Secure Wireless Mesh Networking for Nuclear Sensing

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

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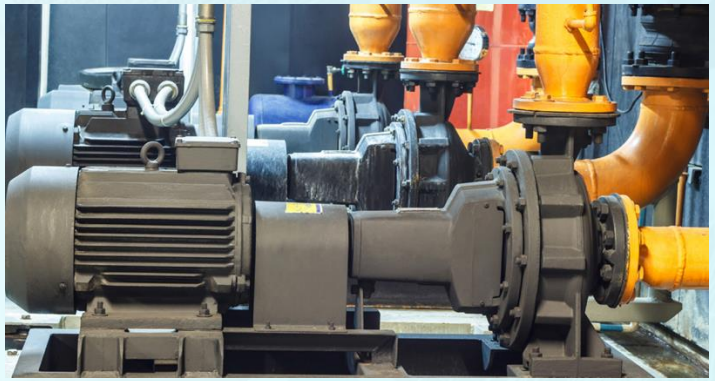
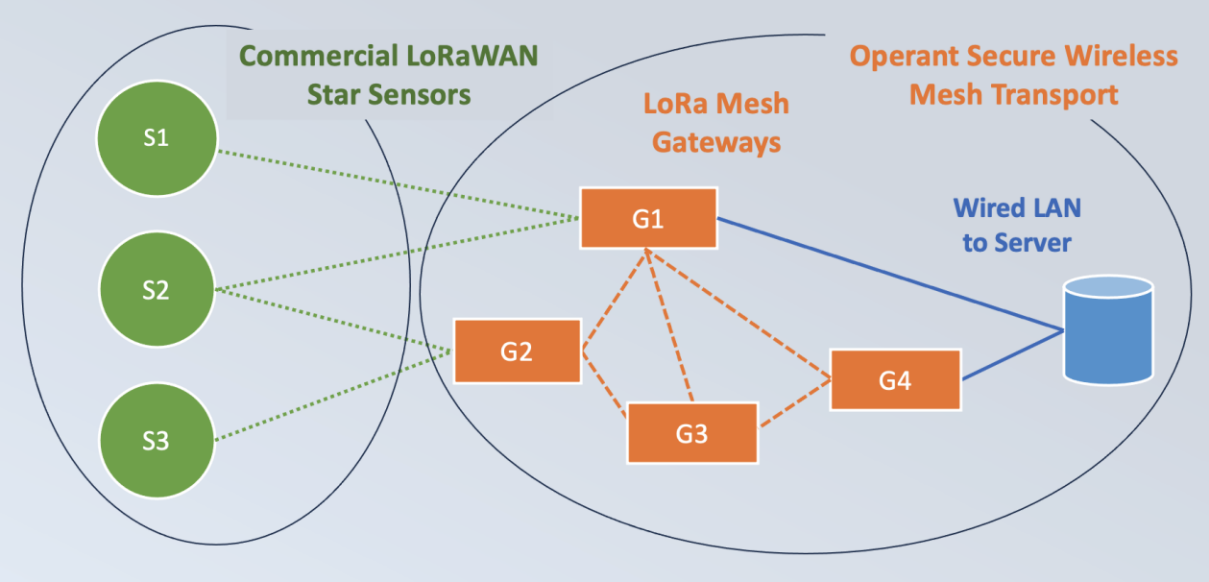
Project Overview / Motivation: Nuclear Wireless Sensors

- **Background:** Operant's Named Data Networking is currently deployed for the secure transport marketing telemetry data from Constellation existing nuclear plants to the control center.
  → This project expands this transport to wireless nuclear sensors.
- **Problem:** Monitoring and predictive maintenance sensors are needed to extend nuclear plant lifetime but retrofit wiring costs are extremely high. Wireless sensors show promise.
  - Vibration, pressure, temperature, and wireless gauge reader sensors.
  - Plant shielding attenuation and interference make reliable wireless NPP connections difficult.
- **Benefits:** Reduced personnel expenses for routine monitoring and predictive maintenance for increased up-time and fewer repairs.



Project Overview / Motivation: Nuclear Wireless Sensors

- **Technology:** Operant's networking software uniquely enables extreme range wireless technology (LoRa) in an end-to-end cybersecure **mesh** topology that promises a resilient sensor network.
  - Low-cost commercial LoRaWAN sensors are used.



- **Results:** It worked!

LoRa Mesh Hardware

LoRaWAN Wireless Gauge Reader

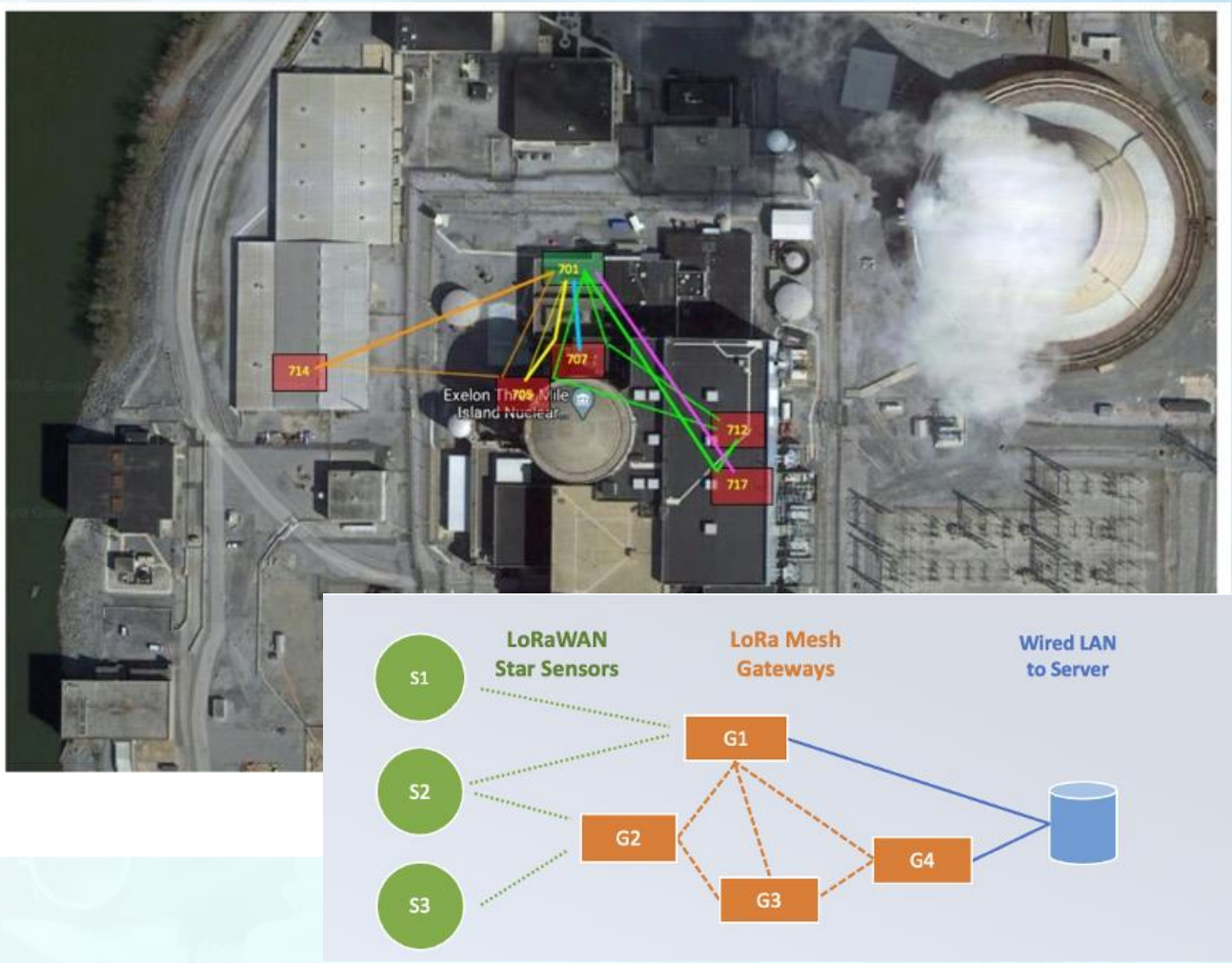
LoRa Mesh Radio Card

Ruggedized Gateway

Phase I Results – Testing in Constellation TMI Nuclear Power Plant

- LoRa successfully penetrates thick plant walls in decommissioned plant.
- Battery-powered LoRaWAN sensors could retrofit existing analog gauges, but range is limited.
- Few wired broadband backhaul locations → LoRa Mesh can likely extend range to entire plant.
- **Resilient Mesh networking needed.**

Constellation announced plans to restart the TMI Unit 1 in 2028 in conjunction with Microsoft for data center applications.



Phase II - Mesh Technology / Advanced Multi-Party Communications

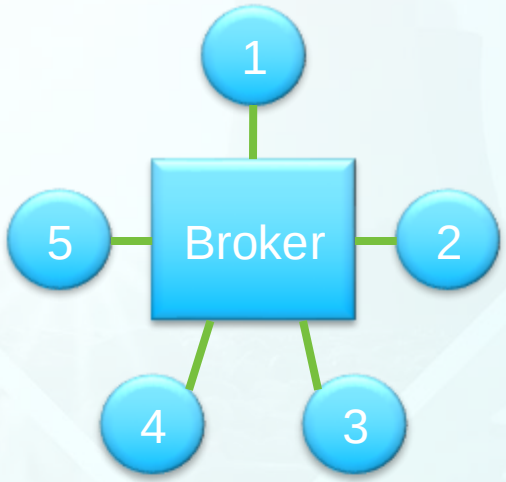
Wireless mesh provides end-to-end cybersecurity and native communications support for advanced multi-party communication patterns such as Publish/Subscribe

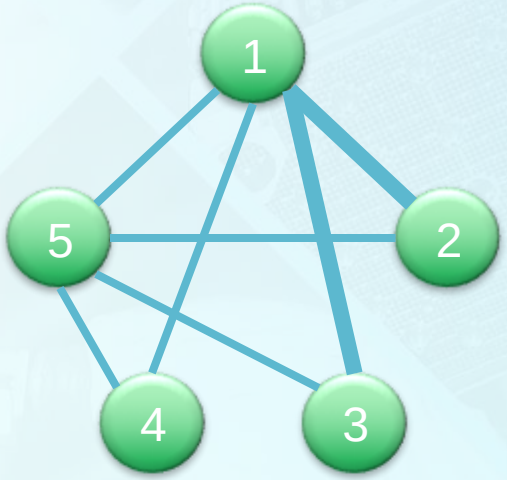
Publishers of messages, do not specify specific recipients by their identity but instead define a topic name which allow subscribers to register their interests ahead of time

TCP/IP-based Pub/Sub must send all messages to a central Broker so that each message is a simple ‘A-to-B’.

TLS security.

The Broker is a single point of failure for security and delivery.

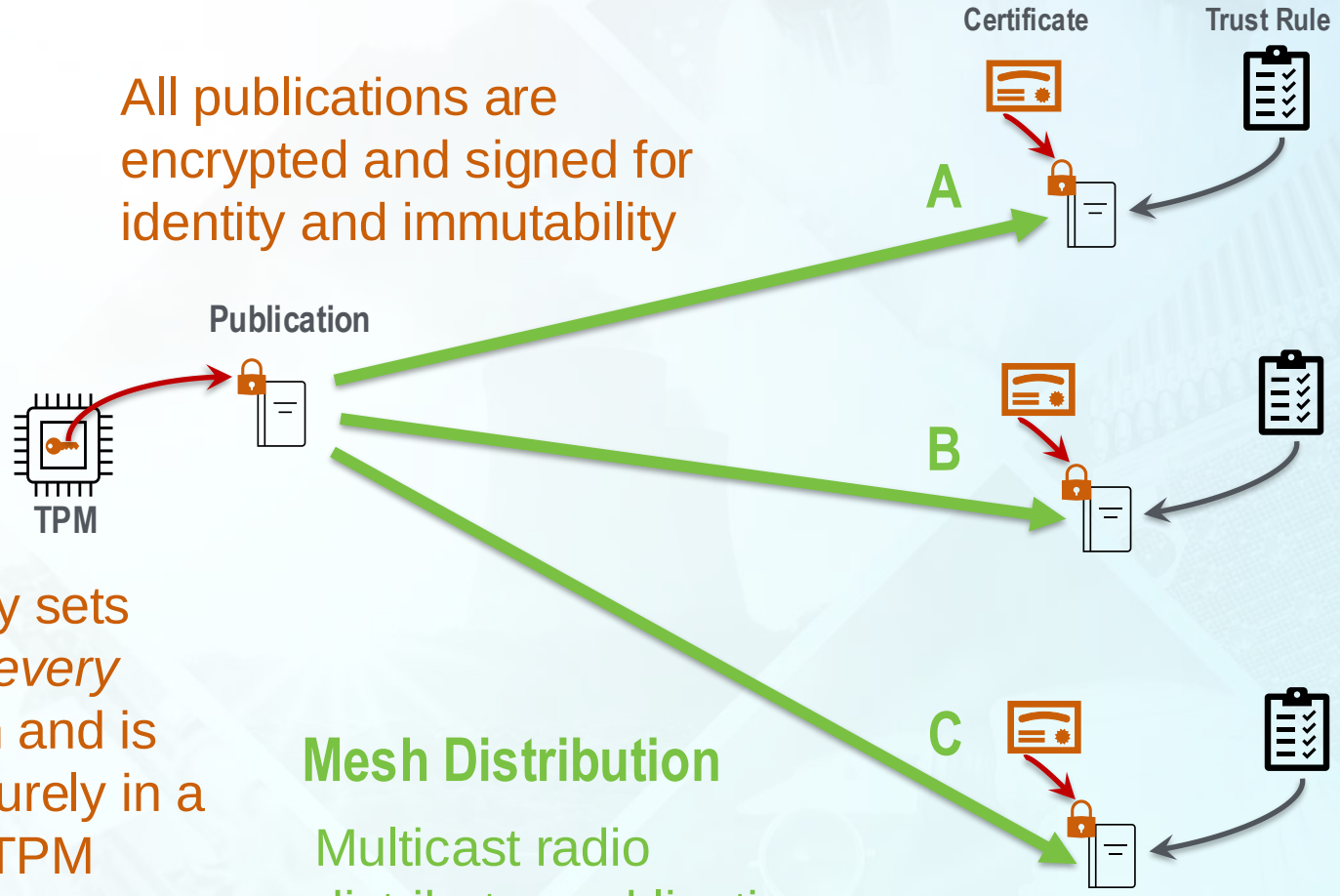




Operant Named Data Networking (NDN) Pub/Sub is fully distributed and efficiently delivers messages over any available link with forwarding, caching and end-to-end cybersecurity assured by design.

Security and Resiliency: Trust-based Pub / Sub

All publications are encrypted and signed for identity and immutability



Private Key sets identity of *every* publication and is stored securely in a hardware TPM

Mesh Distribution

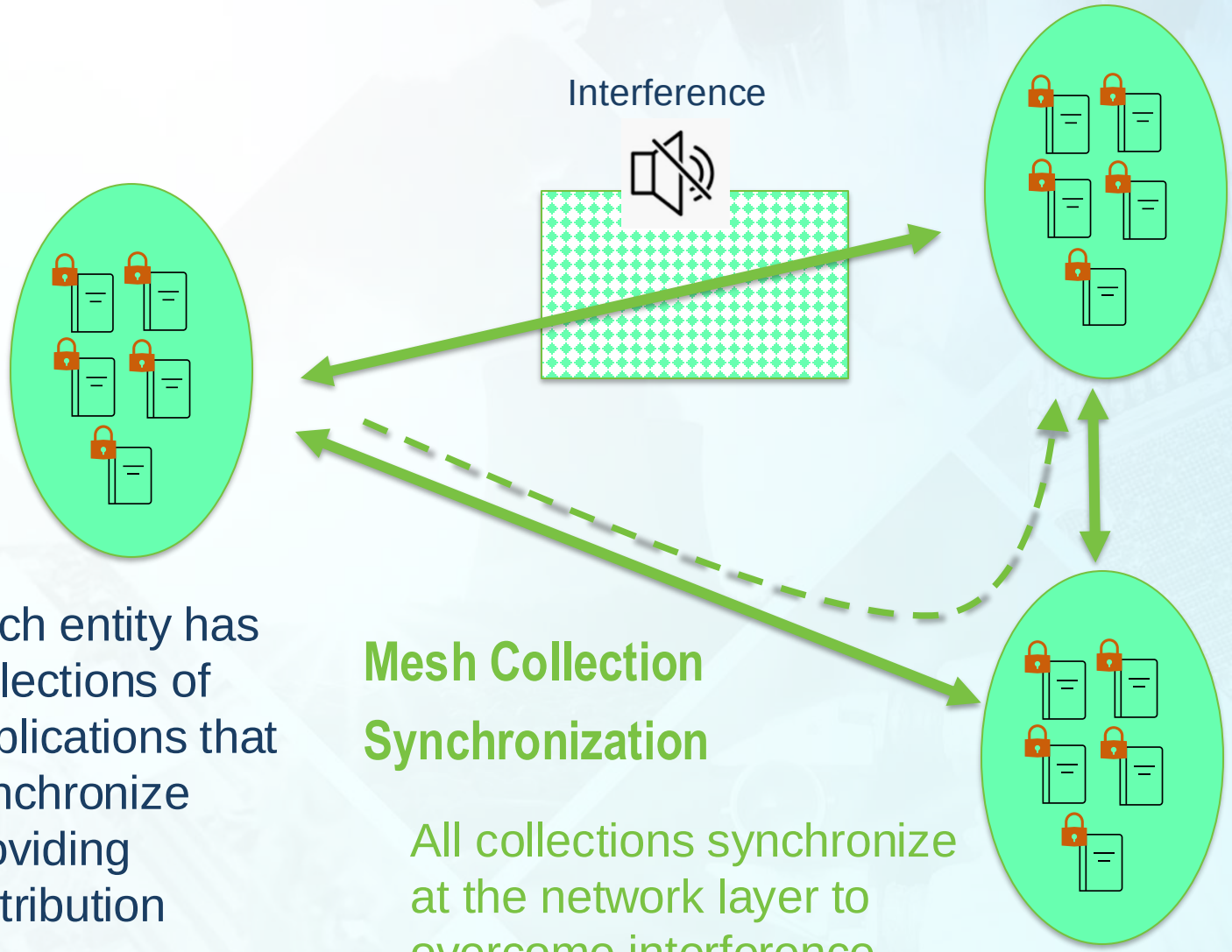
Multicast radio distributes publications to all nodes in range

Distributed Enforcement

Fully distributed enforcement validates:

- Publication ”Lock” with distributed certificates
- Distributed Trust Rule specifies *who* is authorized to subscribe to *each* publication and is enforced throughout the network

Mesh Resiliency - Synchronization and Caching



Each entity has collections of publications that synchronize providing distribution

Mesh Collection Synchronization

All collections synchronize at the network layer to overcome interference

Collections act as a “cache” if needed so that they eventually synchronize to overcome intermittent connections

System Testing at INL – Resiliency and Latency

1. ***Current Best-Practice for sensor readings in a legacy NPP is manual with a clipboard.***

2. ***DAS enables broadband radio in the plant for LoRaWAN sensors but requires high (~$2000 / ft) wired retrofit cost***

3. ***LoRa Mesh is much lower-cost***

INL Testing:

Compare the performance of the new LoRa Mesh with alternative Distributed Antenna Systems (DAS).

- Look at range and resiliency with interference and intermittent connectivity

INL Testing – Mesh vs. DAS

Gateway Name	Source WGR	Reading (Temperature °F)	No. of Packet	Time Difference (sec)
DAS+Multi-tech	WGR-5C	73.49	27	1.26
Operant	WGR-5C	73.49	27	
DAS+Multi-tech	WGR-AD	81.95	28	8.49
Operant	WGR-AD	81.95	28	
DAS+Multi-tech	WGR-5C	73.58	32	1.27
Operant	WGR-5C	73.58	32	
DAS+Multi-tech	WGR-AD	81.86	35	1.23
Operant	WGR-AD	81.86	35	

Acceptable added mesh latency:

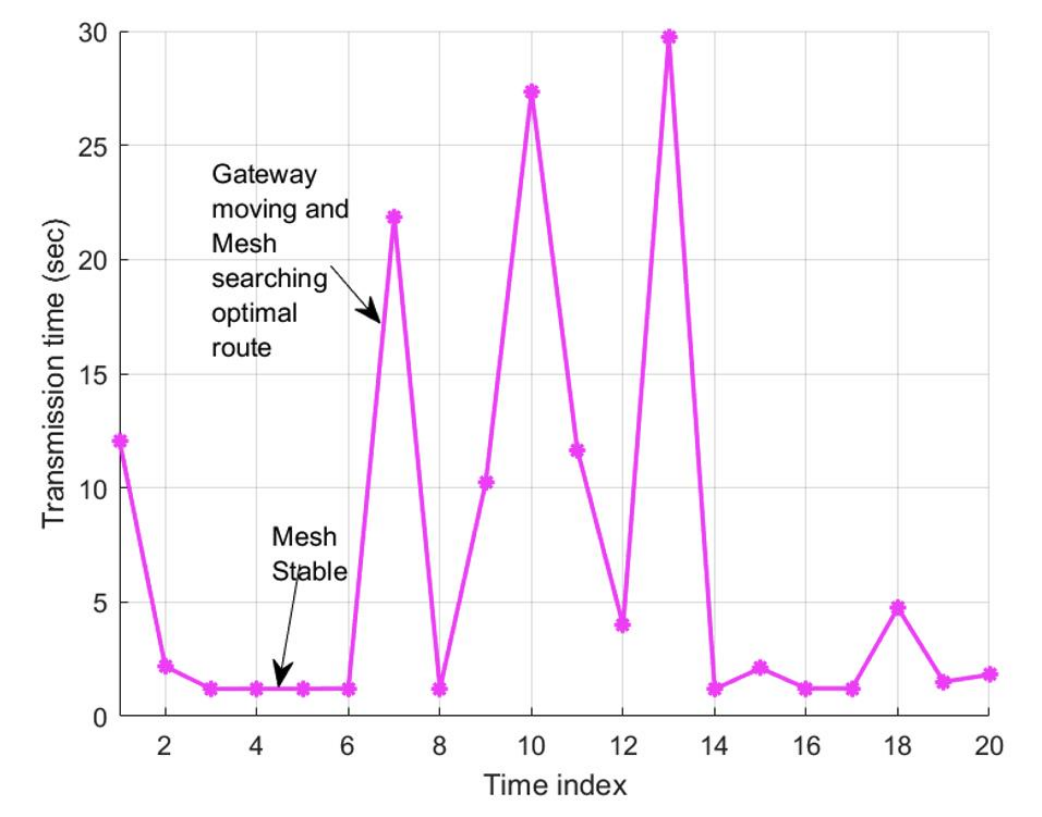
- ~ 1.25 seconds added latency
- ~ 15-minute battery-powered sensor update period

Trade-off:

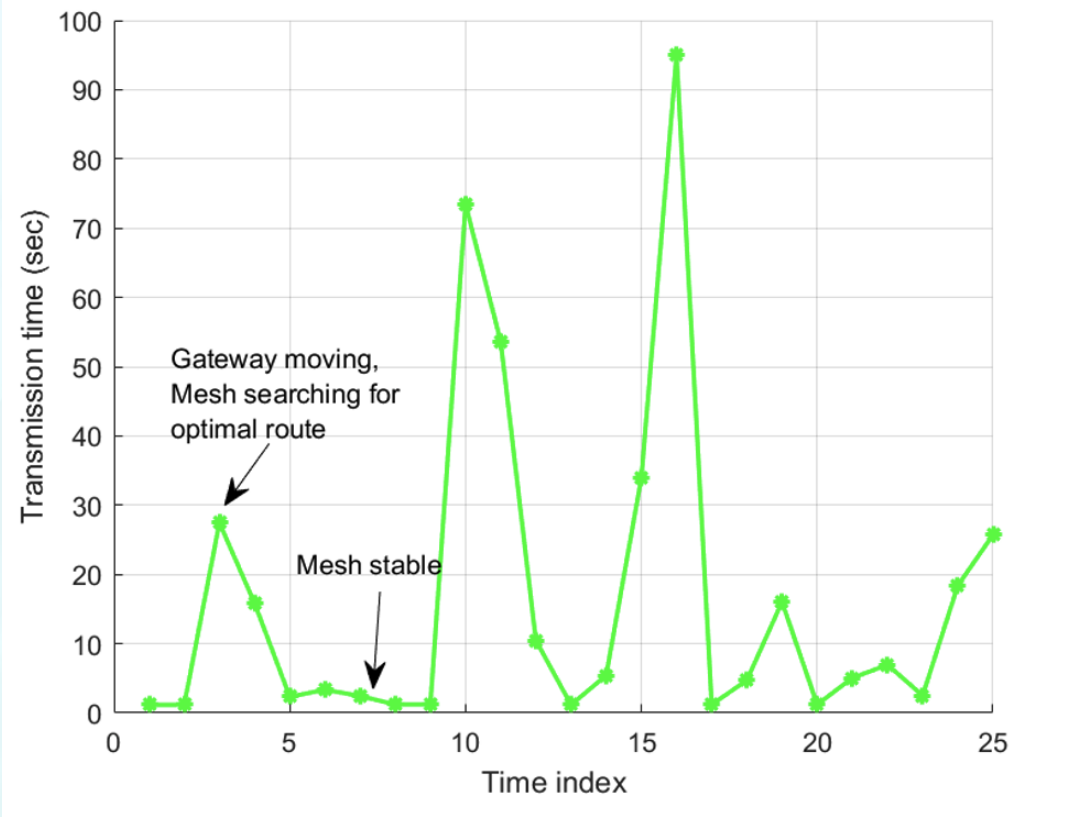
Mesh has much lower cost and installation time.

INL Testing – Resilient Reconfiguration

Robust mesh reconfiguration after network topology disruption. *No data dropped.*



Wireless Gauge Reader: WGR-AD



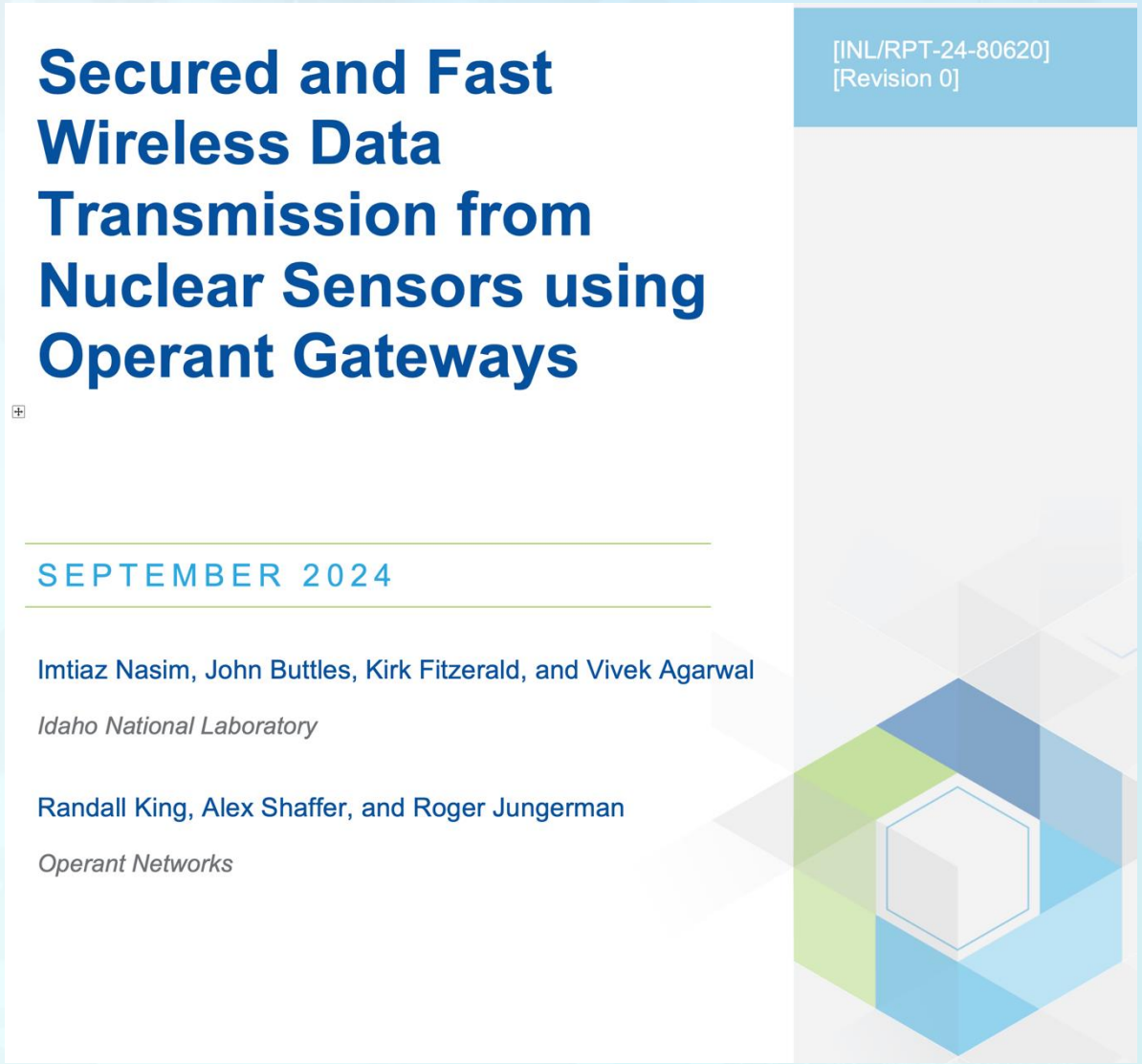
Wireless Gauge Reader: WGR-5C

INL Testing – Report: Results

- Minimal added latency compared to DAS.
- Efficiently addresses wireless connectivity
- Stable connections re-established even with gateways are moved or separated by large distances
- No data lost during reconfiguration

This current was work was focused on connectivity and resiliency, not security….

→ See comments on the next slide.



[INL/RPT-24-80620]
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Secured and Fast Wireless Data Transmission from Nuclear Sensors using Operant Gateways

SEPTEMBER 2024

Imtiaz Nasim, John Buttles, Kirk Fitzerald, and Vivek Agarwal

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Operant Networks

National Renewable Energy Lab (NREL) Cybersecurity Testing

Test	Parameter Tested	Result
Key Strength	Cryptography	☑
Man in the Middle	Authentication	-- ← Requires re-testing
Fraudulent Publication	Authentication	☑
Publication Flooding	Transport	☑
Black Hole	**Resiliency**	-- ← Requires re-testing
Cache Attack	Authentication	☑
Cache Privacy	Encryption	☑
Traffic Throughput	Transport	☑
Transport Privacy	Encryption	☑
Publication Privacy	Encryption	☑

	INL	NREL	Combined
Resiliency	☑	?	☑
Cybersecurity	?	☑	☑

Future Work -

Recent News:

Operant awarded $5M (3-year) DOE Office of Cybersecurity, Energy Security, and Emergency Response (CESER) grant:

Improve and validate transport cybersecurity for DER Renewables, including adding post-quantum cryptography, completing the NREL cyber testing, and evaluating scaling.

Future Nuclear Opportunities:

- Develop ways to visualize and specify Trust Domains with a GUI:
  - *"Who can Access What from Whom".*
- Further development and in-plant testing of this wireless mesh for Legacy Nuclear Retrofit.
- Explore other high bandwidth radio protocols for new Advanced Reactor applications of the sensor mesh:
  - LoRa: Typically, < 50 kb/s but very long range
  - WiFi 6: Up to 10 Gb/s with moderate range

Concluding Remarks

- Demonstrated a new LoRa mesh with range and resiliency adequate for Nuclear Power Plant retrofit.
- The protocol improves resiliency and adds caching for high reliability in INL tests.
- INL testing helped refine the Operant system for mesh radio transport.
- Cybersecurity performance continues to be validated at NREL on an ongoing basis.
- Wireless mesh connectivity provides a secure, cost-effective, and resilient method of interfacing to nuclear sensors.
- Develop and test the transport for future NPP applications, including Advanced Reactors and securing AI communications.

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Thank You