situation. The team are clogging the control channel on Cat-M1 when there are a lot of frequent small packets. The team have already attempted sending a message from all meters in a sector within one minute for the Outage Notifications use case in AMI 1.0, but now the team have this pattern on a continuous basis with applications like Transformer Load Monitoring.

When Itron modeled this on a single Cat-M1 channel, the team hit the limit at around 1,000 meters per sector despite concatenating all messages into one RRC connection. Note that this is with perfect randomization pacing of requests across devices, which is hard to achieve 100%. The NAN+FAN on the other hand, can cope with this by 1) offloading P2P Traffic to a preferably connectionless NAN and 2) aggregating traffic towards headend using a spokesmeter model so that 1 in 7 on average is sending the instantaneous load up to the ADMS via a further centralized takeout point.

These results are specific to the assumptions described above for the Itron modeling, simulation, and testing effort. Actual user plane capacity and control plane signaling capacity will be based on the specific use cases implemented by each utility, the overall density of endpoints, and private LTE network design details.

Lab Test Results

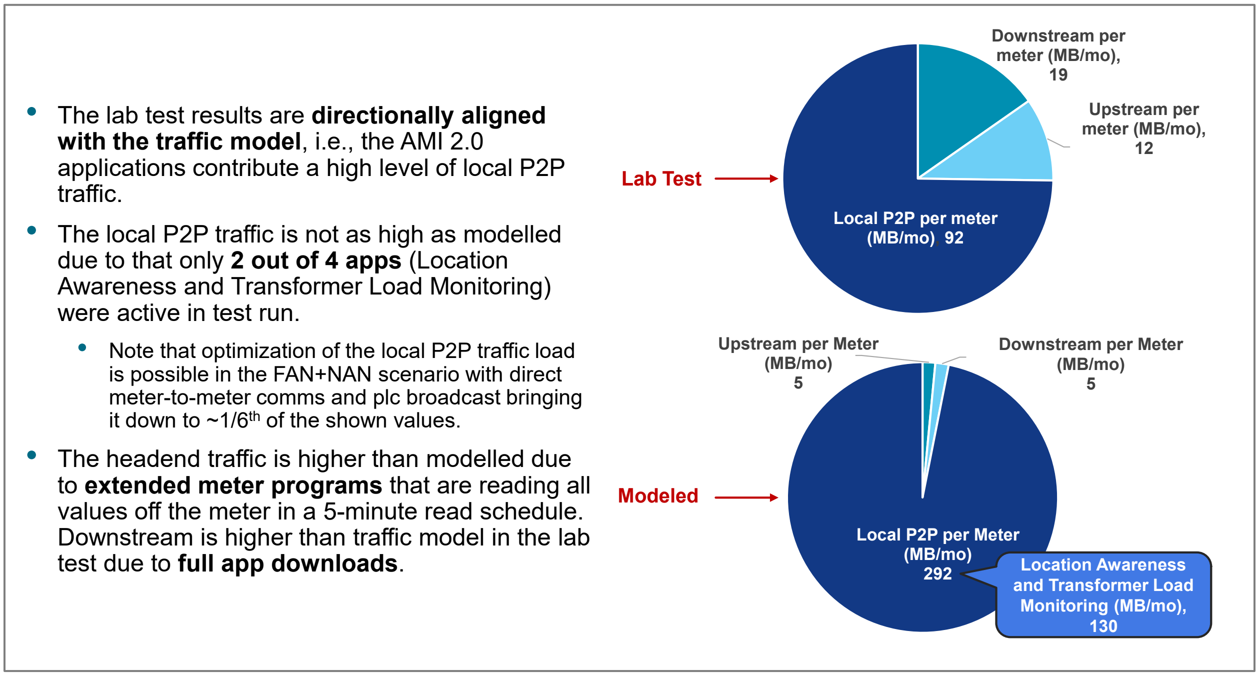
Itron Cellular Lab Test Facility



This diagram shows the lab setup that was implemented at the Itron corporate headquarters facility. The initial lab test results presented at plugfest are based on using Ubiik, Amarisoft, and public carrier RAN/Cores as well as two Itron AMI 2.0 use cases Location Awareness and Active Transformer Monitoring. Testing will continue after the 2024 UBBA Summit and Plugfest using the Nokia NDAC and Ericsson Lab as a Service (LaaS) solutions, along with the Transformer Load Management, EVSE Management, and other Itron Distributed Intelligence (DI) applications and Grid Edge Intelligence (GEI) solutions.

To come up with all the load values, the team added measurement points at the meter level, on the radio and at the headend. The measurements were taken for one day and then extrapolated to monthly values so that they could be compared with the traffic model.

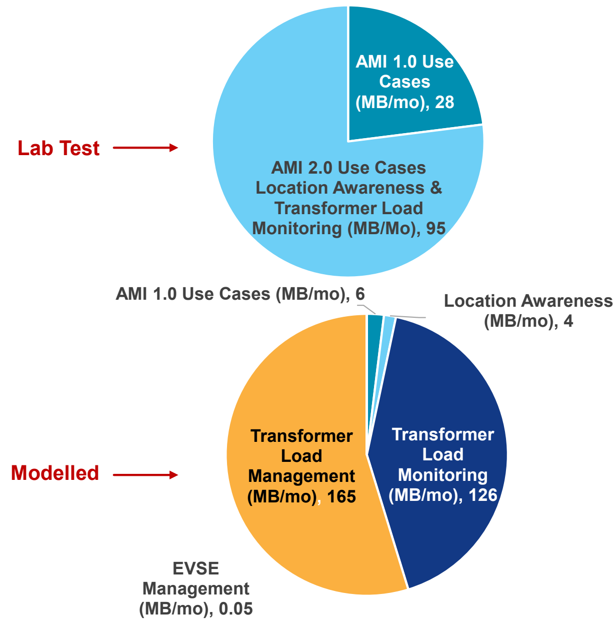
Lab Test Results – Headend vs P2P Traffic



- The upper pie chart shows the Lab Test Results (the actual measured data), while the lower pie chart reflects the modeling results.
- When it comes to headend vs. P2P traffic load the lab test is directionally aligned with the traffic model, i.e., the AMI 2.0 applications contribute to a high level of local P2P traffic.
- That the local P2P traffic is not as high in the lab test comes from the fact that only 2 out of the 4 apps were active in the test run.
- The team can also see a slightly higher headend traffic load in the test results. This comes from the fact that the team had extended meter programs reading all values in the meter, a 5-minute read schedule and a full app download during the test.

Lab Test Results – AMI 1.0 vs. AMI 2.0 Traffic

- The lab test results are **directionally aligned with the traffic model** as AMI 2.0 applications are contributing majority of the load.
- The lab test result is capturing load from **2 out of 4 apps** (Location Awareness and Transformer Load Monitoring). The test runs for the other two were not ready in time.
- As mentioned, AMI 1.0 is contributing with a higher load in the lab test than the large-scale traffic model due to **extended meter programs** reading all values off the meter in a 5-minute read schedule plus complete app downloads.



- This diagram gives the breakdown of AMI 1.0 vs. AMI 2.0 traffic with the lab test results in the top pie chart and the traffic model in the lower pie chart. Both are directionally aligned with AMI 2.0 contributing most of the traffic load even if not as much as in the traffic model due to the previously noted differences of 2 out of 4 apps and extended meter program / app downloads in the lab test.

Reflections on Results- Each member company provided some reflection on the results in this section.

Reflections on Results – Itron

Main Conclusions from UBBA Plugfest Program	Trigger of Further Work and Assessments
• **Frequent P2P communication** between meters (and other grid devices) under same transformer. **A NAN component is essential**.	• **Continue Tests** with all RAN/Cores & spectrum options
• **Headend to device data increases 10x** from 0.5-1.0 MB/month for AMI 1.0 to 6-16 MB/month for AMI 2.0 (and can increase further as more meter apps are added)	• Do a deeper dive on **control plane capacity** for applications with frequent data sending
• **Predictable latency** in the range of 5 seconds for control applications	• Identify further end-to-end system **traffic load and latency optimization priorities**
• Addition of **behind-the-meter comms** to EV, Solar and Storage entities	• Validate **alternative Cellular FAN configurations,** e.g., 5G Redcap
	• Assess **Edge/Fog Processing** for, e.g., ML training on high-resolution meter data

Reflections on Results – Itron

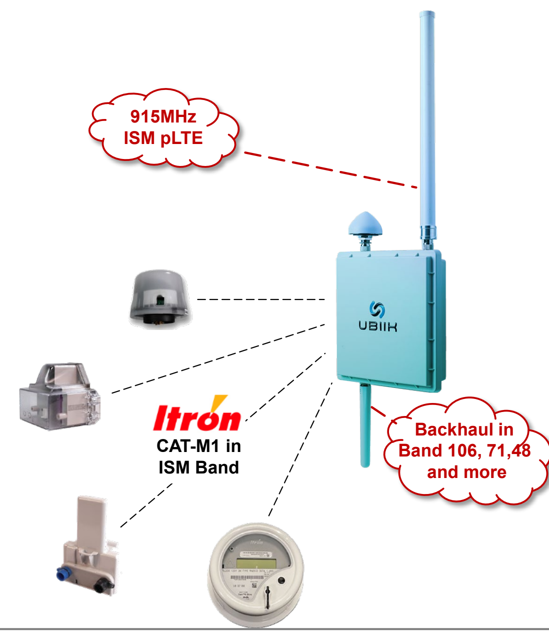
The frequent P2P communication between meters under the same transformer for coordinated monitoring and real-time action is a key takeaway. Overall, the network requirements are complex enough that utilities should investigate all the tools available, and in Itron's perspective, NAN could be an option. At Itron the team see good use of both PLC and 802.15.4g RF in the NAN today but other technologies can be envisioned.

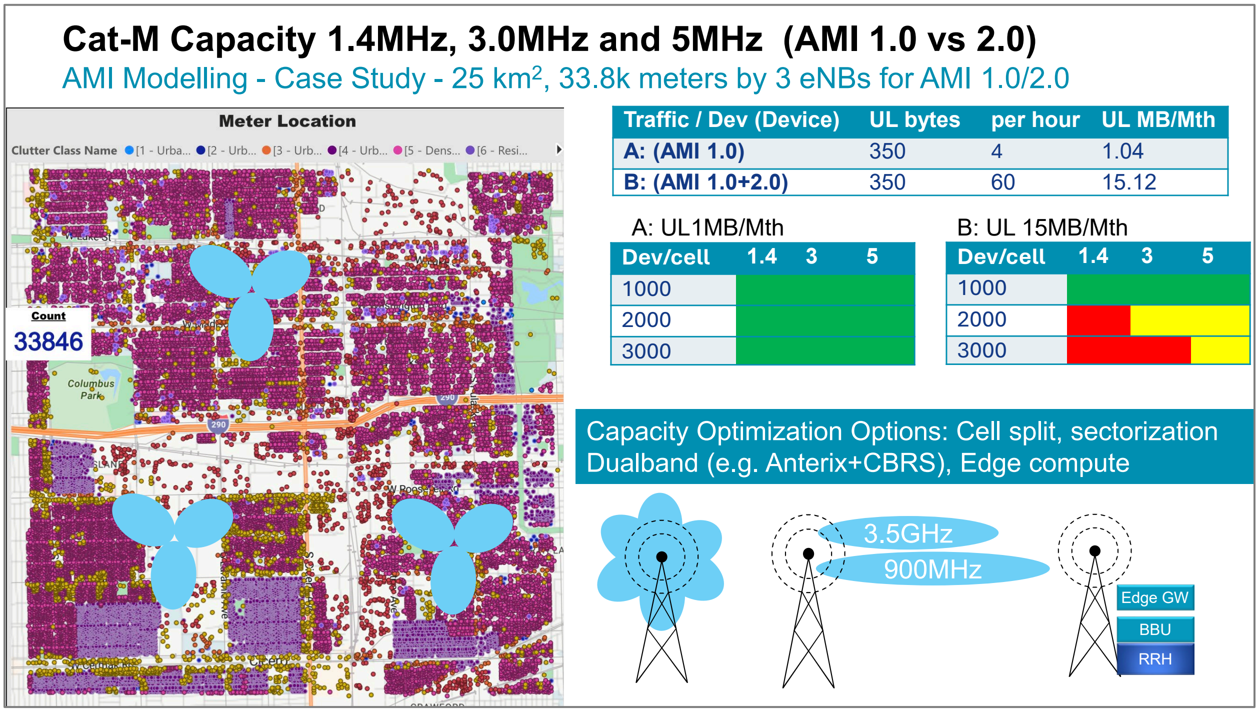
There is also a substantial 10x increase in headend traffic to consider with AMI 2.0 and this can grow over time with new apps added. Predictable latency in the range of 5 seconds between headend and meter is imperative for control applications and leans to have a larger directly connected FAN and a flattened NAN.

Finally, there is a new addition of behind-the-meter comms to take into consideration for EV, Solar and Storage entities that often need to be low latency as well. Also, the team didn't study the ongoing update and training of AI/ML models that may run in the AMI 2.0 meters over their lifetime.

Reflections on Results – Ubiik

- This plugfest work has further **confirmed the higher bandwidth needs of AMI 2.0** and the desire of a NAN to handle part of this traffic in private cellular deployments.
- There are **multiple alternatives for the NAN** that can be considered.
- Ubiik **freeRAN** eNodeB with **Cat-M1 in the 915 MHz ISM band** is one such NAN solution. In this system, freeRAN will communicate with Cat-M1 meters in 915MHz. The backhaul will be pLTE networks operating in Band 106, 71, 48, or other spectrums.
- It can be optimized further by using **compression** on the radio and using an **embedded core in the eNodeB** for efficient routing.



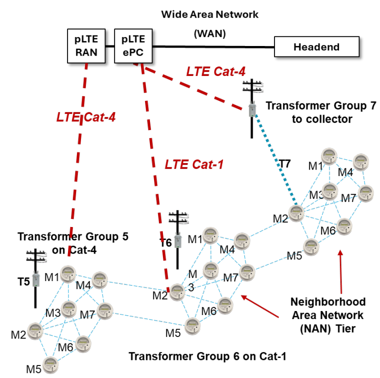


- Based on the assumptions specified for this analysis, Nokia's simulation results revealed control channel congestion challenges limiting the number of AMI 2.0 devices to approximately 1,000 per cell site sector.
- For more dense areas of the utility service territory, utilities may choose to apply:
  - Densification and small cells
  - Increased sectorization
  - Add additional capacity with additional spectrum

Reflections on Results – Ericsson

- The Plugfest analysis brought good insights on how the use cases and traffic models change between AMI 1.0 and AMI 2.0
- Find the right balance of technologies between PLTE/Mesh with smart use of PLTE/Cat-M1 within NAN + FAN to address congestion
  - Lower priced CAT1 instead of higher CAT4 will enable larger volumes of takeout meters in NAN+FAN, improving overall network performance
  - Use of simultaneous CAT-M1+LTE on the PLTE sites allows more selective, on-demand use of CAT-M1 vs CATx with higher network aggregate NAN+FAN throughputs
  - For clusters that are more data heavy, meter aggregation with Cat-4 is an option. These include the Access Points (gateways).
- Leveraging PLTE traffic scheduling algorithms based on AMI 2.0 use cases improve PLTE capacity, performance

Feature	CAT4	CAT1
Max Downlink Speed	150 Mbps	10 Mbps
Max Uplink Speed	50 Mbps	5 Mbps
Power Consumption	Higher	Lower
Cost	**Higher**	**Lower**
Applications	High-bandwidth, low-latency applications	Low to medium data rate applications



- As smart meter networks evolve from AMI 1.0 to AMI 2.0, with the associated change in traffic profile and data volumes, the supporting network infrastructure will need to evolve. Depending on the amount of data sent by the takeout meter in the mesh, modules supporting Cat-4, Cat1 or Cat-M1 are expected under the glass in the meters. The team expect that the legacy model of an Access Point (gateway) device talking to a group of meters will exist for a while before they are replaced by SIM under the glass. In all cases, the capability of PLTE to intelligently schedule bursty meter traffic will allow for many meters to be supported per LTE site.

Reflections on Results – Anterix

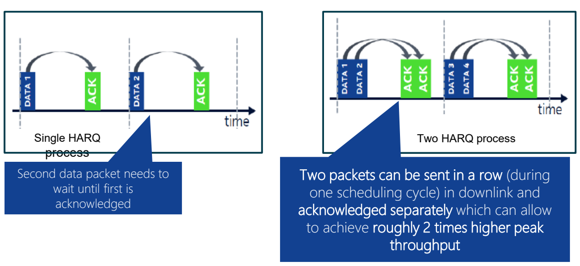
- AMI 2.0 and grid edge are positioned to bring value to utilities beyond the traditional billing application. Utilities will drive prioritization of capabilities based on their distributed grid intelligence strategies.
- Private LTE is the optimal choice to support AMI 2.0 including mesh, direct to meter and hybrid networks; utilizing CAT-4, CAT-M1 as necessary.
- The private LTE FAN supports AMI 2.0 , including data processing at edge, and data that needs to be backhauled to the headend.
- 900 MHz 3x3 Cat-M is well positioned to support projected meter traffic for the next 5 years and more, in addition to Cat1-4 for the foreseeable future. 900 MHz Cat-M is supported by RAN vendors today, highlighted from testing and modeling with Nokia.
- We are working with utility customers and ecosystem members (Nokia) to develop capacity models to manage and optimize network configuration to support Cat-M; 900 MHz 3x3 delivers ample capacity to support these models

HARQ and eDRX

Cat-M Evaluation | Modifying parameters to increase throughput, extend battery life, and improve coverage in a Cat-M cell.

Increase Throughput

Method: using Multiple Hybrid Automatic Repeat Request (HARQ)
- 2 HARQ for Cat-M1 UE in DL that allows to achieve approx. 2 times higher peak throughput
- 3 HARQ for Cat-M1 UE in UL that allows to achieve roughly 3 times higher peak throughput



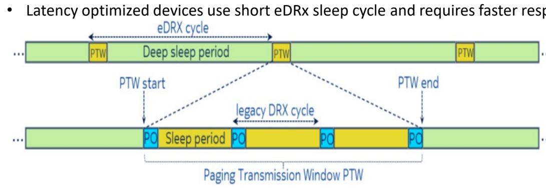
Lab Test Results

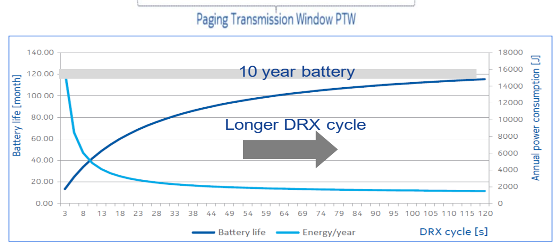
Using multiple HARQ:
- Average uplink (UL) peak throughput was increased from **56kbps to 223kbps. (298% increase)**
- Average downlink (DL) peak throughput was increased from **50kbps to 175kbps. (250% increase)**

Testing conducted in Anterix lab

Extend battery Life

Method: using extended Discontinuous Reception (eDRX))
- eDRX extends the period between paging thod: using extended
- eDRX extends the period between paging occasions for idle mode to save power
- eDRX cycle ranges from 5.12secs up to 43.69mins
- Energy optimized devices use long eDRX sleep cycle and requires slower response.
- Latency optimized devices use short eDRx sleep cycle and requires faster response.





Lab Test Result: Extended battery life was tested on a battery-powered gas pressure sensor with a set eDRX sleep cycle of 2.73mins (163 secs). The interval between paging time window was measured to be equal to the set eDRX cycle. This results in significant power savings and is expected to increase battery life as shown in the chart above. **eDRX cycle time is dependent on the application use case.**

Coverage Extension

Cat-M Evaluation | CE Mode A using Multi-frame Repetition

AT	Phone Number	9987050070
	Cellular IP Address	100.110.0.177
AT	Cellular State	Connected
AT	Cellular State Details	IP Acquired
	Cellular End-to-End Connection	Not Verified
	Carrier Availability	Available
AT	SIM Network Operator	998 705
	Serving Network Operator	998 705 Anterix
AT	Signal Strength (RSSI)	-103
AT	LTE Signal Strength (RSRP)	-133
AT	LTE Signal Quality (RSRQ)	-19
AT	LTE Signal Interference (SINR)	-4.1
	ESN/EID/IMEI	356050090108452
AT	SIM ID	8988211000000660806
	APN Status	internet
AT	Number of SIMs present	1
AT	Primary SIM	Slot 1
AT	Secondary SIM	Slot 2
AT	Active SIM	Slot 1
AT	Radio Technology	LTE
	Network Service Type	4G
	Active Frequency Band	LTE BAND 8

Lab Test Results

- Using a baseline Cat-M coverage with no coverage enhancement, UE detached from network at a Reference Signal Received Power (RSRP) level below -126dBm.
- Using CE ModeA coverage enhancement, UE attached in a remote location at RSRP -133dBm. (See UE RF in Screenshot)
- Hence, CE ModeA increased the Maximum Coupling Loss by ~10dB.

HARQ	Coverage	RSRP (dBm)	SINR	UL Tput (kbps)
Single	Near Cell	-60	30	**56**
Multiple	Near Cell	-53	30	**223**
	Mid Cell	-113	14	**201**
	Cell edge	-126	0.9	**67**
	CE Mode A	-133	-4.1	**17**

HARQ	Coverage	RSRP (dBm)	SINR	DL Tput (kbps)
Single	Near Cell	-60	30	**50**
Multiple	Near Cell	-53	30	**175**
	Mid Cell	-113	14	**132**
	Cell edge	-126	0.9	**100**
	CEMode A	-133	-4.1	**11.6**

Testing conducted in Anterix lab

Early Adopter Status of Itron's solution

DI REALIZATION*

	Q3 2024
DI-enabled Endpoints Shipped & Booked	22.3M
Total App Licenses Issued	9.1M
Average # of Apps per Enabled Endpoint	3
Itron Apps	16
Active Partners	16

12.3M + 10M
DI-enabled endpoints shipped and booked

3
Average number of apps per enabled endpoint

9.1M
DI licenses issued

16
Number of DI Applications developed by Itron

11
Utilities with DI apps either in production or in field trial

16
Number of active developer partners

Source: Itron, Inc., Q3 2024 Data

- Itron Note: It has taken Itron 7-8 years to build up to this level. Part of the challenges have been outside of the networking component and more related to creating a framework scalable enough to manage millions of apps in the field. There are a lot of logistic issues to resolve to manage all the apps in the field at scale.

Team 2 – Aetheros, Hubbell | Aclara, Ericsson

Use Case Overview

AMI 2.0 use cases include the semi-autonomous and autonomous:

i. integration of electric vehicles, renewables, battery systems, and smart appliances with the distribution network
ii. dynamic balancing of the exponentially growing energy demand against the available energy sources on the distribution network, and
iii. protection of distribution network assets (e.g., transformers, capacitor banks, switches)

While the simple AMI 1.0 revenue-driven use case required remote communications capability to be added to every meter on the distribution network, the diverse and complex AMI 2.0 use cases require that open, secure, edge computing and communications capabilities be added to every meter on the distribution network. While these new use case requirements will raise the retail cost of a smart meter by $15-20, the measurable cost savings that can be specifically derived from improved operational efficiencies, asset protection, and lower line losses over the term of the AMI 2.0 rate plan is over tenfold.

All the products and technologies used in our team's use case testing are commercially available, market proven, and are ready for large scale AMI 2.0 deployments.

What Was Tested

AMI 2.0 Use Case – Distribution Network Transformer Protection

One of the looming issues for AMI 2.0 to address is the autonomous and dynamic protection of the utility's MV/LV Transformers from overloaded conditions caused by non-controlled electric vehicle charging.

Test Network Design & Components

A lab-based secondary circuit test network environment consisting of four (4) smart meters with secure edge computing and LTE communications, four (4) simulated 240V EV charging stations, and one (1) MV/LV transformer was constructed. For the AMI 2.0 communications network, a Private LTE test network, consisting of a single sector eNodeB (base station and router) and a hosted enterprise core network, was constructed.

Figure 1 – Secondary Circuit Test Network

Figure 2 – Private LTE Test Network

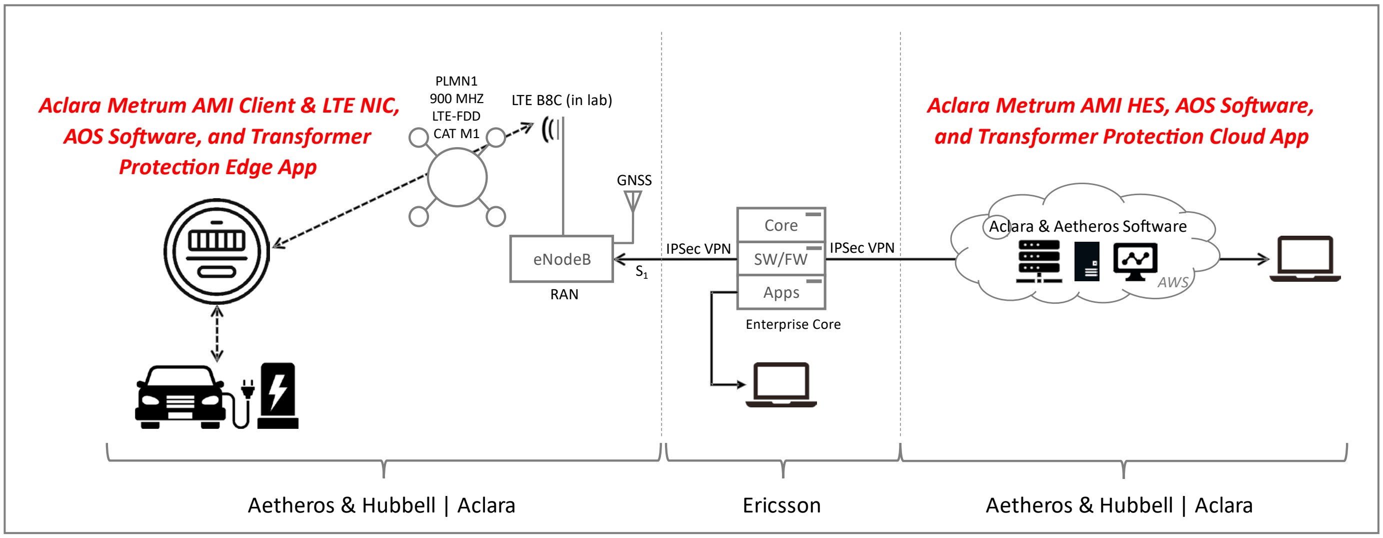


Figure 3 – Private LTE Test Network Diagram

Use Case Assumptions & Conditions

For the Distribution Network Transformer Protection use case, the following assumptions were made:

- MV/LV Transformer Rated Capacity = 25 kVA
- Average continuous demand for each household = 1.28 kVA
- Average full charge rate demand for a Level 2 charger = 7.20 kVA

With four (4) households on the test secondary feeder network, the average continuous power demand on the MV/LV Transformer is 5.14 kVA (or 21% of its rated capacity). With 4 EVs on the secondary circuit charging simultaneously at their full charge rate, the MV/LV Transformer will be operating above its rated capacity (by ~36%). In addition to degrading the lifespan of the transformer, the overload condition also results in additional line losses and life safety issues (i.e., transformer explosion).

Edge Application

To demonstrate how edge computing can be used to address this issue, an AMI 2.0 smart meter edge application to autonomously and dynamically control EV charging on secondary circuits was developed.

In addition to "pre-understanding" the average power demand of each household (e.g., 1.28 kVA), the edge applications running on each of the smart meters also monitored, in real-time, for apparent power demand levels associated with EV charging demands at their households to detect EV charging.

To autonomously and dynamically control the EV charger loads, a fair weighted queuing algorithm was used to curtail the EV charging. The application also included "over-ride" load control features for basic life safety (e.g., <10% vehicle charge) and demand response opt-in/opt-out considerations (e.g., no, low, medium, high charge rates).

When an EV charging load is detected the edge application, running on the meter, directly communicates this fact to the other edge application instances on the secondary feeder using an MQTT/IP field message bus using OpenFMB Protobuf messages based on the IEC 61968-9 standard.

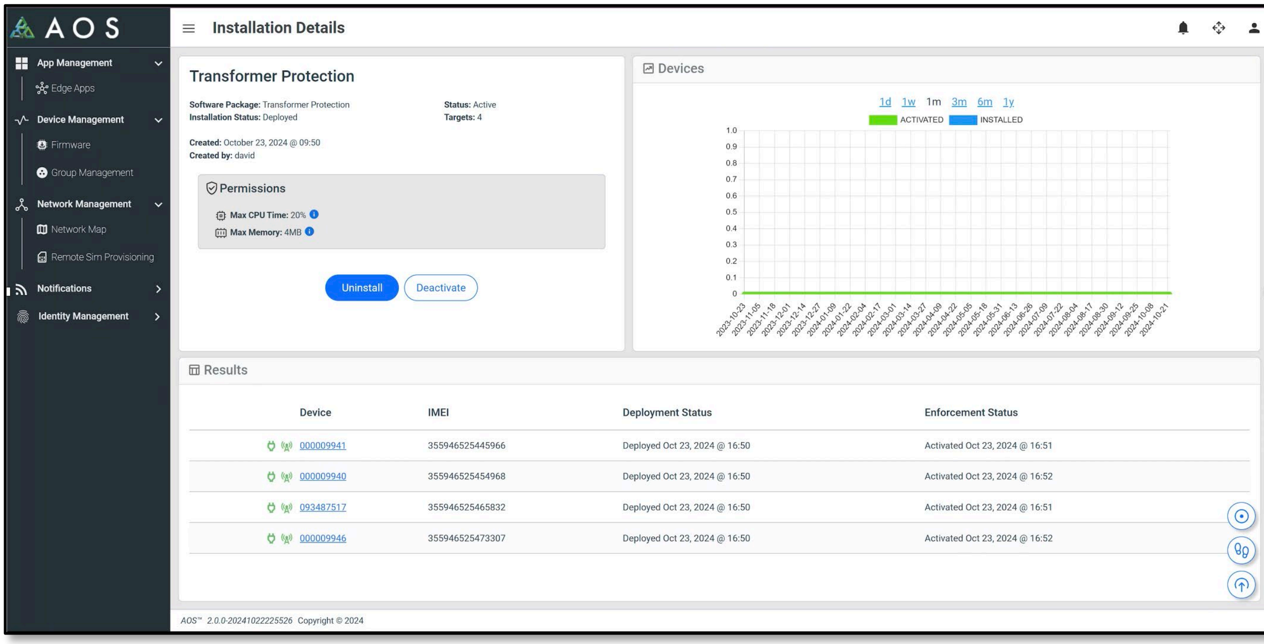


Figure 6 – Edge Application Deployed and Enforcing on Test Meters

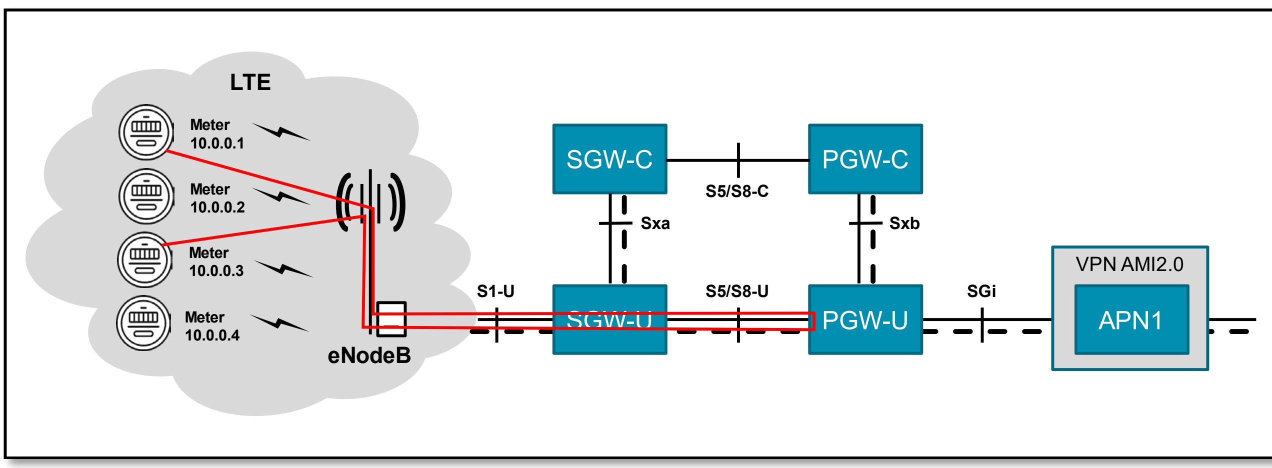
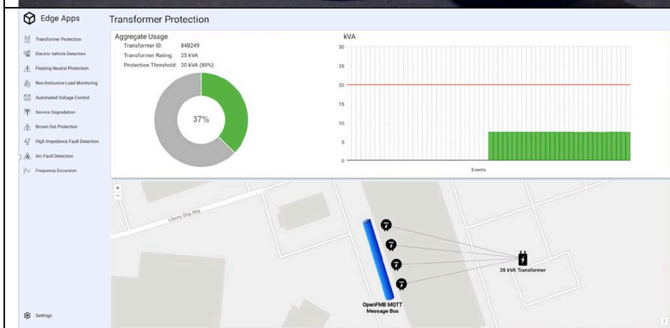


Figure 5 – Meter to Meter Communications over LTE and MQTT/IP

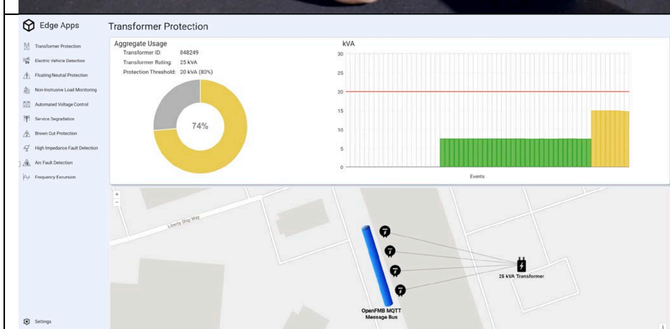
Test Results

1) First EV Charger simulator is turned on.

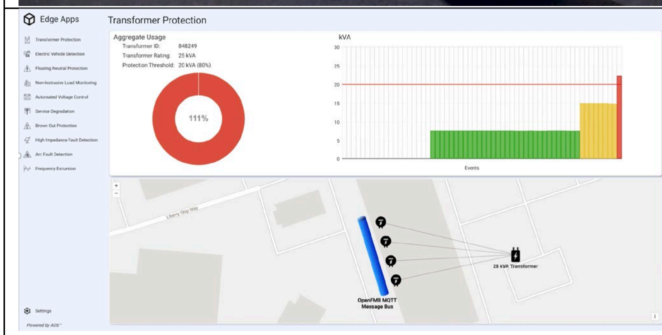
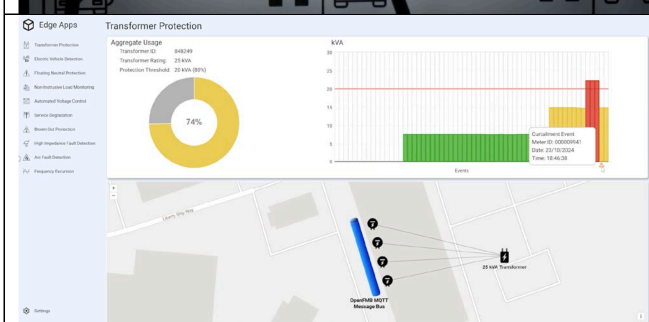


2) The Edge Application, running on the first meter, is shown measuring and reporting the houshold's real-time apparent demand associated with EV charging to the other meters on the secondary feeder and to an application console running in the cloud.

3) Second EV Charger simulator turned on.



4) The Edge Application, running on the second meter, is shown measuring and reporting the houshold's real-time apparent demand associated with EV charging to the other meters on the secondary feeder and to an application console running in the cloud.

	5) Third EV Charger simulator turned on.
	6) The Edge Application, running on the third meter, is shown measuring and reporting the houshold's real-time apparent demand associated with EV charging to the other meters on the secondary feeder and to an application console running in the cloud. The MV/LV Transformer's rated capacity exceeded.
	7) The Edge Application, based on the fair weighted queuing algorithm and configurable load control functions, autonomously curtails one of the EV Charger loads.
	8) The Edge Application console in the cloud shows the autonomous EV charger curtailment event.

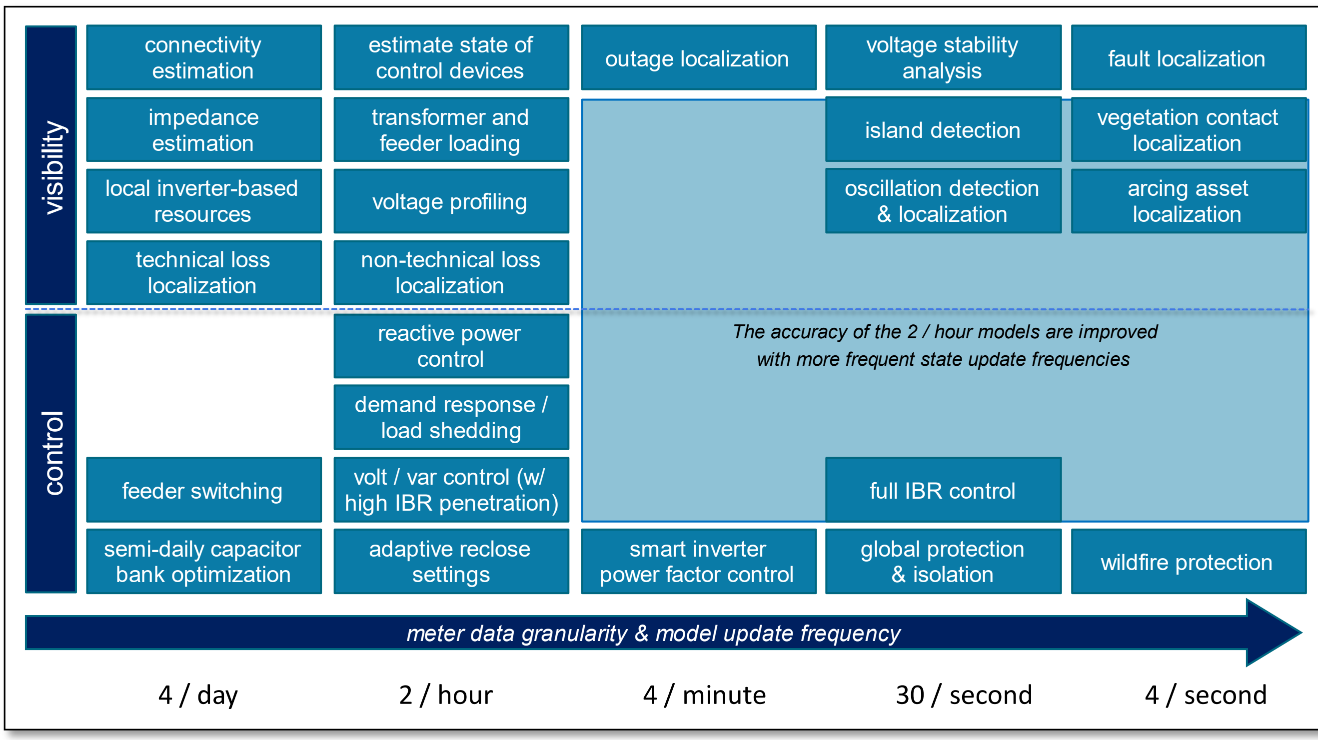
Utility Applicability

Utilities can derive many cost saving benefits that from AMI 2.0 smart meters with edge computing and communications capabilities, such as:

- Reduced line losses
- Improved quality of supply

- Targeted foliage management
- Extension of network equipment lifetimes
- Targeted preventative maintenance to reduce outage events & lower repair costs

While the volume of AMI 2.0 use case meter read data significantly increases over the simple AMI 1.0 revenue use case (from 60KB/day to 1-20MB/day), data does not need to reported in near real-time for most benefits to be derived. Where <4 minute meter data reporting is required, the utility can nominate strategically located AMI 2.0 meters throughout the distribution network to perform near real-time meter read reporting (i.e., bellwether meters).



What does the industry need to focus on and work towards?

Based on multiple conversations with vendors during the UBBA 2024 Plugfest, Team #2's overall perception is that there are many misconceptions being espoused within the utility industry regarding Private LTE's Control and Data Channel Configurability, Uplink / Downlink Channel Resource Capacities, Machine Type Communication Patterns, and Bandwidth Latencies & Throughput Capabilities. The team believe that focused technical / non-technical workshops that can address and close this knowledge gap will greatly benefit the utilities and vendors alike.

Use Case 2: Device Routing

Team 1 – GE, Ericsson, Hubbell, NovaTech

This article provides a summary of the Direct Transfer Trip Anti-Islanding via Private LTE testing completed for the 2024 UBBA Plugfest.

Team leaders:

Brian Dob – RFL Hubbell
Kevin Linehan – Ericsson
Thomas Schwartz – GE Vernova
Rana Chalhoub – GE Vernova
Ryan McAuliffe – NovaTech Automation

Introduction:

In today's rapidly evolving technological landscape, collaboration between industry leaders is critical to drive innovation and address global challenges. Imagine the power of GE Vernova, RFL Hubble, Ericsson, and NovaTech uniting their expertise to transform the energy and communications sectors.

GE Vernova - A leading name in sustainable energy solutions, brings its advanced technology and commitment to decarbonizing the energy industry.

RFL Hubbell - Adding precision and reliability with its products in utility protection, monitoring, and automation.

Ericsson - A pioneer in telecommunications, enables seamless connectivity and next-generation networks to power smart grid solutions.

NovaTech - With its expertise in operational technology and industrial automation, ensures efficient and secure systems integration.

Together, this powerhouse collaboration combines renewable energy, robust grid solutions, advanced connectivity, and intelligent automation to revolutionize the way the team power and connect our world. Whether it's accelerating grid modernization, enhancing renewable energy integration, or deploying real-time communication for critical infrastructure, this partnership exemplifies the future of innovation and sustainable development in the Private LTE workspace and beyond.

Power System Islanding:

Power system islanding occurs when a part of the grid becomes isolated from the main system while continuing to supply power to the remaining connected area. This can happen intentionally for operational reasons, such as isolating a section for maintenance or preventing cascading blackouts, or unintentionally due to equipment failures, system faults, or environmental factors. While islanding can preserve loads and mitigate blackouts, it also poses significant risks, such as power quality issues, equipment damage from voltage fluctuations, and safety hazards for utility workers due to back feeding power.

Unintentional islanding is particularly dangerous because it can cause voltage instability and disrupt power regulation, leading to equipment damage. To prevent these risks, islanding detection and prevention methods are crucial, with standards like IEEE 1547 recommending island detection within two seconds. Detection can be done using both local and remote techniques, with passive methods being more cost-effective and less likely to affect power quality.

Direct Transfer Trip (DTT) Islanding Detection and Prevention:

A Direct Transfer Trip (DTT) system is used to prevent islanding in power grids by automatically disconnecting Distributed Energy Resources (DERs), such as solar inverters, from the grid when a fault or loss of connection is detected. This is achieved through a communication link between the substation protection relays and the DER, which sends a trip signal to open the DER's local breaker. DTT helps maintain grid stability by ensuring that DERs don't continue to feed power into an isolated grid segment, preventing potential safety hazards for utility workers. The system typically monitors voltage and frequency changes to detect islanding conditions and initiates disconnection if abnormal values are detected. While it provides significant safety and stability benefits, DTT can be costly to install and maintain, particularly with large-scale distributed generation systems, and requires coordination between utilities and DER operators. Communication methods such as fiber optics, microwave links, or cellular networks are used to transmit the trip signal.

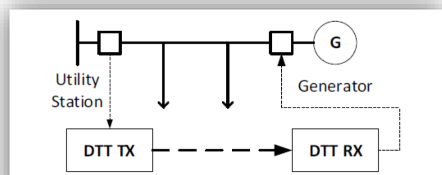


Fig. 1. DTT Radial Line Example

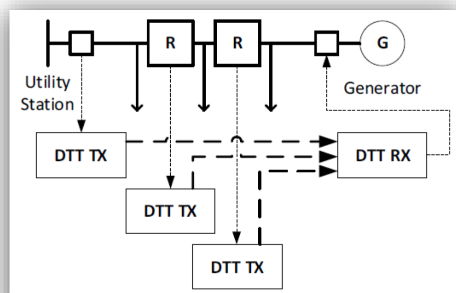


Fig. 2. DTT Example with Multiple Recloser

Why Direct Transfer Trip?

- Non-Detection Zone (NDZ)

    - A point at which the islanding detection method is not able to detect the island condition.
    - Communications assisted methods, like DTT, are unique in that they effectively eliminate the NDZ found in local methods. As a result, protection elements may be set less sensitively, reducing false operations during system disturbances.

Performance Characteristics of DTT:

- Security
    - The ability to NOT falsely operate in the presence of noise or bit errors. Most important for DTT in order to prevent false tripping as there is no supervision.
- Dependability
    - The ability to operate when a valid command exists, in the presence of noise or bit errors.
- Latency
    - The amount of time it takes for the system to operate. Measured in milliseconds (ms) or cycles from the keying of the local input to the closing of the remote output.

DER/DG Applications:

- Anti-Islanding/DTT
    - Less stringent latency requirements vs. Ultra High Voltage (UHV) line protection applications
- Legacy Communications
    - Leased telco audio tone or T1 circuits
        - Expensive, reliability and obsolescence concerns
        - Telco services have already moved to packet technology
- Communications Today
    - Direct/Dark Fiber
    - Telco packet-based network infrastructure
        - Example: E-line or E-LAN service
    - Wireless Radio

- Cellular, Unlicensed, Licensed
- Cost effective
- Sub 100 ms latency

Why Cellular Communications:

Cellular communications are a solution to growing concerns with legacy Telco Communications. Legacy Telco Communications have become obsolete, unavailable, and hard to maintain. There have also been instances of unnecessary tripping when loss of communications occurs. These incidents create reliability concerns to an already expensive, recurring cost solution. Although direct fiber is another solution to legacy Telco Communications, it is high in cost and there can be significant challenges with laying a fiber path.

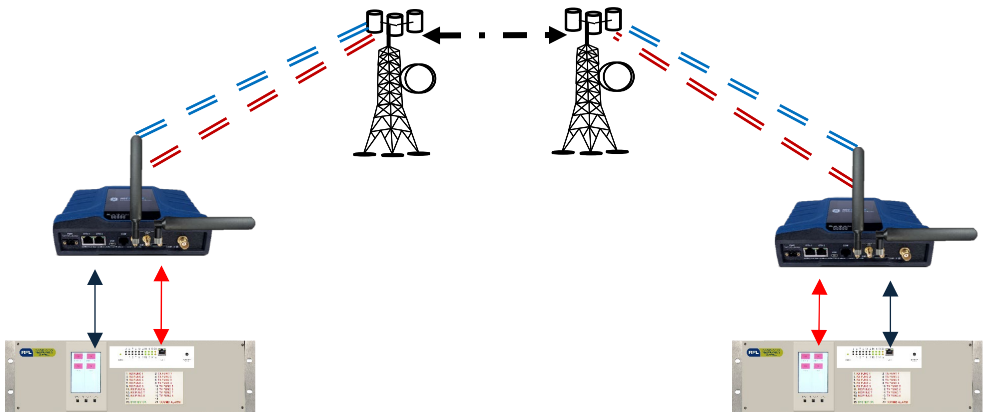
There are a couple of different options when it comes to cellular communications, namely, private, and public LTE. Public cellular LTE is a widely available, low recurring cost solution that allows the user to easily utilize multiple public carriers. Public cellular LTE standards also allow for easily interoperating with various vendors. Conversely, private LTE appeals to many users due to having full control over their network. Users own the network end-to-end and can be built to be very secure because traffic never leaves the private network. There are additional benefits to private cellular LTE, including Mission-Critical Push-To-Talk (MCPTT) and mobile private data coverage.

Cellular Redundancy:

A beneficial application used with cellular systems is parallel system redundancy. Parallel system redundancy means that two cellular networks can be utilized simultaneously to communicate data, ensuring a zero-switching time and a seamless failover and failback between carriers. This is achieved through Parallel Redundancy Protocol (PRP), which creates hitless network redundancy by sending packets through both cellular networks to allow for a constant stream of traffic.

GE Vernova Orbit Cellular Routers:

The MDS Orbit Dual-Active Cellular Tri-SIM Router can achieve cellular redundancy with private and public cellular networks. In this example, the team use two active connections to separate CBRS and Anterix networks. This achieves a seamless failover between the two networks through PRP. The MDS Orbit also has dedicated routing tables for CBRS and Anterix through the use of Virtual Routing and Forwarding (VRF), allowing for segmented traffic without using multiple devices. Lastly, there is an option for a third SIM for maximum flexibility and redundancy for mission critical networks.



GE Vernova Orbit Cellular Routers:

MDS Orbit Dual-Active Cellular Tri-SIM Router

- Two active connections to separate CBRS and Anterix networks
- *Optional Triple* SIM for maximum flexibility/redundancy for mission critical networks
- Seamless Failover between modems using Packet Redundancy Protocol (PRP)
- Dedicated Routing Tables for CBRS and Anterix using Virtual Routing and Forwarding (VRF)

ETH1 is Dedicated to CBRS | ETH2 is Dedicated to Anterix Active™

Lab Setup and Equipment Components

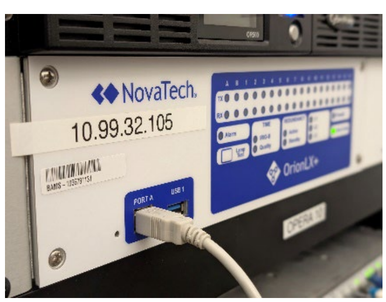
As with other teams demonstrating various utility use cases for the 2024 UBBA Plugfest, the team leveraged the state-of-the-art Ericsson Utility Experience Center located in Plano, Texas. The lab is uniquely designed to showcase wireless technologies for the utility and industrial markets. The center is home to Ericsson's working Private LTE infrastructure and can exercise various use cases under lab and field test environments.

With our DTT use case, the lab was set up with a single evolved packet core (ePC) and two sets of eNodeB installations, one indoor and one outdoor. Each of the nodes supported two spectrum bands, Anterix Band 106 and CBRS Band 48. This ensured the team could operate our use cases on both bands to provide the PLTE coverage and redundancy needed. Both eNodeB installations were connected to the ePC via a fiber backhaul.

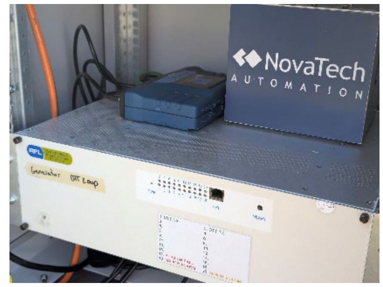
Equipment Components

The indoor equipment was comprised of GE's MDS Orbit MCR routers equipped with dual, active/active modules with sim connectivity to both Anterix and CBRS bands simultaneously.

RFL Hubbell used the Gard 4000 DTT gateways to manage, detect, and trigger substation DTT. An instance of the NovaTech Orion LX served as the SCADA manager to direct, manage, and collect network traffic data. Additionally, Ericsson had both PLTE Core and eNodeb systems fully operational within the lab setting.



The outdoor eNodeB equipment mirrored the indoor components but included slightly different antenna configurations as well as an outdoor enclosure for the MCRs and RFL Gard 4000.



Test Results:

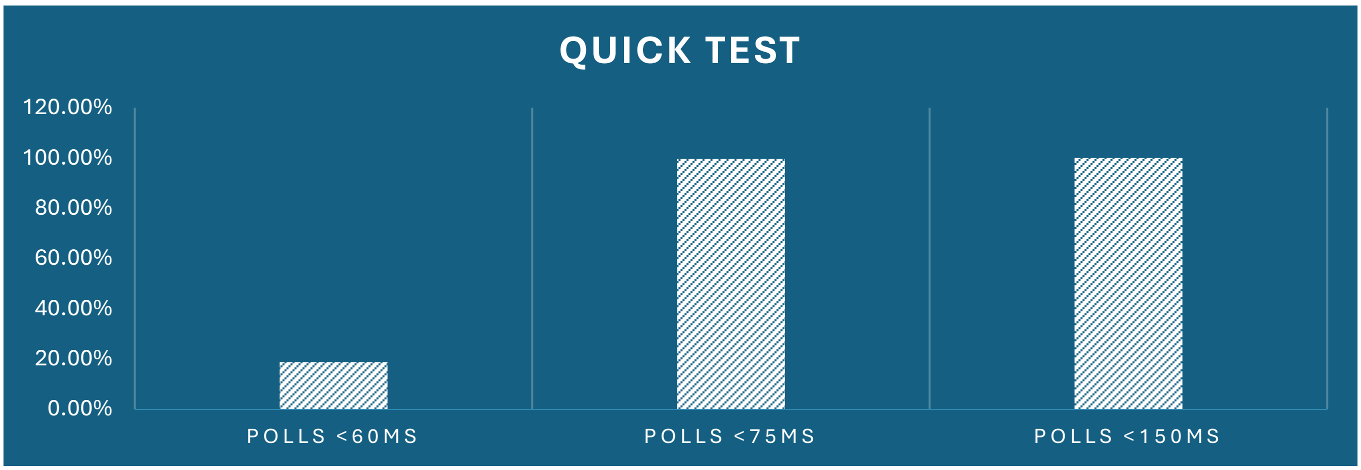
Test results for dependability focused on round-trip dependability, specifically measuring the number of trips sent from point A to B and back to A within a specified time frame. The assessment considered trips received within three-time intervals: 60 milliseconds (ms), 75 ms, and 150 ms, with the requirement that a trip received must be asserted for at least 1 ms to be counted.

Testing conducted over approximately 16 hours at a frequency of 2 Hertz (Hz), the following results were recorded: Out of 11,876 trips sent from A, 2,232 trips (18.79%) were received within 60 ms, 11,830 trips (99.61%) were received within 75 ms, and all 11,876 trips (100%) were received within 150 ms. Notably, there were no alarms received during this testing period.

Raw Results:

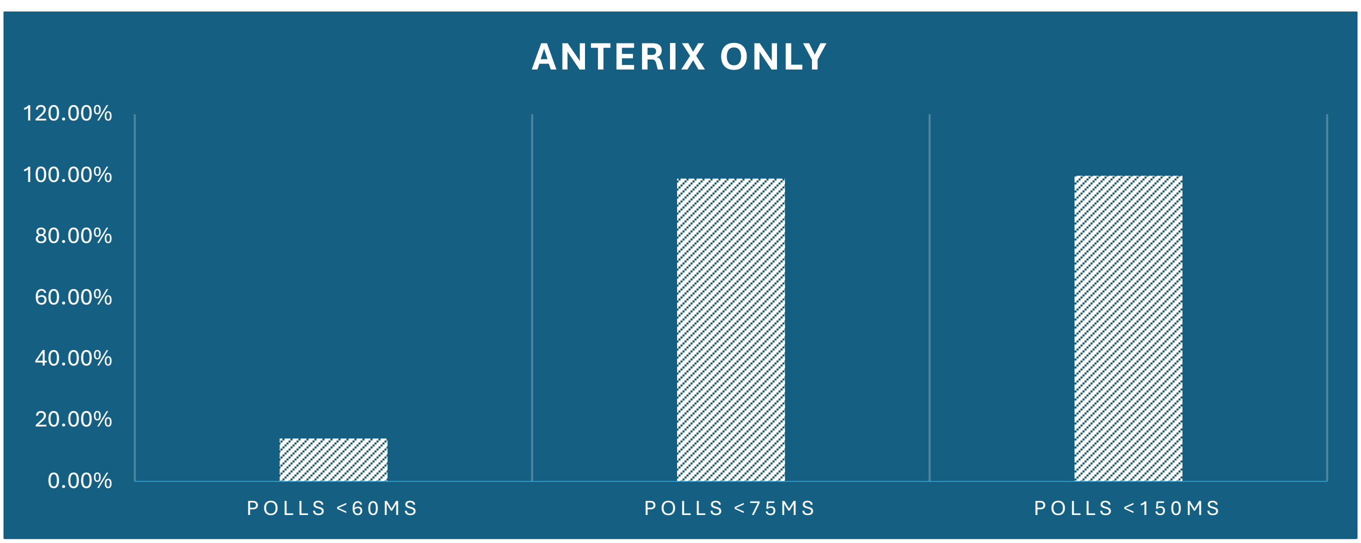
"Quick" Test:

Total Polls Sent		11876	
Polls <60ms	2232	2232	18.79%
Polls <75ms	11830	9598	99.61%
Polls <150ms	11876	46	100.00%
Dropped Polls	0	0	



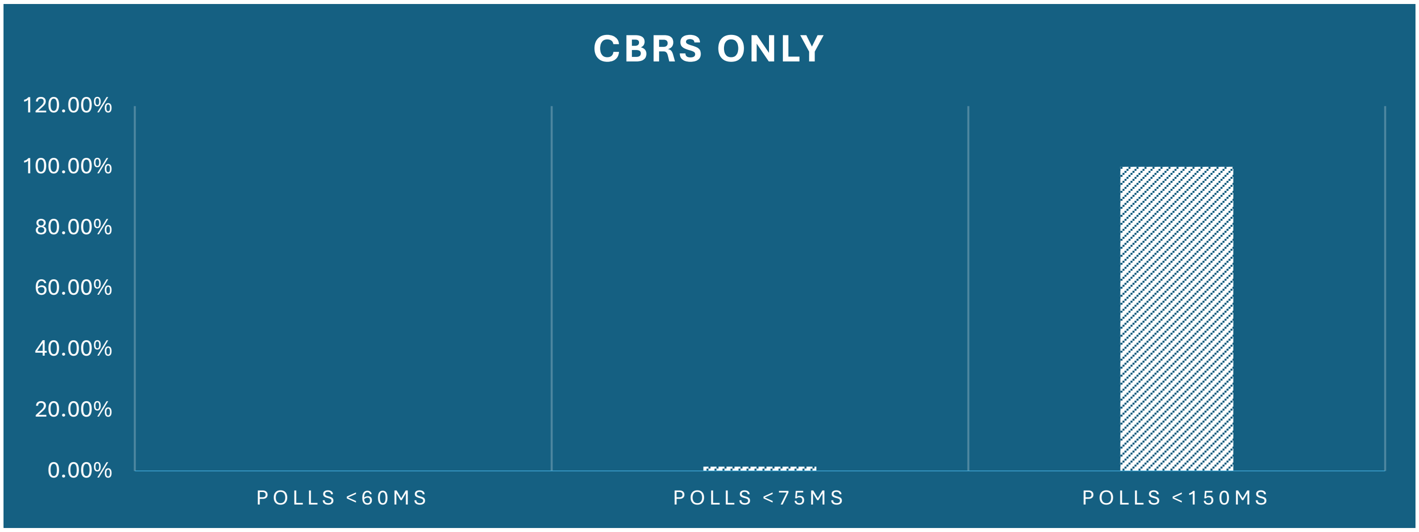
Anterix Only

Total Polls Sent		7392	
Polls <60ms	1032	1032	13.96%
Polls <75ms	7312	6280	98.92%
Polls <150ms	7386	74	99.92%
Dropped Polls	6	6	



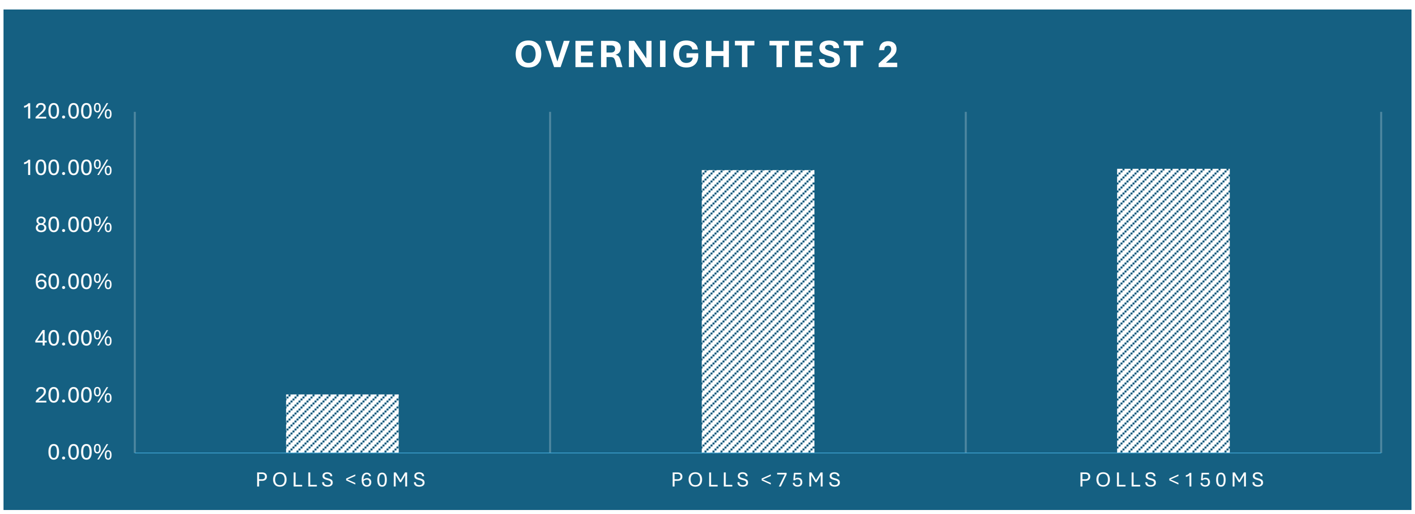
CBRS Only

Total Polls Sent		6246	
Polls <60ms	0	0	0.00%
Polls <75ms	90	90	1.44%
Polls <150ms	6246	6156	100.00%
Dropped Polls		0	



Overnight Test 2

Total Polls Sent		288179	
Polls <60ms	59340	59340	20.59%
Polls <75ms	286744	227404	99.50%
Polls <150ms	288179	1435	100.00%
Dropped Polls		0	



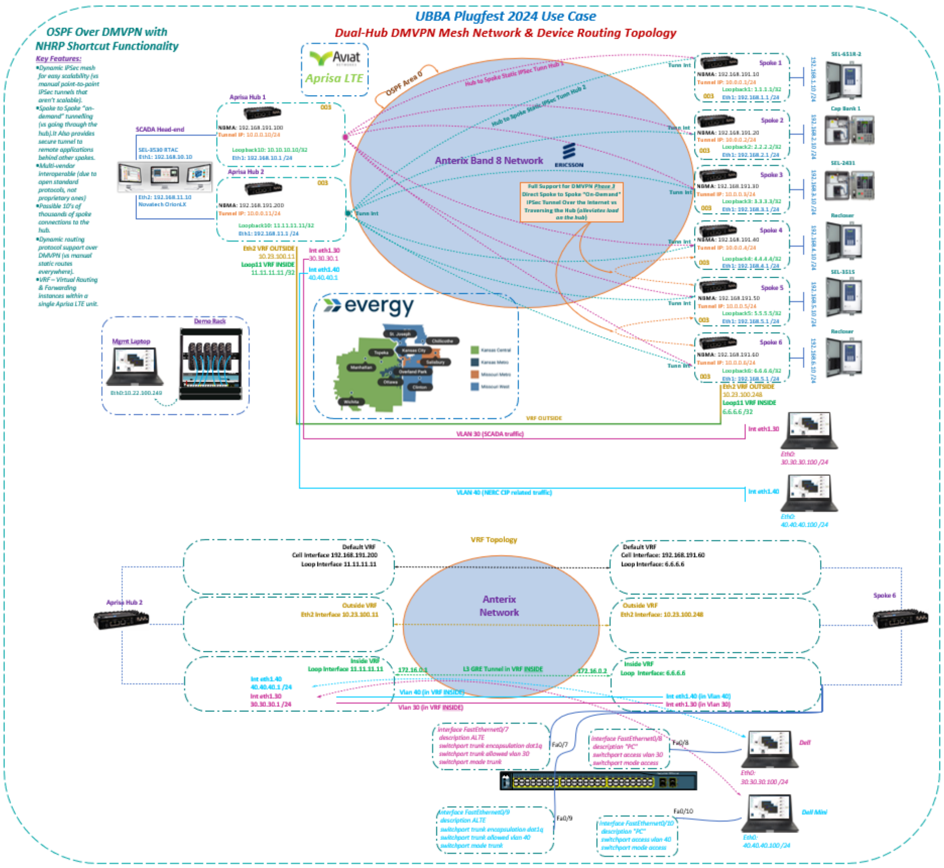
Team 2 – Aviat, Evergy

Lab Test Setup and KPIs:

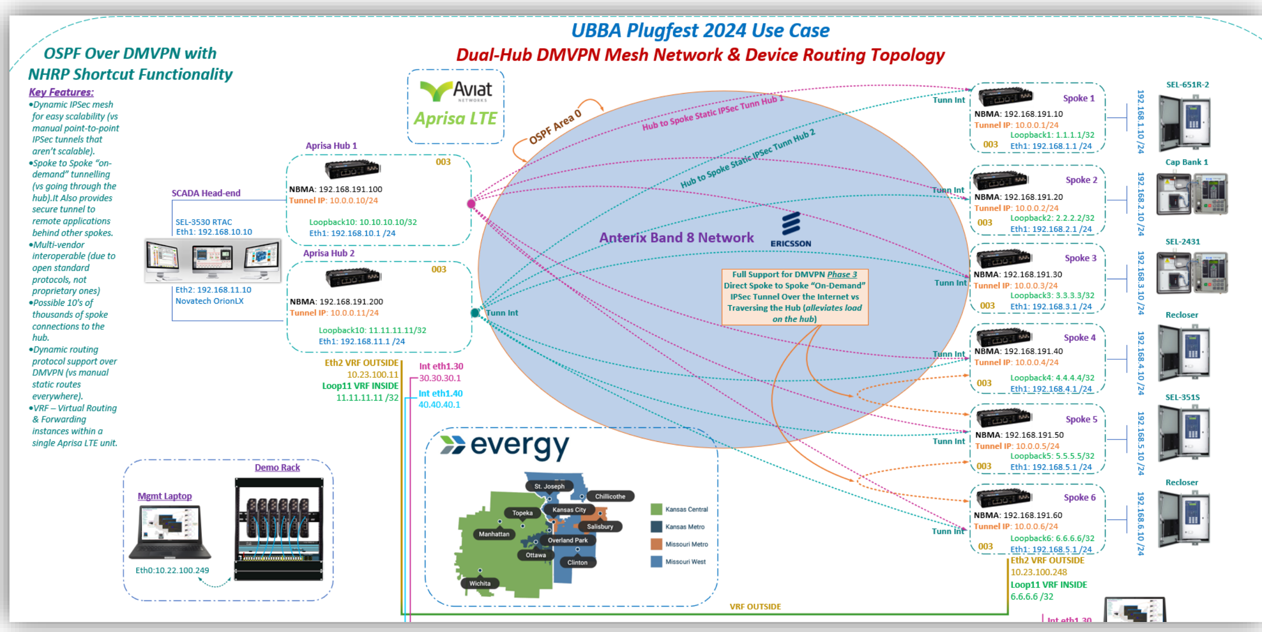
Aviat Networks prepared a demo rack and travelled to Evergy Energy's GO in downtown Topeka to perform our device routing topology use case. All testing was performed on Evergy's live Private LTE network (with a test APN). KPI's monitored for this lab were:

- Uptime metrics (how many 9's?)
- Speed, latency, jitter, PDV, packet loss etc.
- Dual-wan availability/redundancy
- Overall performance and reliability
- Mean Time to Repair (MTTR)
- Security, Firewalls (any penetration and vulnerability issues?)
- Device Utilization
- QoS (Quality of service and/or prioritization of traffic, routes, tunnels etc.)
- Traffic virtualization / segregation techniques

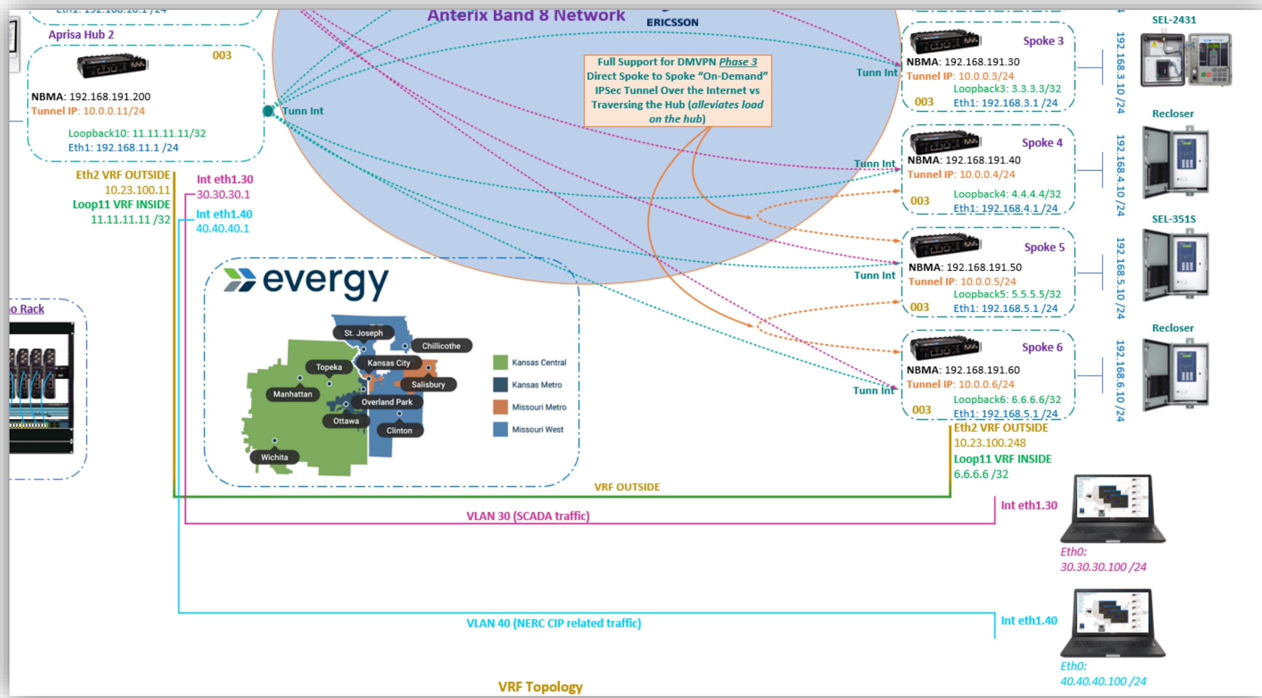
Topology:



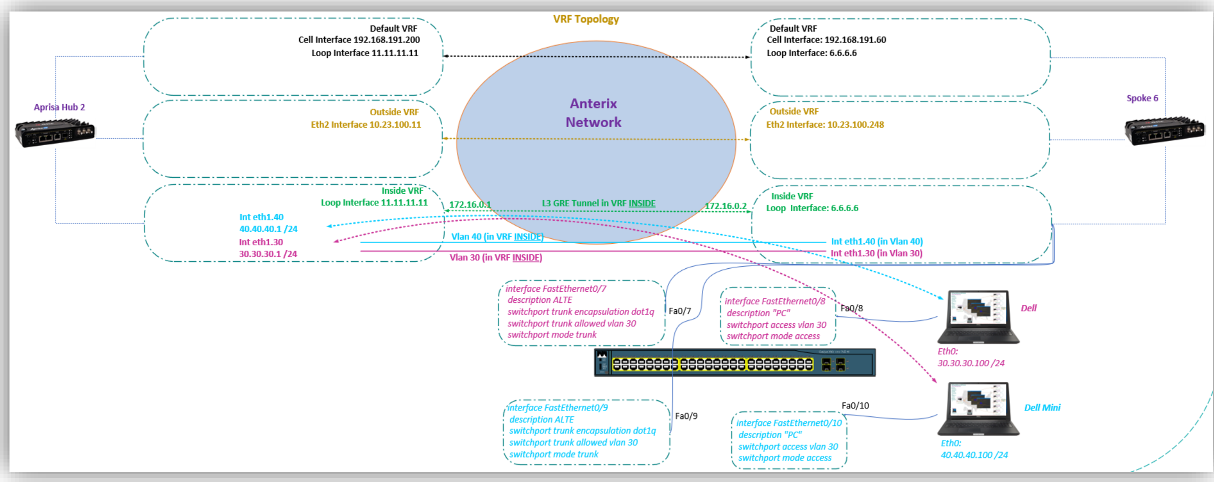
Zoomed into all three sections:
Section 1 DMVPN: Dual hub to six remote spokes



Section 2 VRF: (between hub 2 and remote spoke 6)



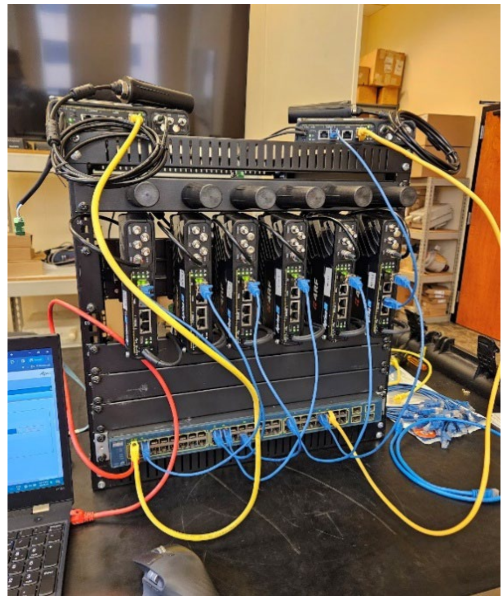
Section 3: Vlan separation over the VRF instance:

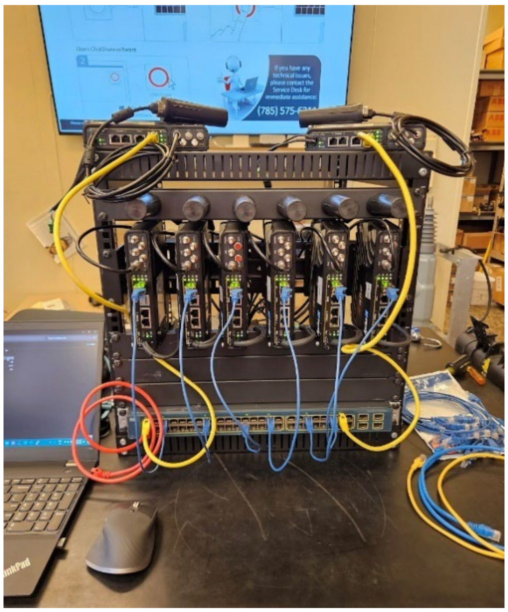


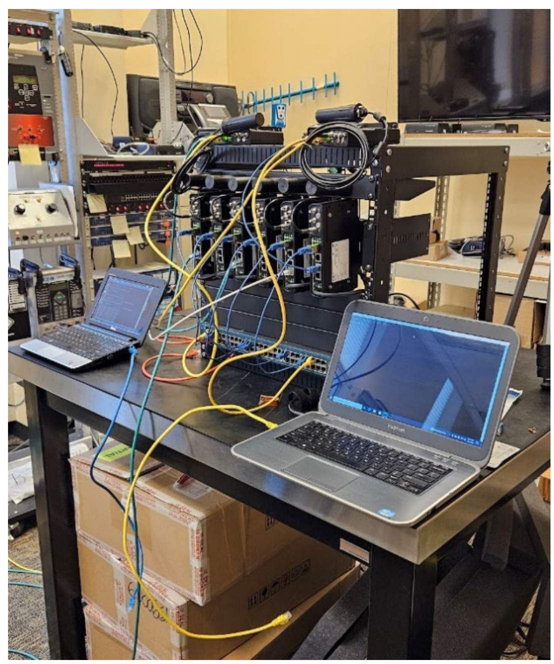
Demo Rack:

- 12 RU rack
- 6 Aprisa LTE routers supporting Anterix Band 8 on a din-rail mount
- Two more Aprisa LTE routers sitting on top of the rack were setup as hubs
- A Cisco 3560 router for port density and access into all Aprisa routers.

- Two laptops for simulating the vlan separation over the VRF instance per the diagram above.

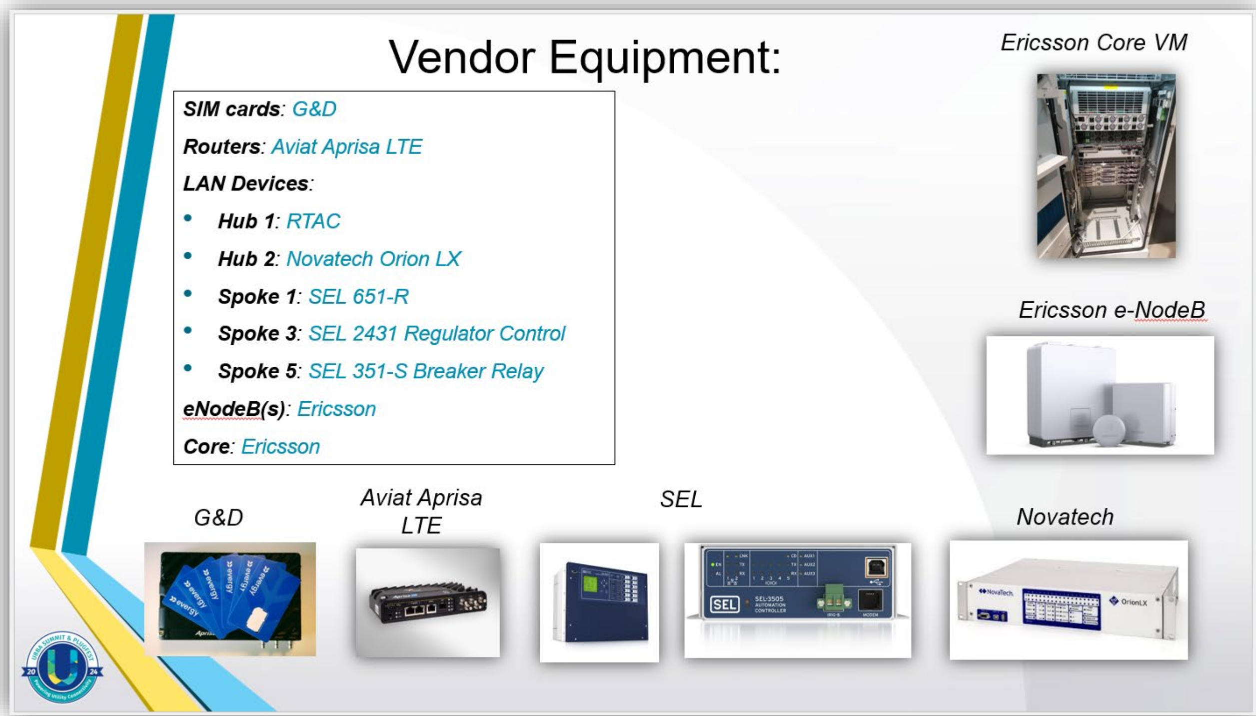






Evergy Lab environment

All vendor equipment



Tests Performed

Test 1:

- Proved DMVPN mesh was up and operational and that all hubs can reach all remote spokes, and all remote spokes could reach both hubs providing full WAN redundancy in the event of a single hub failure.
    - Tested a cellular failure by pulling the main antenna from hub 1 and thus severing cellular connectivity. The spoke could still send traffic back via hub 2.
    - Tested a physical cable failure by removing the ethernet cable between the head-end polling unit and the Aprisa LTE router that is hub 1. Traffic was still able to flow from the respective remote spoke back to the head-end over the hub 2 path.
- Created a dynamic routing protocol over the DMVPN mesh so as not to configure dozens of manual point-to-point static routes. All routers learned each other's routes via the dynamic routing protocol "OSPF" which is highly efficient and converges very quickly during an outage or topology change. OSPF uses "cost" in that the higher the bandwidth path, the lower the cost assigned to it and preferred by the routing engine (example A 100 Mbps link = cost of 1 while a 10 Mbps link is a cost of 10. This will minimize downtime for utilities for critical infrastructure.

- Tested the ability of DMVPN Phase III "spoke to spoke" communications using a feature called "NHRP Shortcut". In Phase I & II all spokes will traverse the hub no matter where the traffic destination is. However, if spokes are geographically closer, there is no need to always traverse the hub location first. The team tested spoke to spoke showing that remote spoke 2 when attempting to gain access to the remote spoke 4 & 6 LAN, the hub redirected them to no longer come through itself but rather update its routing table and "dynamically" built a new route directly to spoke 4 and 6. This allows utilities to leverage several features and benefits for large point to multipoint networks:
    - Alleviates load on the hub devices as the main payload traffic is no longer traversing the hub but going directly to the respective destination spoke. Only minor communication packets travers the hub to let the hub know the spoke is still participating in the mesh.
    - Reduces latency, jitter, PDV and increases throughput as the spoke no longer needs to span the distance of where the hub is located if the remote destination spoke is much closer.
    - Each "on-demand" tunnel built is a secure IPSec encrypted tunnel just like the static ones created between all spokes and the hub, the only difference is the spoke-to-spoke tunnel is torn down to save resources once all communications between the two spokes are completed.
    - Provides better failover support with failover mechanisms which improves network resilience.
    - Uses bandwidth more efficiently (saving costs) since traffic doesn't need to be constantly routed to the hub router.
- Created a VRF (virtual routing and forwarding) instance between hub 2 and remote spoke 6 with physical connections. In addition to the initial setup of hub 2 as a hub, there was now a separate topology occurring between hub 2 and remote spoke 6. Two new virtual instances of an Aprisa LTE were connected with each other. A GRE tunnel was created over this instance bridging the VRF LANs on both sides showing this topology can run in parallel to the DMVPN setup. In addition, this allows utilities to use overlapping IP addresses that are needed but may otherwise be used in another topology (whether permanent or temporary) as the router will not see an overlapping issue because it treats each VRF as a separate router with their own respective IP addresses, routing tables, CPUs, ports etc.
- The team created layer 2 VLANs over the VRF instance (showing how robust and flexible the virtual instances are) to keep the traffic from two different laptops separate. The laptops represent critical data that cannot leak over into any other VLAN or environment. Testing showed that the laptop in VLAN 30 was unable to

reach the laptop in VLAN 40 and vice versa, thus keeping their traffic separate. This could be used by utilities to keep traffic like Transmission vs Distribution or traffic from a regulatory entity separate and safe, such as NERC CIP traffic.

Lessons learned:

- A "mesh" network will most certainly be more efficient, resilient, and robust compared to dozens, hundreds or even thousands of manual point-to-point links. In addition, today's router must be able to support many secure and encrypted links, especially in an IoT environment. There are several routers in production today for utilities that still only offer a limit of five IPSec tunnels only.
- A dynamic routing protocol is more efficient than standard point-to-point static routes everywhere. This is inefficient for larger topologies, especially if a topology change is required in the future. There will be too many routes to undo. In addition, using a dynamic routing protocol acts as a self-healing network mechanism when a failure is present as the protocol allows for quick convergence with no human intervention for the most part.

What would be the next steps for maturing this technology?

- DMVPN is an extremely mature technology (It's a suite of different protocols working together such as *IPSec*, *mGRE*, *NHRP*) and is widely used in datacenters all over the world. The technology is now being adopted more and more by utilities due to its flexibility, redundancy, robustness and resiliency and compliments IoT topologies seamlessly. I think creating "awareness' is necessary at this point as many utilities do not know that this is available in today's router offerings for cellular. Often, a typical catalyst for utilities will come when the company realizes the non-dynamic nature of their setup as they've spent quite some time configuring setups manually and one at a time. The need for a dynamic self-healing mesh comes much later and will unfortunately require a lot of work to set up. In addition, technicians will need to improve and/or increase their knowledge of networks, especially for those with only heavy RF backgrounds. Today's devices and networks require at the very least basic knowledge of IP and networking but the understanding of how routing, switching and end-to-end networking is performed will be extremely beneficial and important for utilities.

Collaboration efforts:

Aviat Networks is in a special position to work with one of our biggest customers today, Evergy Energy. In addition, the team leveraged the fact that the event was performed in

Evergy's hometown and on their Private LTE equipment which presented other utilities the opportunity to see how a large utility was able to support and benefit from this type of topology, as opposed to performing the testing in a lab. Evergy is already using this type of setup in several portions of their network and has been proving its stability in a live production network for quite some time.
All equipment in Evergy's lab (noted above) is the same exact modelled units being used in the field today. This collaborative effort is as close to a real production network and scenario that one can observe.

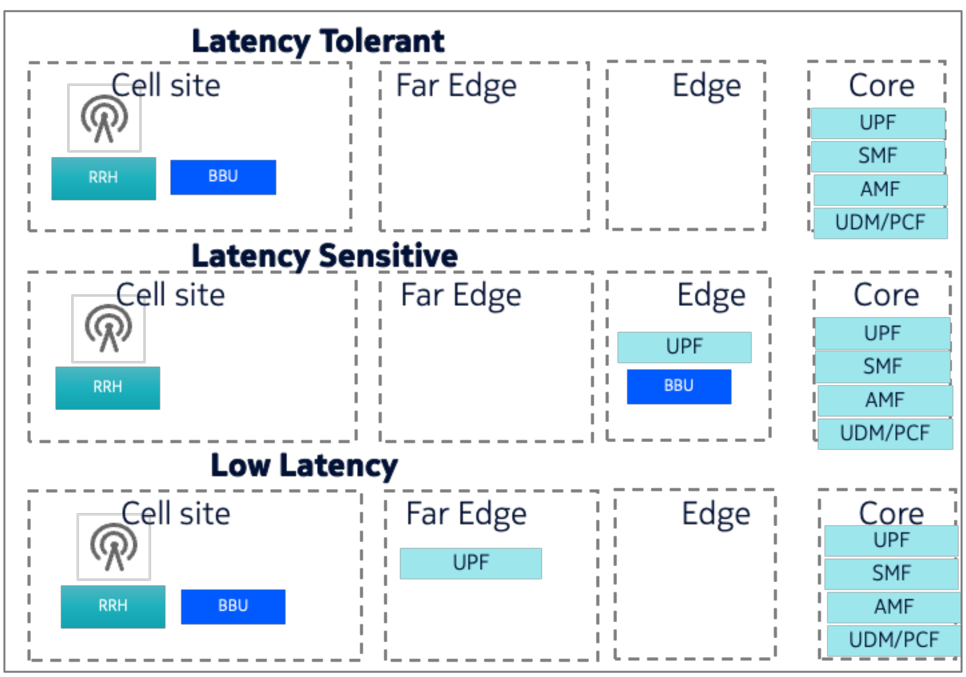
Use Case 3: Edge Computing & Low Latency

Team 1 – Nokia, Druid, EPRI

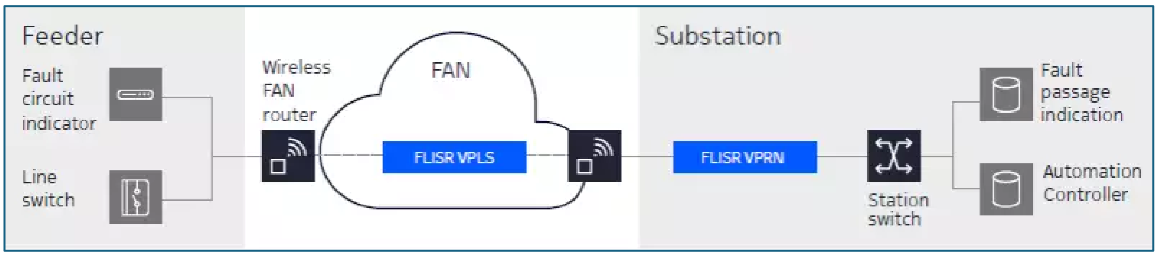
Edge compute implies the compute is closer to the "use case" where the data is created, and the raw data is processed: enabling real-time insights. The benefits relate to:

- Maximizing grid resiliency/redundancy
- Minimizing latency
- Cutting down on backhaul traffic volumes
- Reducing operational costs

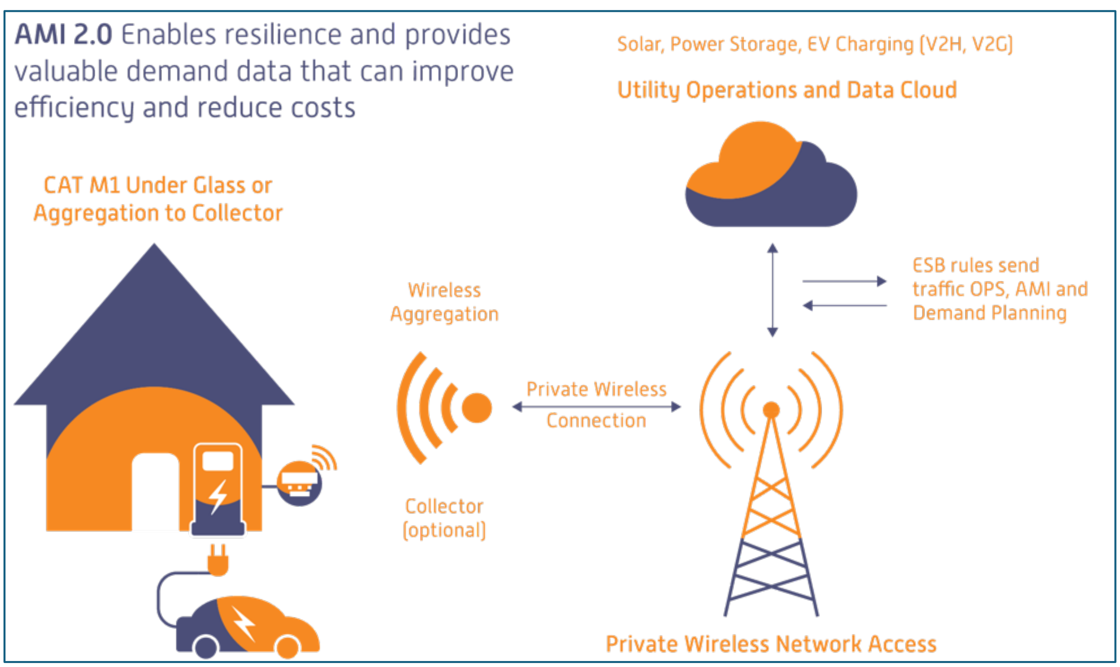
As showcased in the following figure the concepts are applicable to both LTE and 5G – although the core depicted is a 5G Core with UPF (User Plane Function), SMF (Session Management Function), and an AMF (Access Mobility Function).



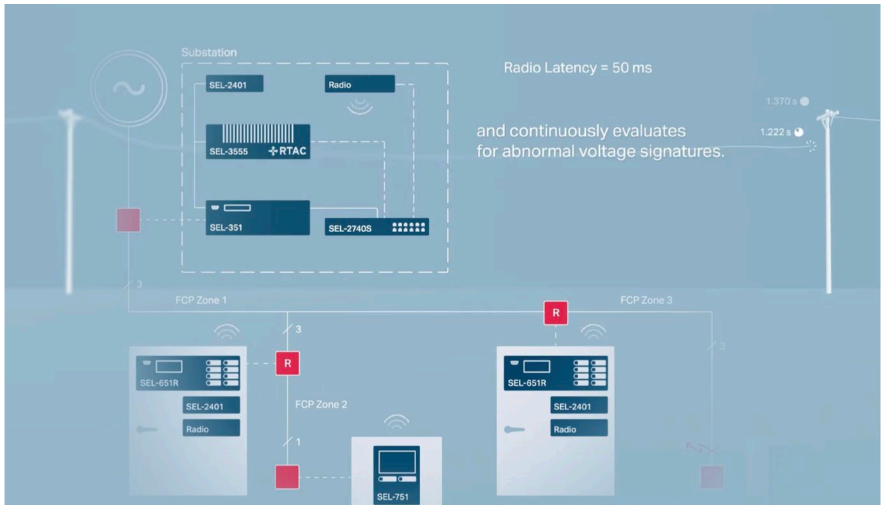
The background of this use case stems from multiple Utility applications that require low latency, such as mentioned in the references (1) FLISR – Fault Location Isolation and Service Restoration:



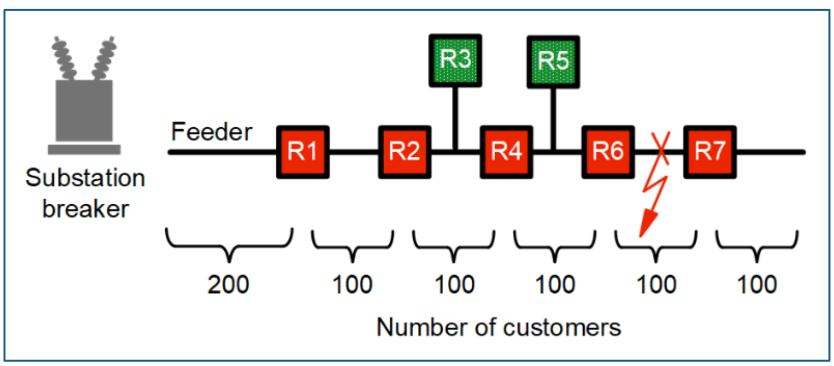
Similarly, AMI 2.0 has a major dependence on edge compute and lowering latency as explained below in Reference 2. Meter technology is advancing, transforming meters into grid sensors which become a network of powerful intelligent grid edge computing devices that can run many applications, execute complex calculations at the edge, and control energy devices in real time.

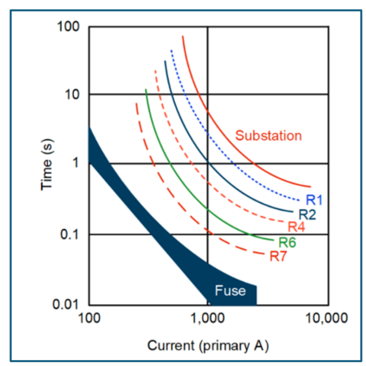


As explained below in Reference 3, SEL's Fallen Conductor Protection is dependent on low latency networks.

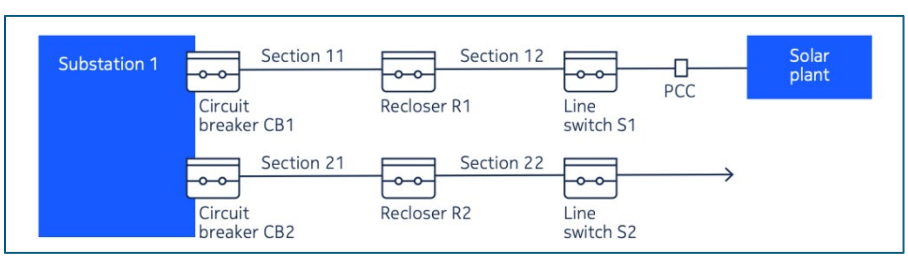


And as described below in Reference 4, high density coordination is also latency sensitive.

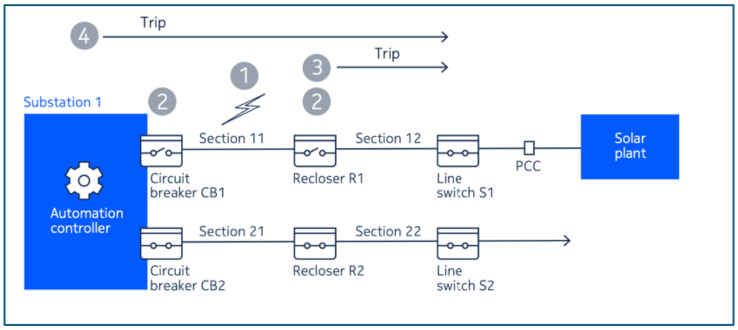




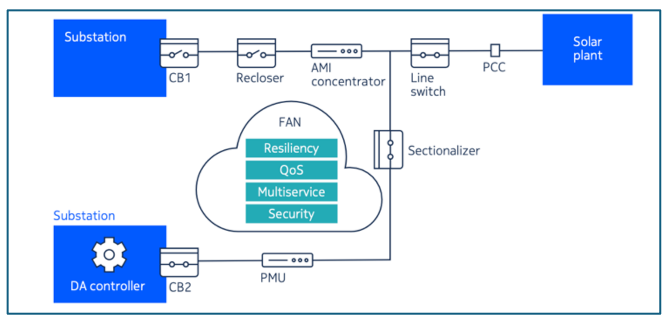
As explained below in reference 5 for DTT (Direct Transfer Trip), DER (Distributed Energy Resources) need continuous and intensive oversight of energy infeed. Suppose at the interconnection point, the point of common coupling (PCC): A fault occurs in Section 11, adjacent circuit breaker de-energize the circuit, Solar plant energizes Section 12 via PCC, creating "unintentional islanding"; Islanding - can cause hazards for the maintenance crew: out-of-range voltage, frequency, damaging customer equipment in Section 12



DTT relay sends a trip command to protect the generator or high-voltage transformer; needs to occur in the range of 5 – 50 ms. DTT – an effective islanding protection scheme:



1. A fault occurs in Section 11.
2. Upon detection, the adjacent circuit breaker and recloser open to clear the fault and to de-energize.
3. Recloser 1 (R1) then sends trip signals to the downstream line switch S1 at the PCC. S1 then becomes open and the solar plant stops energizing the connected feeder.
4. Trip signals can alternatively be sent from an automation controller in the substation when the substation automation controller detects that a midline recloser is open, The converged FAN architecture: four essential attributes for DTT and other grid communications:



- strong multi-fault network resiliency,
- deterministic QoS,
- any-to-any multiservice,
- and network security

Goose Messages IEC 61850

The modernization of electric distribution grids is essential for enhancing their reliability, efficiency, and responsiveness (Reference 1). An important key to this modernization is the implementation of advanced communication technologies to support critical distribution automation (DA) operations such as fault location, isolation, and service restoration (FLISR).

The IEC 61850 standards provide the communications foundation for FLISR and other distribution automation applications through the Generic Object-Oriented Substation Event (GOOSE) protocol, which is vital for real-time protection and control. GOOSE messaging provides rapid communication between intelligent electronic devices (IEDs) to support protection and control operations.

Achieving the low latency that these operations require necessitates a robust field area network (FAN) communication infrastructure.

A converged FAN, based on LTE/5G technology combined with quality of service (QoS) and IP/MPLS Virtual Private LAN Service (VPLS) to meet GOOSE layer 2 requirements, offers a solid communications solution.

IEC 61850 Standard

The IEC 61850 standard provides a comprehensive framework for communication networks and systems in substations and across the distribution grid. It facilitates interoperability between devices and systems used in the generation, transmission, and distribution of electrical power.

The standard defines communication protocols for data exchange between devices, system configuration and engineering processes, and data modeling and semantic definitions for equipment. The communication protocols include:

- Manufacturing Message Specification (MMS): A real-time communication and control protocol that facilitates the exchange of data between IEDs and control systems.
- GOOSE: A multicast communication protocol used for fast transmission of time-critical messages, such as protection and control signals. This paper focuses on this protocol.
- Sampled Values (SV): A protocol for the transmission of sampled measurement data, primarily used in digital protection and control systems.

While initially focused on substation automation, IEC 61850 has been extended to cover distribution automation applications and other domains, such as hydropower plants (IEC 61850-7-410), distributed energy resources (IEC 61850-7-420) and wind power plants (IEC 61400-25).

GOOSE Messaging

Described in IEC 61850-8-1, GOOSE is a layer 2 protocol that transports messages over Ethernet. It facilitates high-speed, event-driven communication between IEDs in substations and across the distribution grid.

The key characteristics of GOOSE messaging include:

- Low latency: GOOSE messages require extremely low transmission latency to ensure timely execution of protection and control commands.
- High reliability: GOOSE communication must be highly reliable to ensure the integrity of protection and control functions, often including redundant paths.
- Event driven: GOOSE transmits messages based on specific events, ensuring timely responses.

- Multicast capabilities: GOOSE supports layer 2 multicast transmission, allowing multiple devices to receive the same message simultaneously. This is essential for coordinated protection schemes.

Effective GOOSE communication is essential for the protection and control operations in electrical distribution systems. It requires a communication network that can meet stringent latency and reliability requirements. Table 1 shows the different time requirements for GOOSE messages.

Table 1: GOOSE message types

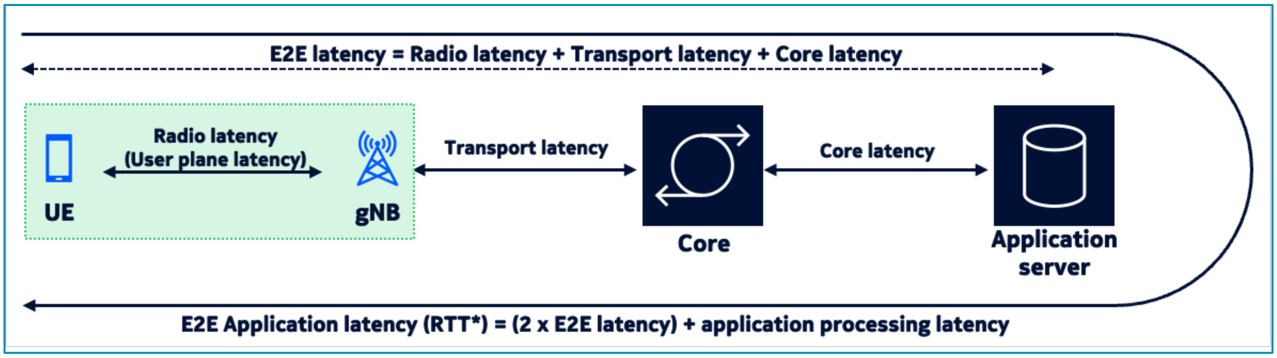
Message type	Performance class	Application	GOOSE transmission time
1A	Fast messages (trip)	P1	10 ms
		P2/P3	3 ms
1B	Fast messages (others)	P1	100 ms
		P2/P3	20 ms
2	Medium speed		100 ms
3	Low speed		500 ms
4	Raw data	P1	10 ms
		P2/P3	3 ms
5	File transfer		≥1000 ms
6	Time synchronization	T1 (time)	± 1 (accuracy)
		T2 (time)	± 0.1 (accuracy)

Testing for UBBA Plugfest Team 3

Most previous industry testing of communications for DTT has been with LTE. Team 3 Nokia collaboration focused on testing the same with 5G.

Test set-up and KPIs

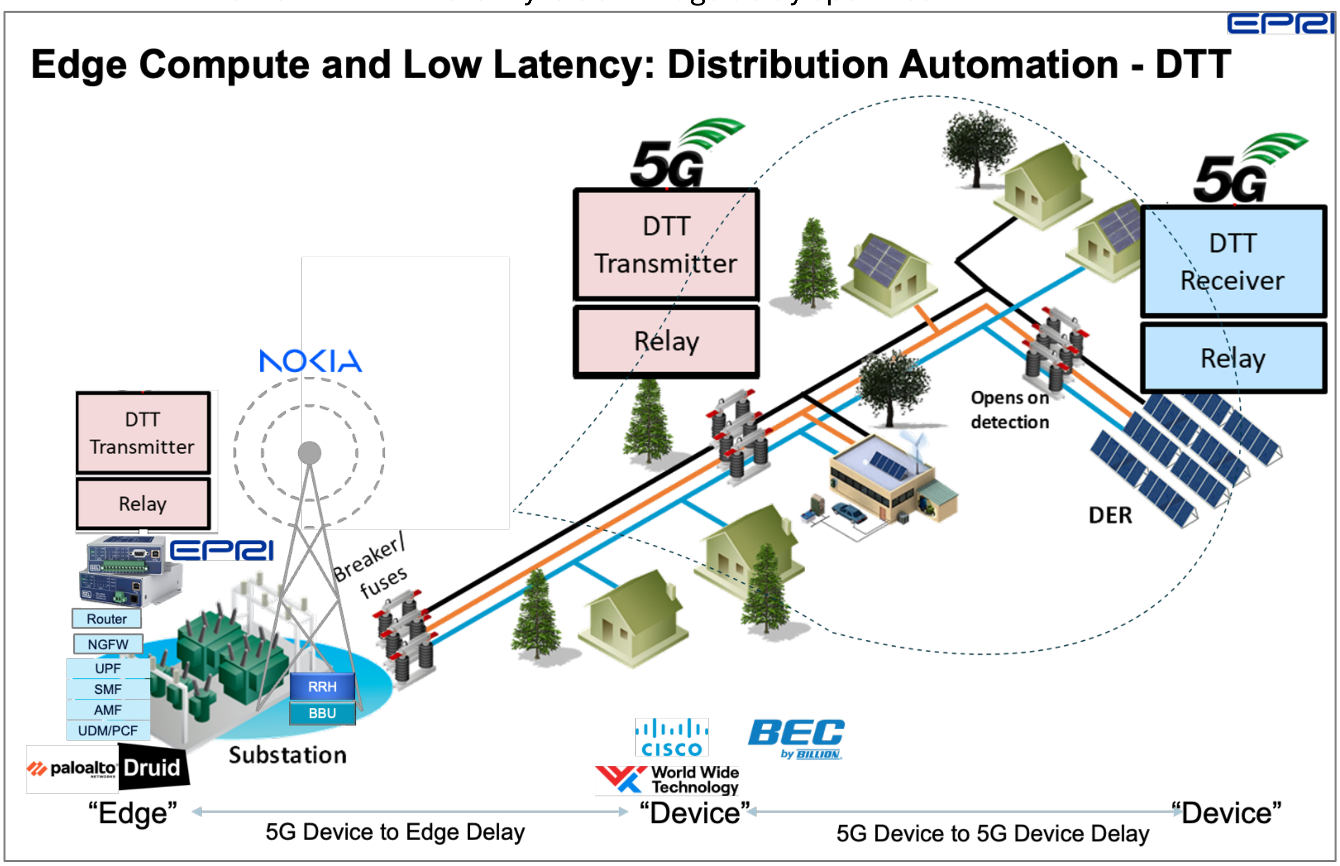
The latency is defined as the time for a packet to go from the UE to the Application (1 way)



By configuring the Core functionality close to the edge, latency was reduced. There are two KPIs:

1. E2E latency – LTE/5G UE -> RF-> eNB/gNB -> Transport -> Core -> Application
2. RTT = 2 x E2E latency

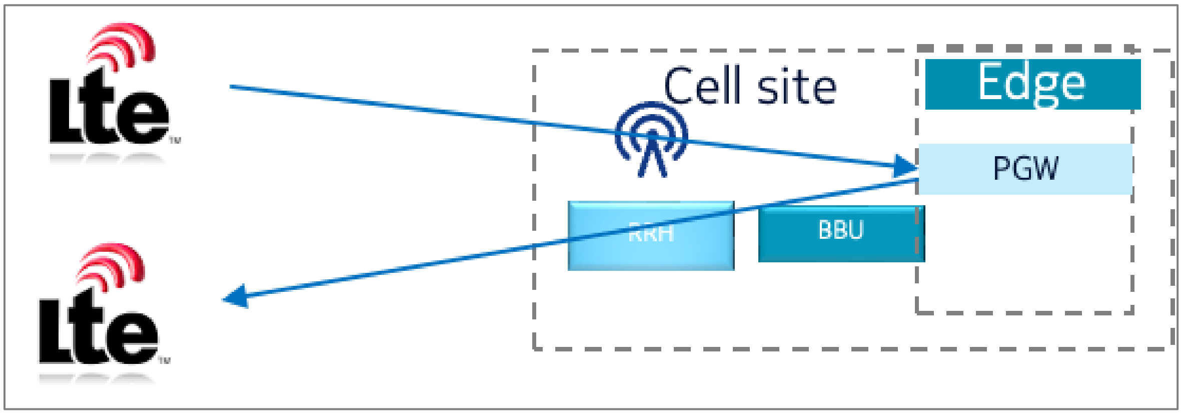
Another term for E2E latency is 5G to Edge delay specified.



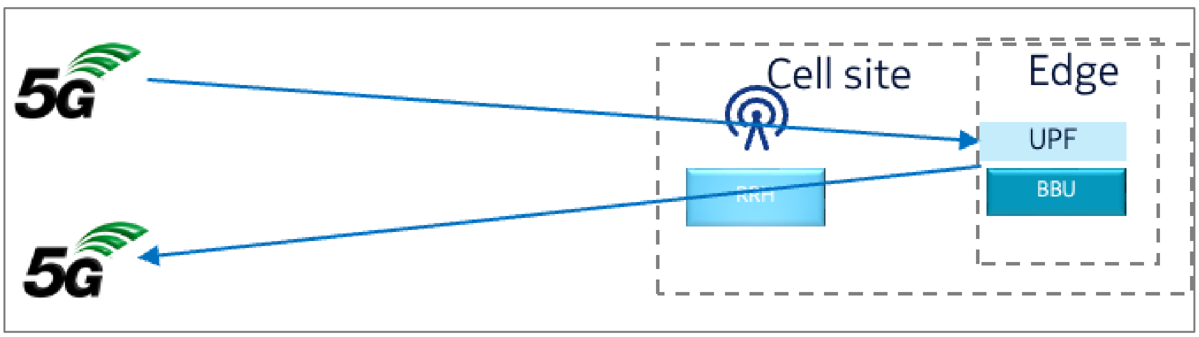
Direct Transfer Trip: A Real-world Use Case for Anti-Islanding and Protection

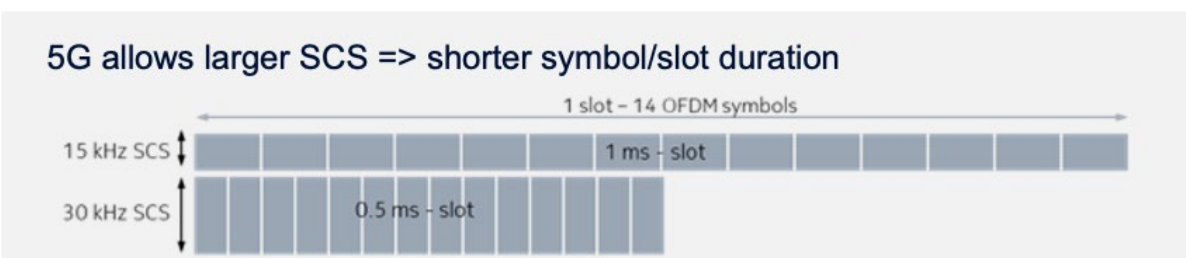
- Use IEC 61850 GOOSE Messages
- Layer 2 Multicast
- L2 not natively supported by 4G or 5G
- RTAC sends/receives GOOSE in demo
- 5G provides low-latency peer to peer

5G Latency in Ideal Conditions



The 5G scenario allows for changes to SCS for a TDD band e.g., CBRS –

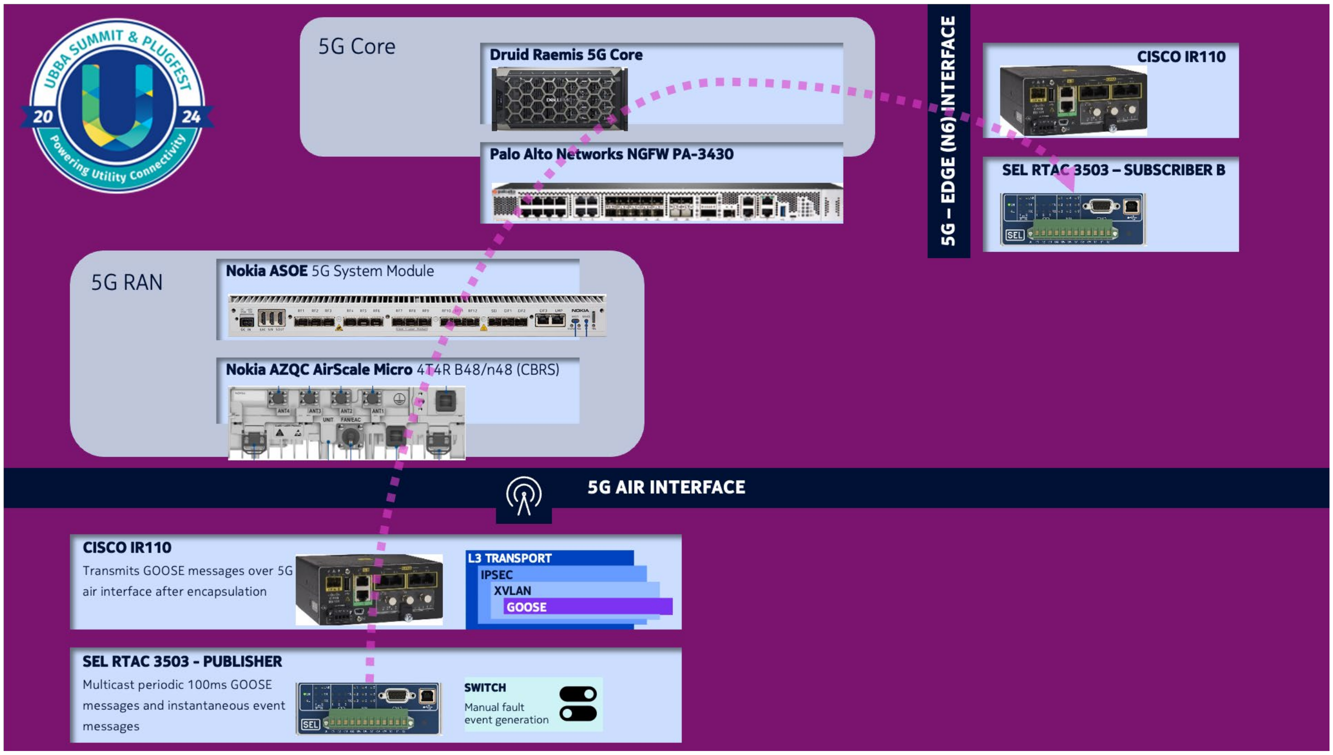




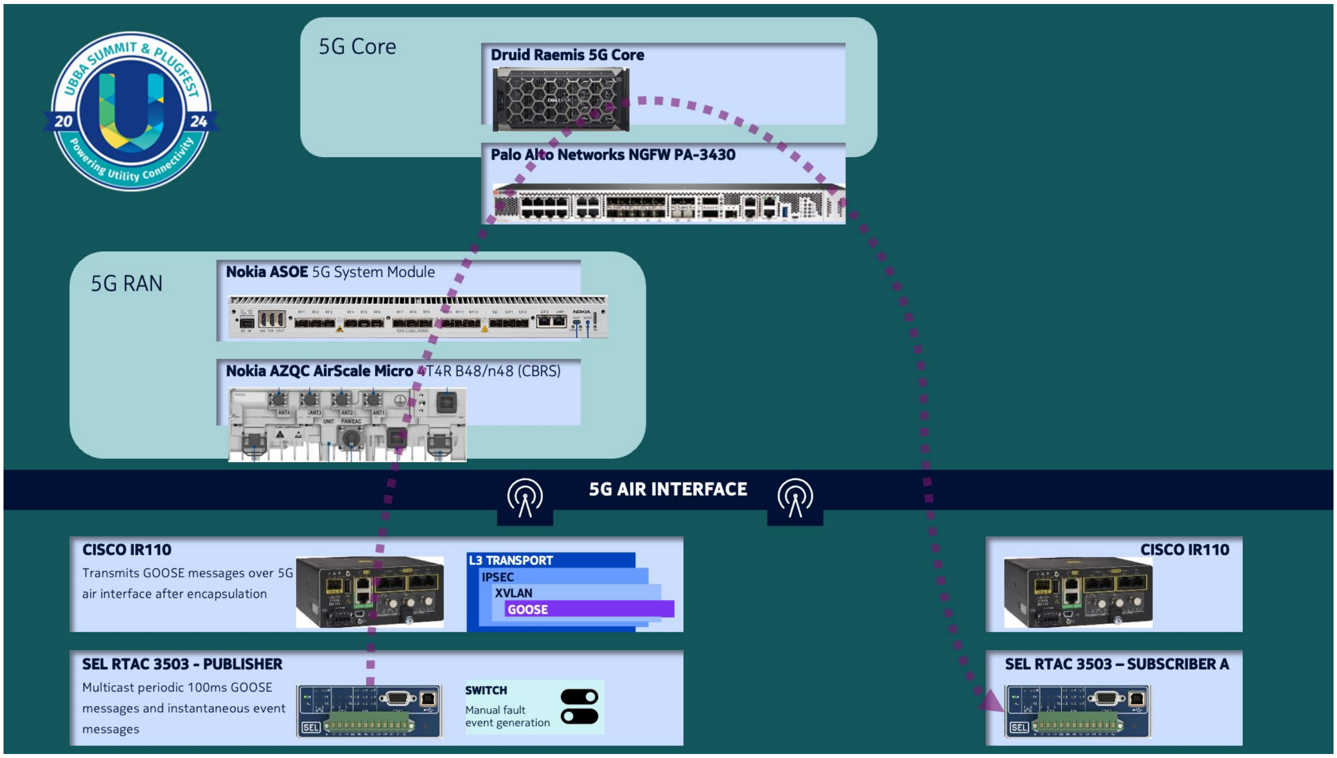
FDD vs TDD	Latency in ideal conditions
FDD, SCS = 15 kHz	15 ms
TDD FR1, SCS = 30 kHz	10 ms

GOOSE Message flow

As per the test set-up the GOOSE Message flow is shown for the latency measurements in the following diagram:



As per the test set-up the GOOSE Message flow is shown for the Round-Trip measurements in the following diagram.



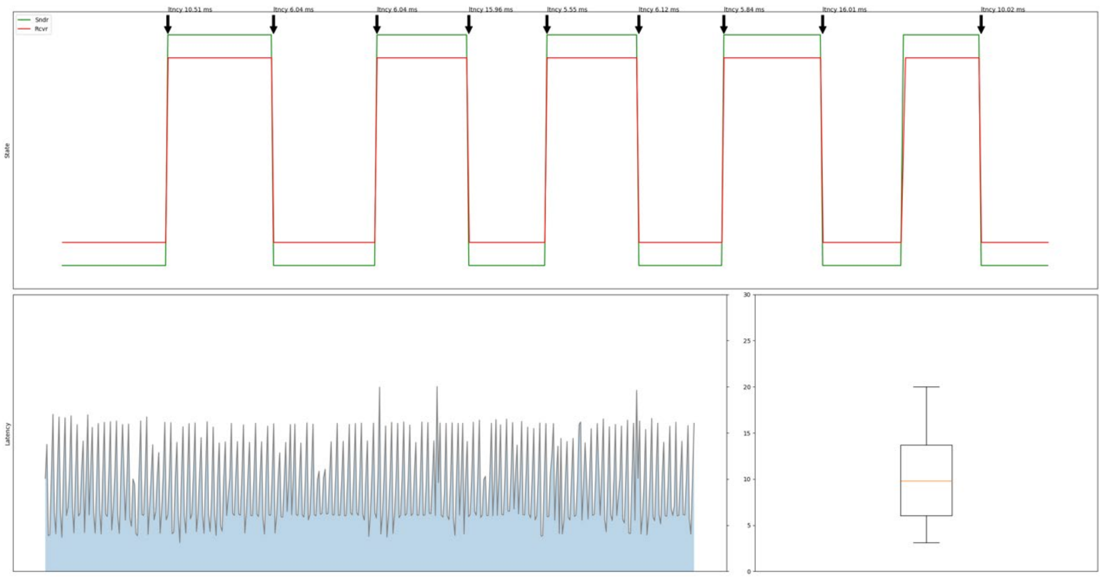
Latency results

Therefore, 5G with Edge compute can significantly reduce the latency as was demonstrated in the results Pro-active (or grant-free) scheduling (ProactUL=Y vs =N.)

Latency (msec)	Cell Center – ProactUL = Y	Cell Center – Load ProactUL = N
5G Device - 5G Device	20/44/80	28/47/96
5G Device to Edge	8/16/28	12/24/64

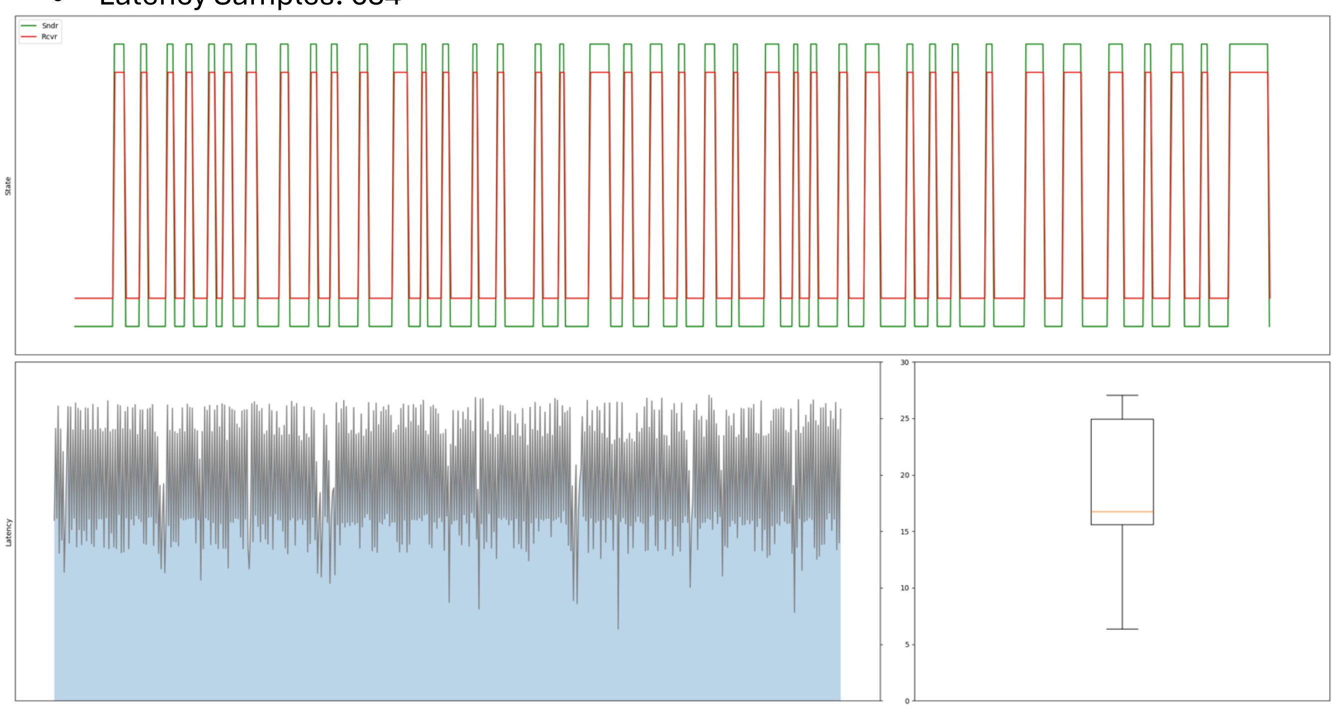
5G to Edge (5G – N6 Latency) results

- Latency Average: 9.44 ms
- Latency Median: 9.785 ms
- Latency Maximum: 20.03 ms
- Latency Minimum: 3.12 ms
- Latency Samples: 424



5G to 5G RTT

- Latency Average: 19.7 ms
- Latency Median: 16.765 ms
- Latency Maximum: 27.05 ms
- Latency Minimum: 6.35 ms
- Latency Samples: 634



Why this matters for utilities

Lays the framework:

- for future testing scenarios for Edge Compute and Low Latency
- also shows the different device/Network combinations
- shows a path to improve latency with evolution to 5G
- the edge compute scenarios are also applicable to LTE

The value of lower latency is for a multitude of Utility use cases including:

- DTT – Direct Transfer Trip
- FLISR – Fault Location Identification and Service Restoration
- AMI 2.0
- Fallen Conductor Protection
- High Density Coordination

References

1. FLISR and IEC 61850 GOOSE Communications over LTE networks using QoS and IP/MPLS, Mauricio Subieta Nokia, Energy Central https://energycentral.com/c/iu/flisr-and-iec-61850-goose-communications-over-lte-network-using-qos-and-ipmpls
2. Improving Grid Edge Communications, Efficiency and Control Successful evolution to AMI 2.0 https://anterix.com/docs/Solutions-Overview-AMI.pdf
3. Fallen Conductor Protection https://selinc.com/mktg/135956/
    a. Catching Falling Conductors in Midair—Detecting and Tripping Broken Distribution Circuit Conductors at Protection Speeds
    b. Wildfire Mitigation: Detecting and Isolating Falling Conductors in Midair Using 900 MHz Private LTE at Protection Speeds
    c. Detecting and Isolating Falling Conductors in Midair—First Field Implementation Using Private LTE at Protection Speeds
4. Improving Distribution System Reliability with High-Density Coordination and Automatic System Restoration https://selinc.com/api/download/137363/
5. Direct Transfer Trip IEC 61850 https://energycentral.com/Nokia/how-robust-communication-infrastructure-can-help-utilities-harness-power-iec

Team 2 – Cisco, DTE Energy, Eaton, Ericsson, Nokia, Verizon

Q1: What were the use cases? Why are they important to utilities?

Use Case 3 Team 2's task was to demonstrate the ability of edge compute (i.e. focused software applications at the network edge) to dramatically improve the efficiency of utility operations. Edge compute is important to utilities because it eases bottlenecks at centralized control systems by moving key decision-making functions to the edge of utility networks. This will be a critical strategy for improving grid optimization and scale, particularly for those having large, distributed energy resource (DER) components which add variability and increase the need for frequent optimization.

The specific SCADA use cases demonstrated were Volt/VAR Optimization and Stored Energy Optimization, however these are just two examples of the edge compute's broader potential. The solution can be readily extended to many other value-add solutions. The test system consisted of utility cellular routers as edge nodes securely hosting software applications which perform key field operations and provide connectivity to SCADA field assets. Data transport between the edge nodes and utility control center was over standard public and private cellular. Enterprise-class management and orchestration solutions were used to deploy and manage the cellular routers, SIM cards, and applications hosted on the routers. Importantly, the team demonstrated that the solution can gracefully scale to thousands of edge nodes to meet the expanding needs of grid modernization.

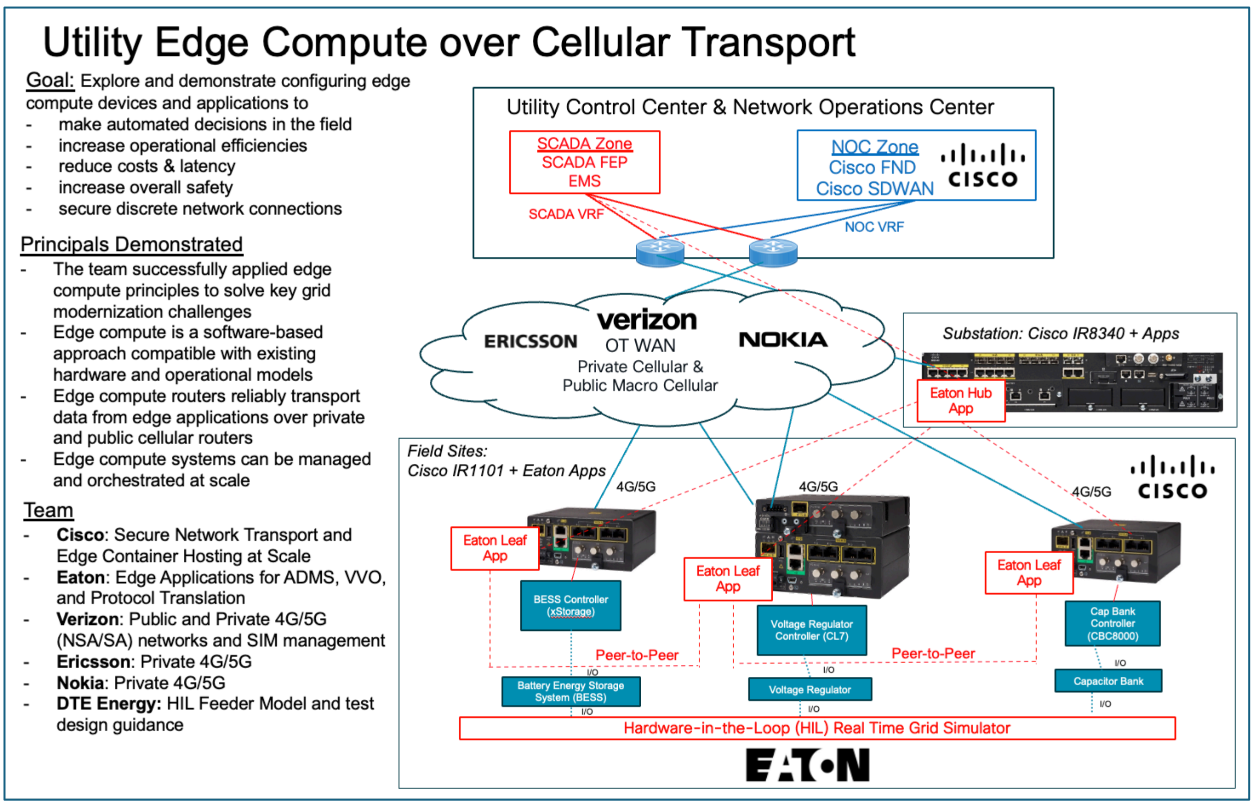


Figure 1: Project Summary

In summary, the project clearly demonstrated that utility edge compute solutions:

- are technically mature
- significantly improve grid optimization
- can be deployed via software on existing utility routers and use existing cellular infrastructure (no truckrolls)
- easily scale to thousands+ of nodes since the edge routers and applications are managed using enterprise-class orchestration tools

Q2: Who were the use case teams? What were the responsibilities? What was the focus?

The team was led by Cisco and included the following members and focus elements:

- Cisco: Provide overall project leadership and architectures for utility networking and edge compute solutions, including
    - Utility routers for secure network transport and edge application hosting
    - Enterprise-grade management and orchestration tools to secure, deploy, and manage utility routers and edge applications at scale
- Eaton: Provide leadership on utility edge compute architectures and power engineering solutions, including
    - Edge applications for advanced distribution management system (ADMS), volt-var optimization (VVO), stored energy optimization, situational awareness, and protocol translation.
    - Utility control solutions for capacitor banks, Voltage Regulators, and Battery Energy Storage (BESS) Systems
    - Hardware-in-Loop (HIL) grid simulation system
- Verizon: Provide test cellular infrastructure and architectural guidance including Private 4G CBRS (Band 48), Private 5G-PWN (Bands 5, 66, and 77), and Verizon Macro 4G/5G
- Ericsson: Provide test cellular infrastructure and architectural guidance including Private 4G CBRS (Band 48) and Private 4G Anterix (US Band 8c)
- Nokia: Provide test cellular infrastructure and architectural guidance including Private 4G CBRS (Band 48) and Private 4G Anterix (US Band 8c)
- DTE Energy: HIL Feeder Model and test design guidance

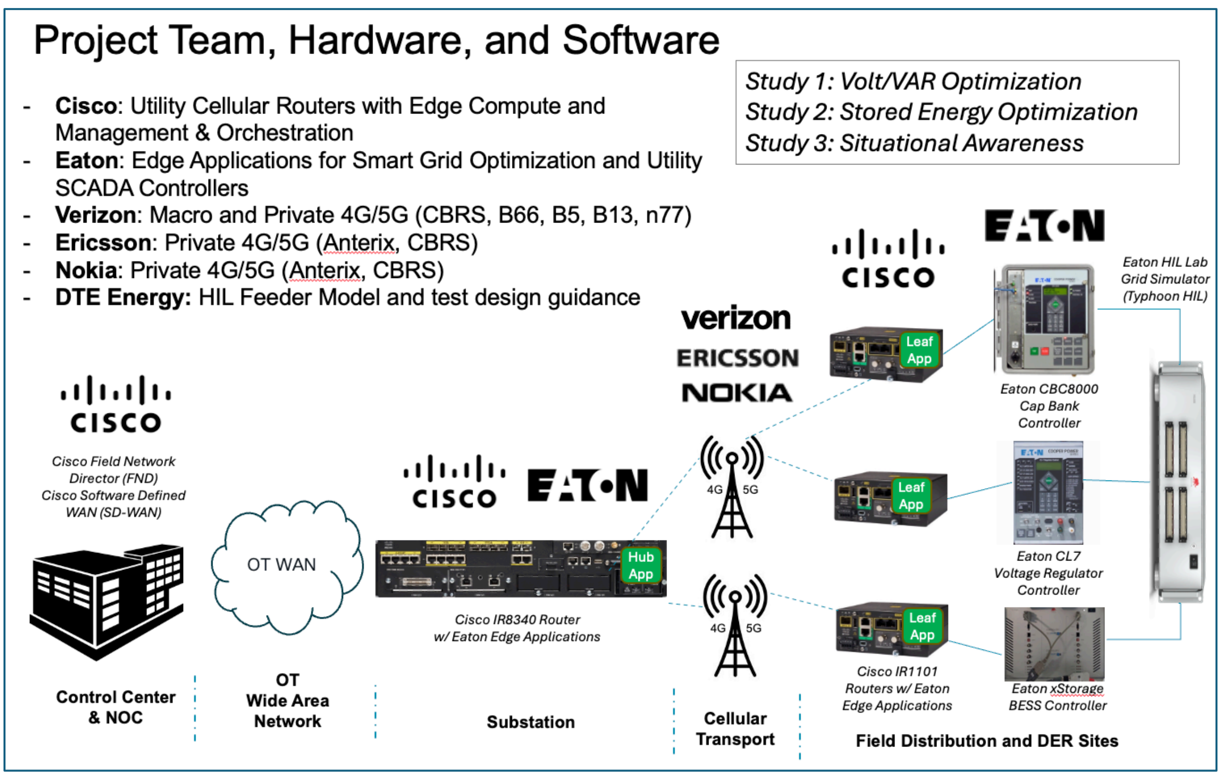


Figure 2: Project Teams and System Components

Q3: Test setups, labs, KPI's, etc. What was tested? How was it tested?

The system consisted of two test beds. Test Bed 1 focused on integration of edge compute nodes with accurate hardware-in-the-loop (HIL) grid simulations for representative testing of concepts and results. Test Bed 2 focused on edge compute over cellular transport using scalable management methods and industry-standard private and public cellular transport.

Test Bed 1 was deployed in Eaton's labs near Pittsburgh, PA and integrated hub and leaf edge applications hosted on utility routers with an accurate grid simulation system (see Figure 3). It consisted of the following hardware and software.

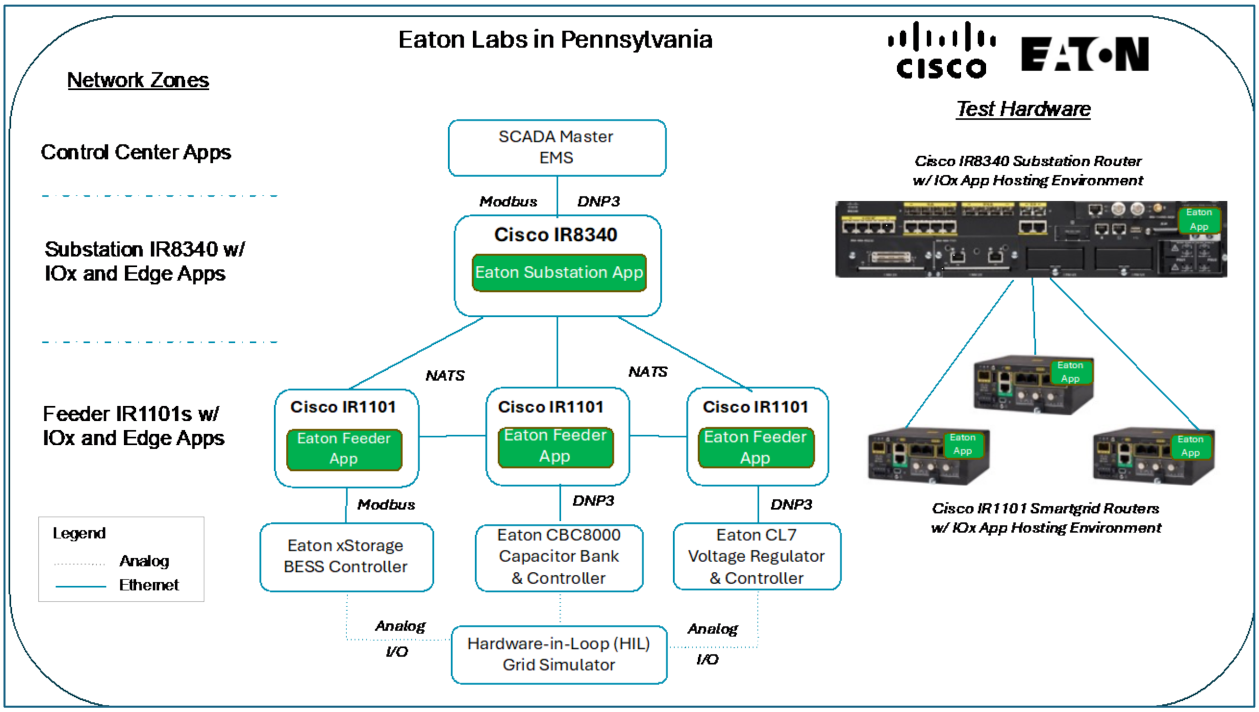


Figure 3: Test Bed 1 Topology – Edge Compute with Grid Simulation

Cisco Networking Solutions

- Cisco IR8340 Substation Router and IR1101 Utility Field Routers with IOS-XE operating system and IOx Application Hosting Environment. All routers hosted Eaton edge applications. The IR8340 served as hub router, representing a substation deployment, and the IR1101s served as leaf routers, representing feeder and DER deployment sites.
- Cisco IOx Client is an edge application utility that was used to package Eaton edge applications as docker containers with the proper configuration for IOx hosting.
- Cisco IOx Local Manager is an edge compute management GUI which was used by Eaton to deploy and configure their edge applications to the IR8340 and IR1101s.
- More information on these solutions is at:
  - IR8340: https://www.cisco.com/go/ir8340
  - IR1101: https://www.cisco.com/go/ir1101
  - IOx: https://www.cisco.com/go/iox and https://developer.cisco.com/docs/iox/

Eaton Utility Solutions

- Eaton Grid Solutions:
  - Eaton Edge Applications were hosted on Cisco IRs and performed several key functions (see Figure 4).
    - Read and Write parameters to SCADA devices using DNP3 or Modbus
    - Communicate with neighboring edge nodes via NATS to use consensus algorithms to calculate the optimal set points.
  - Eaton Control Solutions were energized by the Hardware-in-the-Loop (HIL) grid simulator and communicated with the Eaton Edge Applications.
- More information on these solutions is at:
  - Eaton xStorage: Energy storage | Systems | Eaton
  - Eaton Voltage regulator controller (CL-7): CL-7 | step voltage regulator control | Cooper control | Eaton
  - Eaton Capacitor bank controller (CBC-8000): CBC-8000 capacitor bank control | electric utility | Eaton
  - Eaton Grid Edge Solution: Eaton's Grid Edge platform

Third Party Solutions

- The Typhoon Hardware In Loop (HIL) Grid Simulator was configured by Eaton to emulate realistic grid scenarios and energize the Voltage Regulator, Cap Bank, and BESS used in the testing.
- Open Field Message Bus (OpenFMB) Framework was used for communications between the edge applications. The primary application used was NATS.

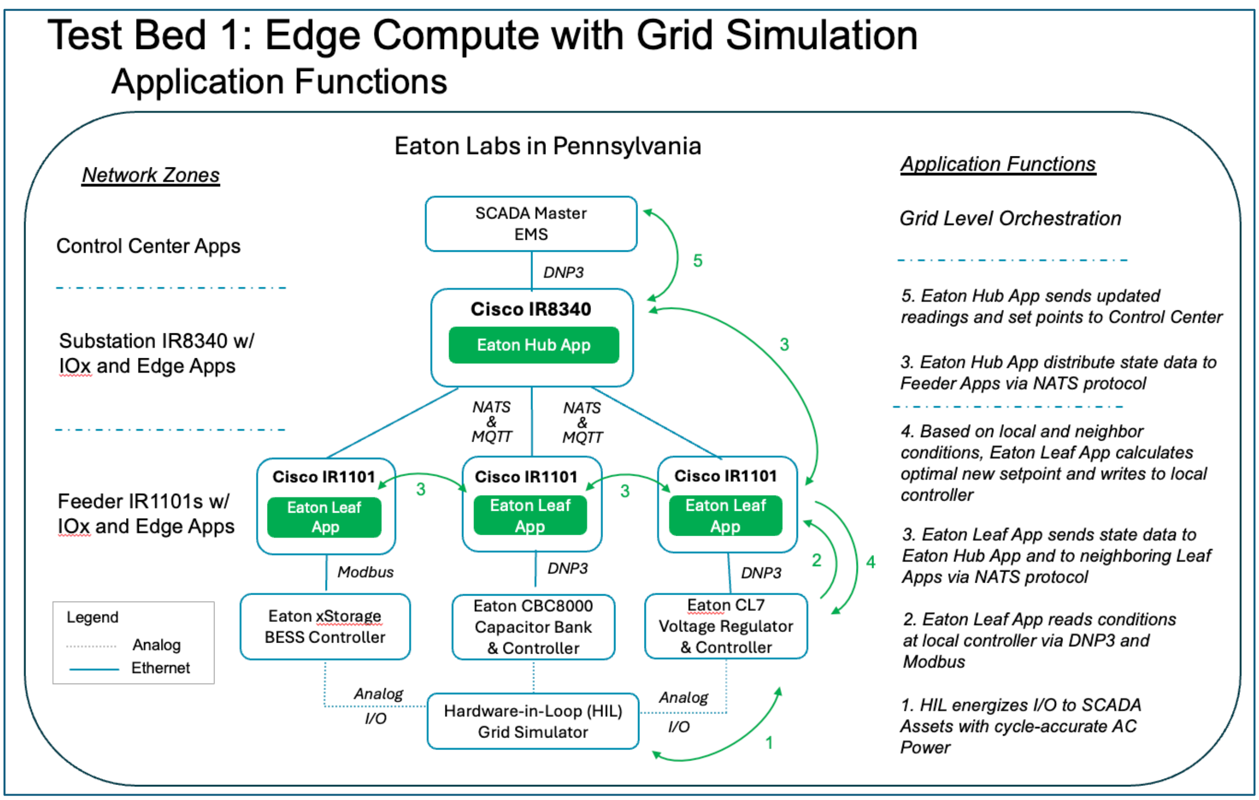


Figure 4: Test Bed 1 Topology – Edge Compute with Grid Simulation

KPIs for Test Bed 1 included:
- Reliable, secure communications between routers, edge applications, and SCADA Devices.
- Data exchange between edge applications within 1 second
- Controller measurement polling time of 1 second and set point response time of 1 second. \

Test Bed 2 was a distributed deployment of cellular routers in multiple locations (see Figure 5). The hub router was located at Eaton in Pennsylvania and leaf routers were deployed in Verizon labs in New Jersey, Ericsson labs Plano, TX, and Nokia labs in Coppell, TX. Testing at Verizon, Ericsson, and Nokia was performed over private cellular networks. Testing over the Macro Verizon cellular network was performed between the hub router at Eaton and leaf routers at Verizon. Cisco network and application management platforms used to demonstrate scalability of the solution were hosted in Cisco data centers in California.

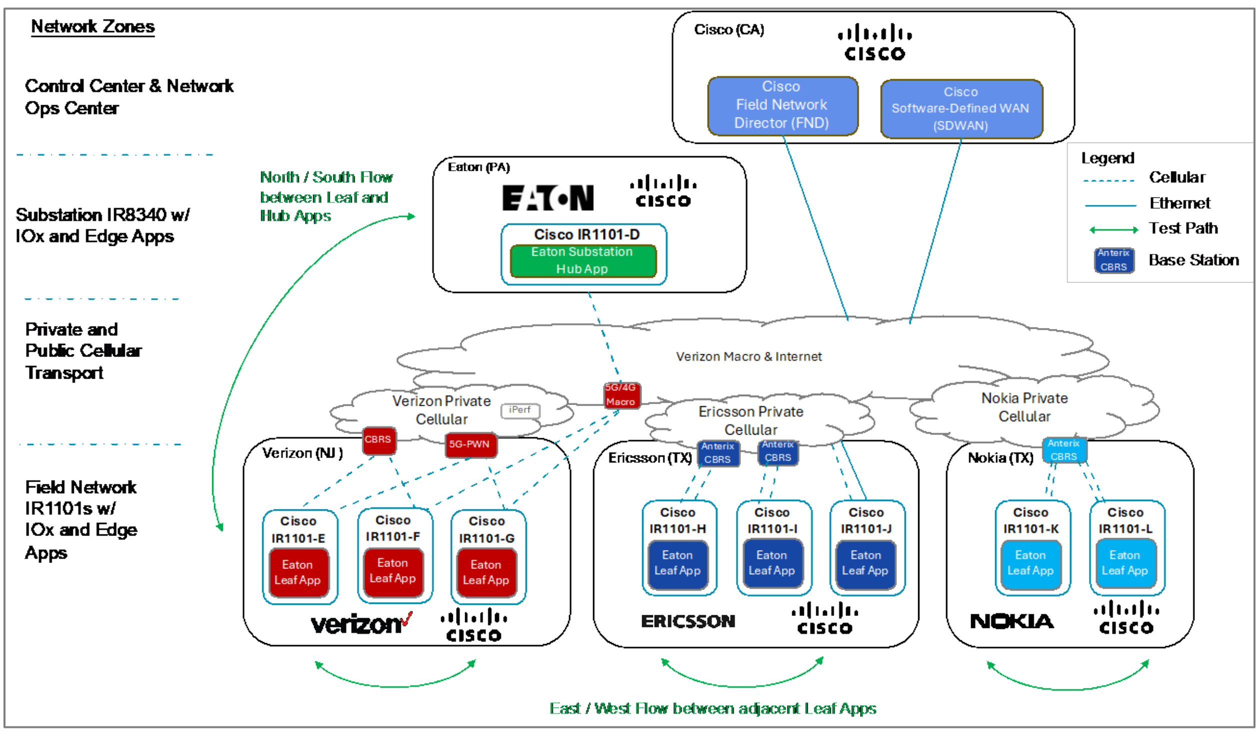


Figure 5: Test Bed 2 Topology -- Edge Compute over Cellular at Scale

Test Bed 2 consisted of the following elements:

Cisco Networking Solutions
- Cisco IR1101 Utility Field Routers with IOS-XE operating system and IOx Application Hosting Environment hosting Eaton edge applications. The IR1101 router at Eaton served as hub router, representing a substation deployment, and the IR1101s at Verizon, Ericsson, and Nokia served as leaf routers, representing feeder and DER deployment sites.
- Cisco SDWAN Management solution was used for deployment and management of the IR1101s at Eaton, Verizon, and Ericsson. SDWAN will support scalable third-party application management in 2025.

- Cisco Field Network Director (FND) was used for deployment and management of the IR1101s at Nokia. Cisco FND was also used for scalable deployment of IOx applications.
- Cisco IOx Local Manager is an edge compute management GUI which was used by Eaton to deploy and configure their edge applications.
- More information on these solutions is at:
  - Cisco SDWAN: https://www.cisco.com/go/sdwan
  - Cisco FND: https://www.cisco.com/go/fnd
  - Cisco IR1101: https://www.cisco.com/go/ir1101
  - IOx: https://www.cisco.com/go/iox and https://developer.cisco.com/docs/iox/

Eaton Utility Solutions

- Eaton hub and leaf edge applications were run on the IR1101s at the Test Bed 2 sites. Eaton team recorded data sourced from edge applications on Test Bed 1 and primed their edge applications within Test Bed 2 to "replay" the recorded data on Test Bed 2 to create representative data flows between the edge nodes.

Test Bed 2 cellular infrastructure provided by Verizon, Ericsson, and Nokia is described in Figures 6 – 8. In all, 31 distinct Router-to-Router cellular data paths were characterized (see Figure 9).

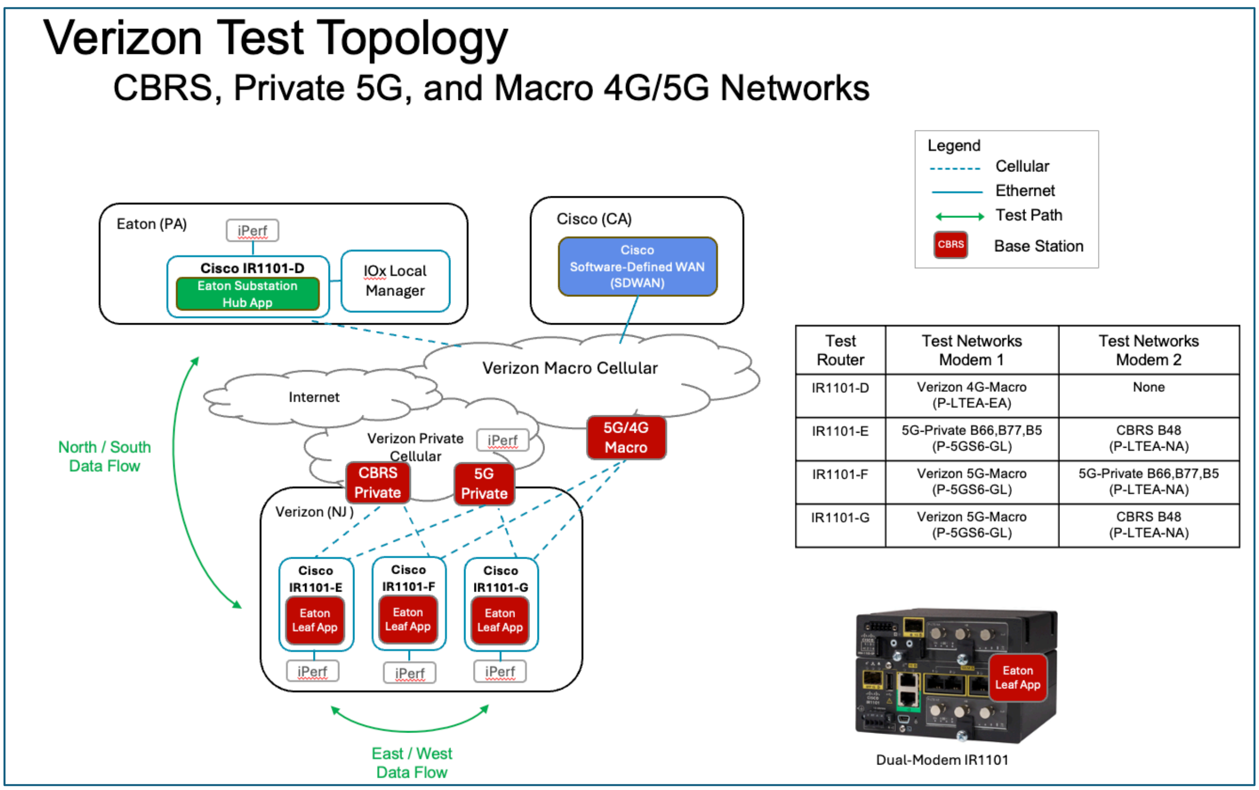
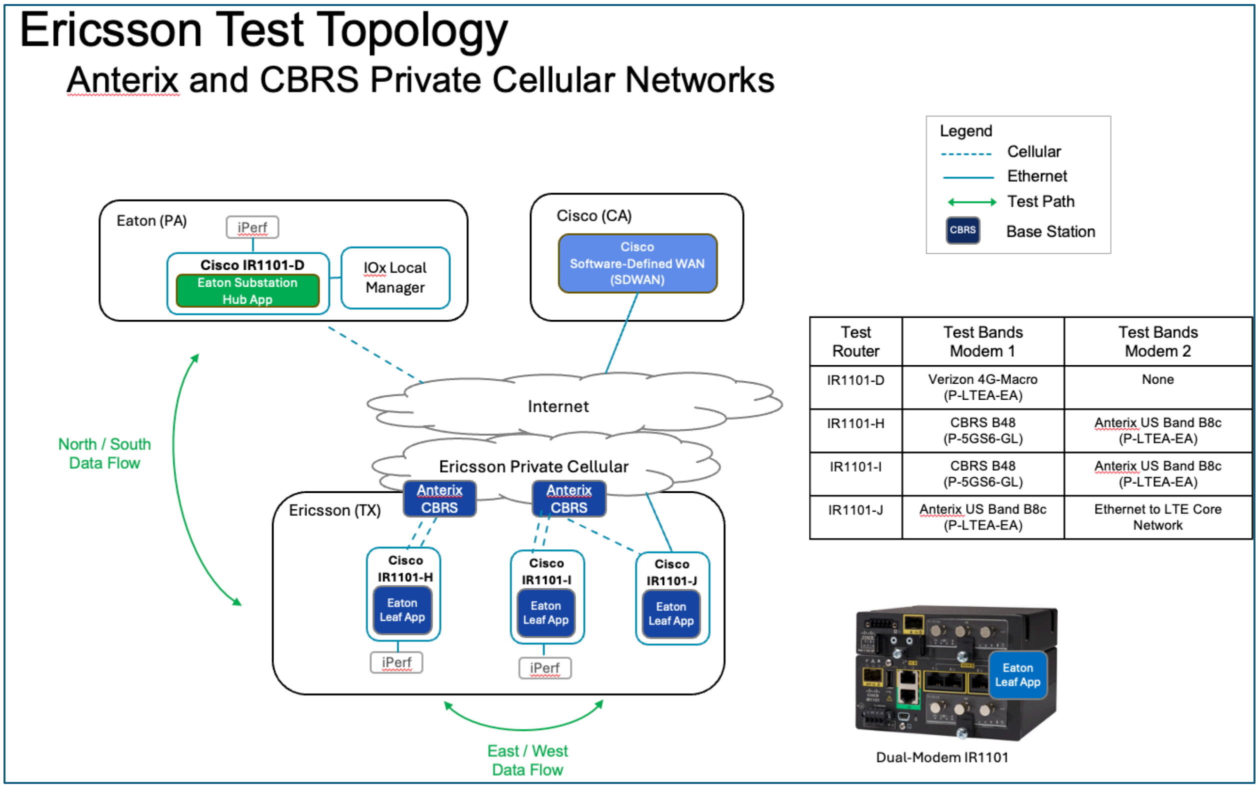
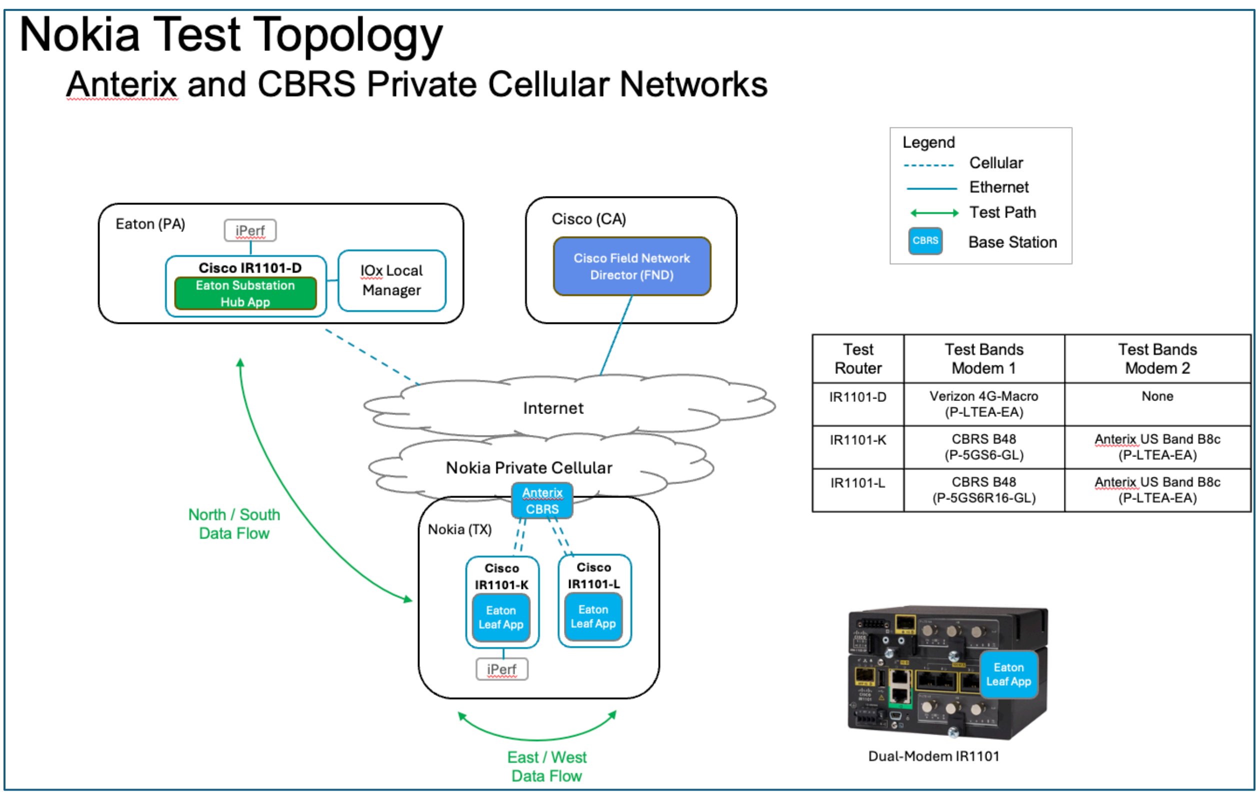


Figure 6: Test Bed 2 topology at Verizon Labs in New Jersey



Test Router	Test Bands Modem 1	Test Bands Modem 2
IR1101-D	Verizon 4G-Macro (P-LTEA-EA)	None
IR1101-H	CBRS B48 (P-5GS6-GL)	Anterix US Band B8c (P-LTEA-EA)
IR1101-I	CBRS B48 (P-5GS6-GL)	Anterix US Band B8c (P-LTEA-EA)
IR1101-J	Anterix US Band B8c (P-LTEA-EA)	Ethernet to LTE Core Network

Figure 7: Test Bed 2 topology at Ericsson Labs in Texas



Test Router	Test Bands Modem 1	Test Bands Modem 2
IR1101-D	Verizon 4G-Macro (P-LTEA-EA)	None
IR1101-K	CBRS B48 (P-5GS6-GL)	Anterix US Band B8c (P-LTEA-EA)
IR1101-L	CBRS B48 (P-5GS6R16-GL)	Anterix US Band B8c (P-LTEA-EA)

Figure 8: Test Bed 2 topology at Nokia Labs in Texas

Experimental Topologies and KPIs for Test Bed 2 are described in Figure 9. KPIs were measured using the following techniques:

- SDWAN Bidirectional Flow Metrics for latency, jitter, packet loss
- SDWAN Packet Traces and Ping tests
- iPerf Testing for jitter, packet loss
- ICMP Ping Testing for latency
- Router Modem measurements of cellular signal quality

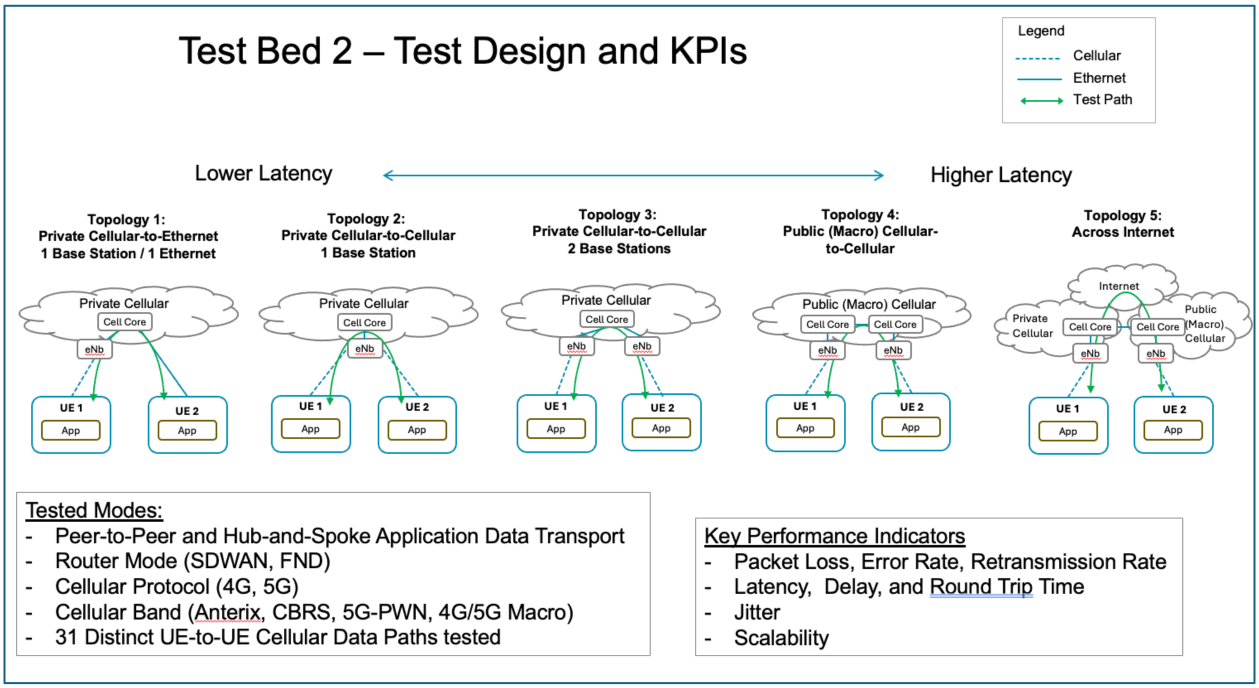


Figure 8: Test Bed 2 topology at Nokia Labs in Texas

Tested Cellular-to-Cellular Connections

31 Distinct UE-to-UE Cellular Data Paths tested

East-West, Leaf-to-Leaf Data Flows

Test Topology	Router 1	Router 1 Transport	Router 2	Router 2 Transport
1	IR1101-H	CBRS (Ericsson)	IR1101-J	Ethernet (Ericsson)
	IR1101-H	Anterix (Ericsson)	IR1101-J	Ethernet (Ericsson)
	IR1101-I	CBRS (Ericsson)	IR1101-J	Ethernet (Ericsson)
	IR1101-I	Anterix (Ericsson)	IR1101-J	Ethernet (Ericsson)
2	IR1101-E	CBRS (Verizon)	IR1101-G	CBRS (Verizon)
	IR1101-E	5G-Private (Verizon)	IR1101-F	5G-Private (Verizon)
	IR1101-I	Anterix (Ericsson)	IR1101-J	Anterix (Ericsson)
	IR1101-K	CBRS (Nokia)	IR1101-L	CBRS (Nokia)
	IR1101-K	Anterix (Nokia)	IR1101-L	Anterix (Nokia)
3	IR1101-H	CBRS (Ericsson)	IR1101-I	Anterix (Ericsson)
	IR1101-H	CBRS (Ericsson)	IR1101-J	Anterix (Ericsson)
	IR1101-H	CBRS (Ericsson)	IR1101-I	CBRS (Ericsson)
	IR1101-H	Anterix (Ericsson)	IR1101-I	Anterix (Ericsson)
	IR1101-H	Anterix (Ericsson)	IR1101-I	CBRS (Ericsson)
	IR1101-H	Anterix (Ericsson)	IR1101-J	Anterix (Ericsson)

North-South, Leaf-to-Hub Data Flows

Test Topology	Router 1	Router 1 Transport	Router 2	Router 2 Transport
4	IR1101-F	Macro (Verizon)	IR1101-D	Macro (Verizon)
	IR1101-G	Macro (Verizon)	IR1101-D	Macro (Verizon)
5	IR1101-D	Macro (Verizon)	IR1101-E	5G Private (Verizon)
	IR1101-D	Macro (Verizon)	IR1101-E	CBRS (Verizon)
	IR1101-D	Macro (Verizon)	IR1101-F	5G Private (Verizon)
	IR1101-D	Macro (Verizon)	IR1101-G	CBRS (Verizon)
	IR1101-D	Macro (Verizon)	IR1101-H	CBRS (Ericsson)
	IR1101-D	Macro (Verizon)	IR1101-H	Anterix (Ericsson)
	IR1101-D	Macro (Verizon)	IR1101-I	CBRS (Ericsson)
	IR1101-D	Macro (Verizon)	IR1101-I	Anterix (Ericsson)
	IR1101-D	Macro (Verizon)	IR1101-J	Anterix (Ericsson)
	IR1101-D	Macro (Verizon)	IR1101-J	Ethernet
	IR1101-D	Macro (Verizon)	IR1101-K	CBRS (Nokia)
	IR1101-D	Macro (Verizon)	IR1101-K	Anterix (Nokia)
	IR1101-D	Macro (Verizon)	IR1101-L	CBRS (Nokia)
	IR1101-D	Macro (Verizon)	IR1101-L	Anterix (Nokia)

Figure 9: North-South and East-West Cellular Paths Characterized in Test Bed 2

Q4: What are the meaningful results?

The project clearly demonstrates that utility edge compute solutions:

- are technically mature
- significantly improve grid optimization
- can be deployed via software on existing utility routers and use existing cellular infrastructure (no truckrolls)
- easily scale to thousands+ of nodes since the edge routers and applications are managed using enterprise-class orchestration tools

Test Bed 1 results proved that the edge compute solution significantly improves optimization of grid SCADA settings as it updated setpoints in sub-second times versus the several minutes that it takes today. The Test Bed 1 tests achieved the goals for all KPIs. The edge applications coordinated with SCADA devices to achieve sub-second data exchanges and set point updates. A video showing the real time tests is available upon request (screen capture from video is in Figure 10).

Test Bed 2 KPI measurements for Latency, Jitter, and Packet Loss/Retransmit demonstrated that cellular transport can be used in conjunction with edge compute to achieve sub-second setpoint update times. Detailed results are presented in Figures 11-14.

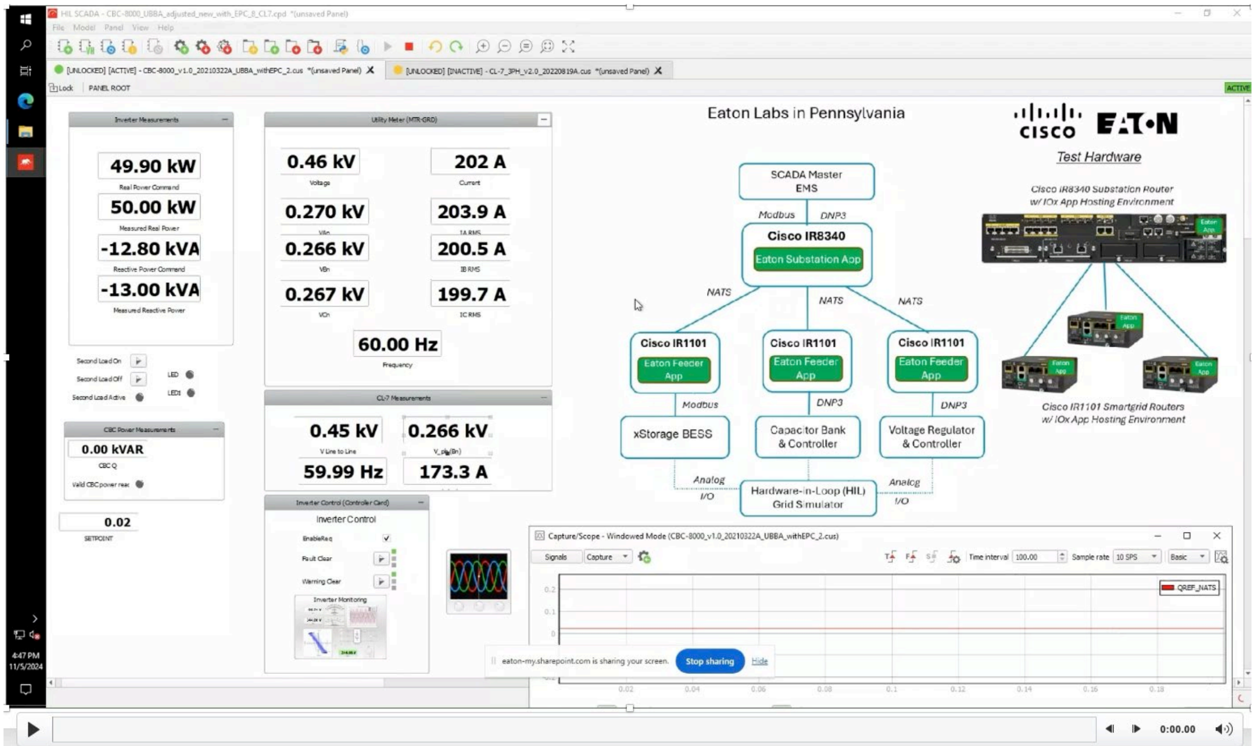


Figure 10: Screen Capture from Test Bed 1 Results Video

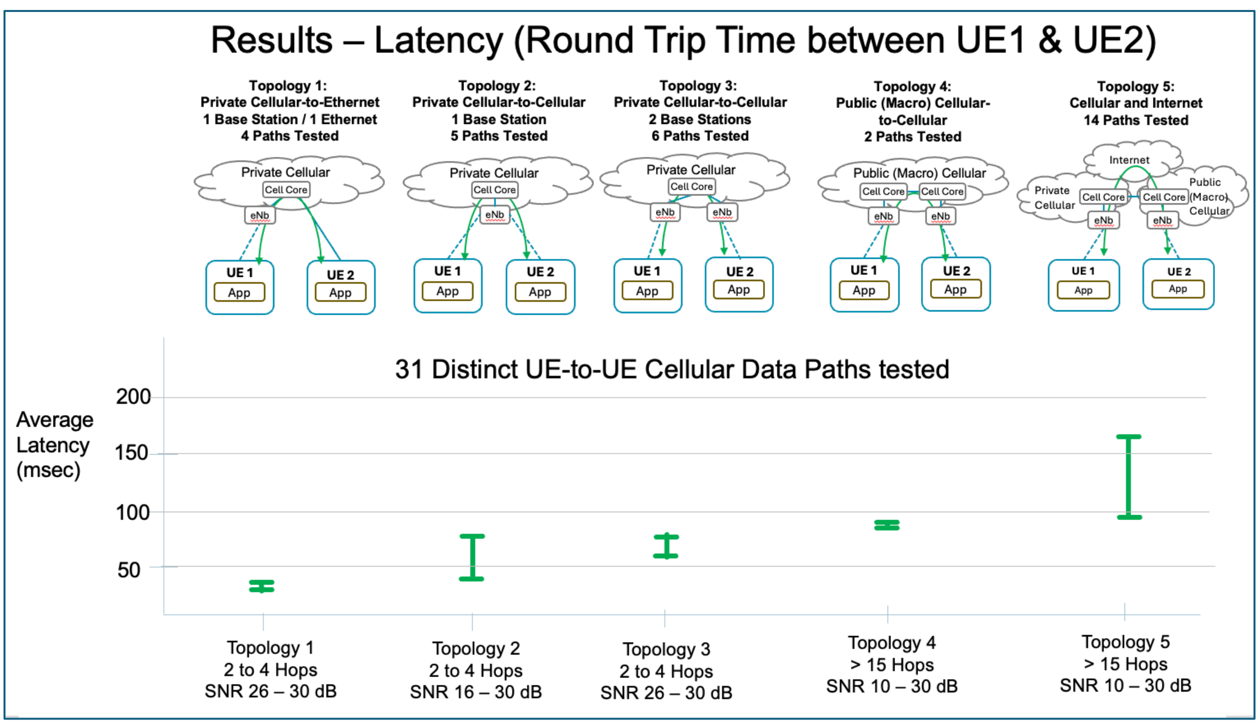


Figure 11: Test Bed 2 Latency Results

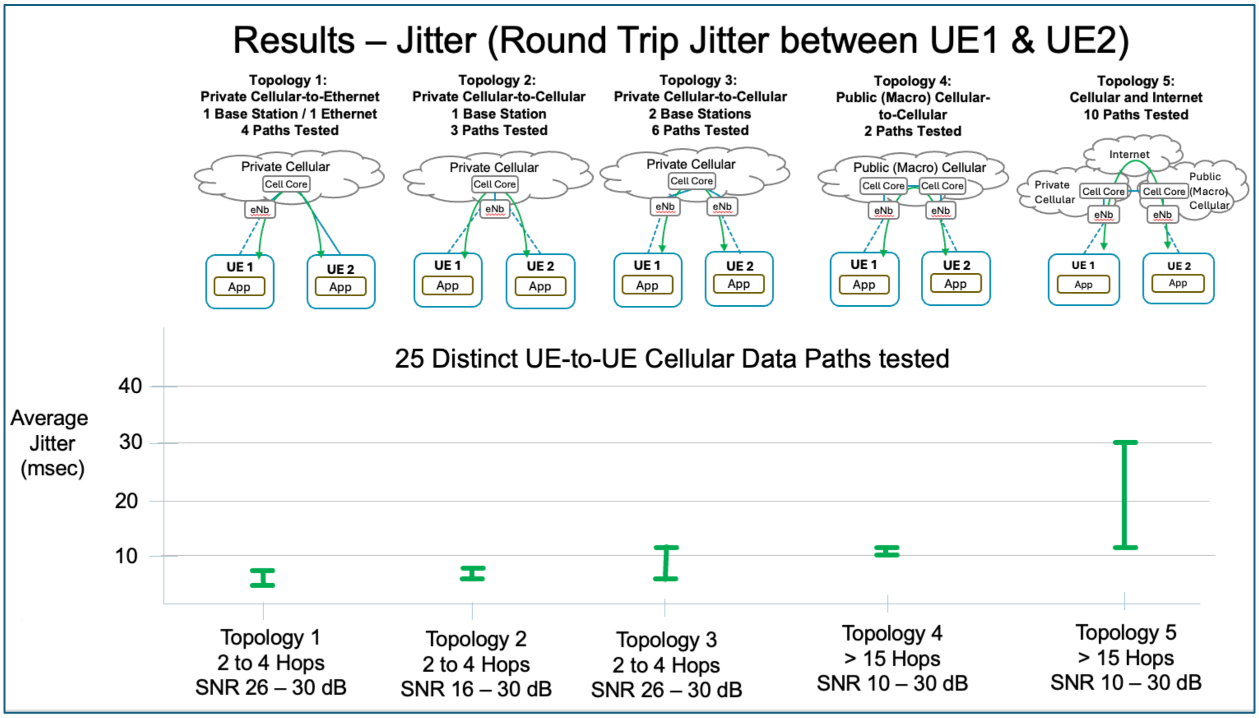


Figure 12: Test Bed 2 Jitter Results

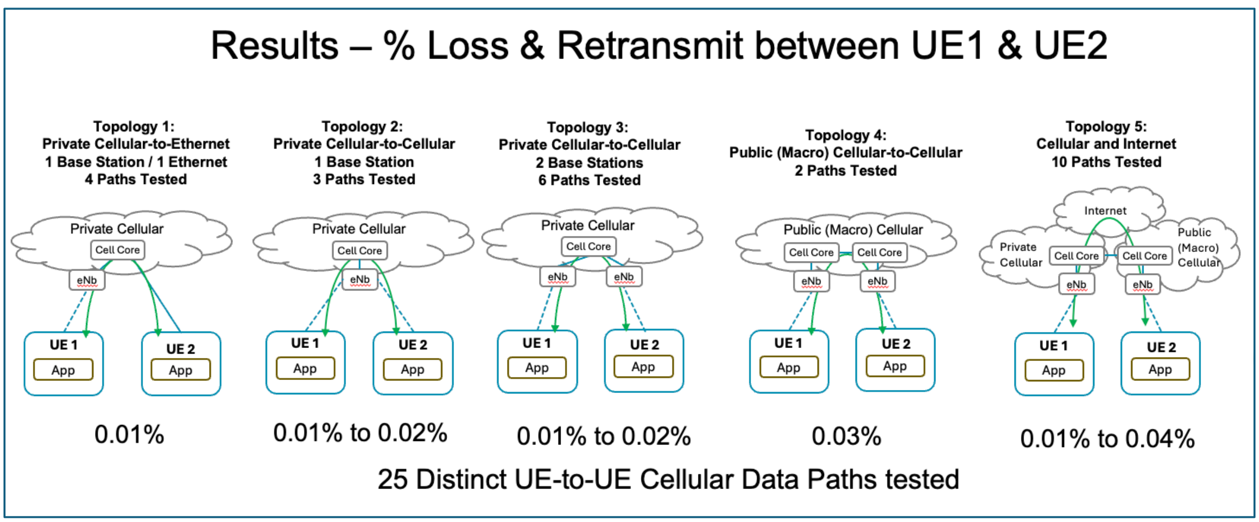


Figure 13: Test Bed 2 Loss/Retransmit Results

Team's Final Notes on Project:

- The team successfully applied edge compute principles to solve key grid modernization challenges
  - ✓ Significant improvements in volt-var optimization (VVO) were demonstrated
- Edge compute is a software-based approach compatible with existing hardware and operational models
  - ✓ Team demonstrated that edge compute can be easily deployed at scale using existing infrastructure
- Edge compute routers reliably transport data from edge applications over private and public cellular routers
  - ✓ Data was reliably transported across 6 different private cellular cores at 3 vendor laboratories and also macro cellular cores with high degree of stability
- Edge compute systems can be managed and orchestrated at scale
  - ✓ Routers and edge apps were deployed and managed using toolsets that can easily scale to thousands of UEs

Figure 14: Team's Project Perspectives

Project Leads:

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UBBA's Perspective on the 2024 Plugfest Testing & Report

As of December 2024, the UBBA community consists of thirty-eight utilities, each playing a crucial role in guiding the focus and direction of the organization. Utilities are essential in leading the development of critical infrastructure strategies, advancing technological capabilities, and identifying key gaps that require attention. In collaboration with solution provider members, these utilities work together to drive continuous improvements to the electrical grid. Along with the utility members, there are more than seventy solution provider members offering solutions for spectrum, infrastructure, engineering and consulting, equipment, SIMs, and several software solutions. These solution providers work together throughout each year to continuously mature their critical infrastructure solutions.

The 2024 UBBA Summit & Plugfest conference was a resounding success, drawing more than 620 attendees and highlighting the pivotal role of innovative solutions in supporting the electrical grid. The growth of UBBA in recent years has been a testament to the collaborative and forward-thinking approach of its utility and solution provider community. Since 2021, the UBBA Plugfest LTE testing projects have stood out for their unique spirit of cooperation, where solution providers, including competitors, join forces alongside utilities - who bear the distinct responsibility of shaping UBBA's strategic direction and focus.

The 2024 Use Case teams that were selected to participate in the Plugfest represented the larger ecosystem community. They delivered on the charter of exploring, testing, and evaluating use cases that are top of mind for utility members with concrete lab results and insights for future study. Additionally, many UBBA member companies demonstrated their own technology solutions during the Innovation Zone hours and on the stages of the Summit.

Building communication systems to utility-grade standards is essential for addressing the demands of critical infrastructure applications. Through ongoing collaboration and exploration, the UBBA community is advancing the capabilities of these critical assets, gaining valuable insights into utility operational use cases, and driving progress across the industry.

Planning is already underway for the 2025 UBBA Summit & Plugfest, which will take place in Charlotte, North Carolina, November 4-6, 2025. For more information and to join the Alliance visit UBBA.com or contact us by email at Info@UBBA.com

Thank You to the 2024 UBBA Plugfest Participating Members

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