U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Advanced Sensors and Instrumentation

High Penetration Wireless Networking for Nuclear Power Plant Sensing

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

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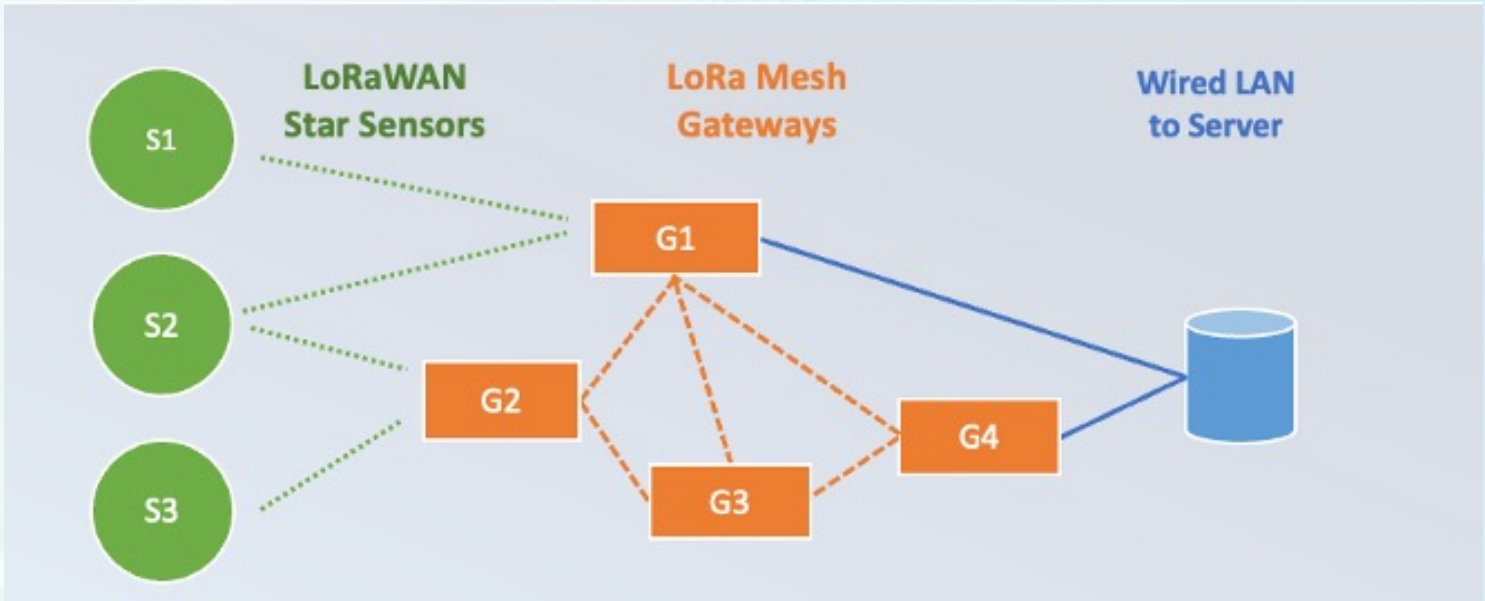
Operant Networks Incorporated

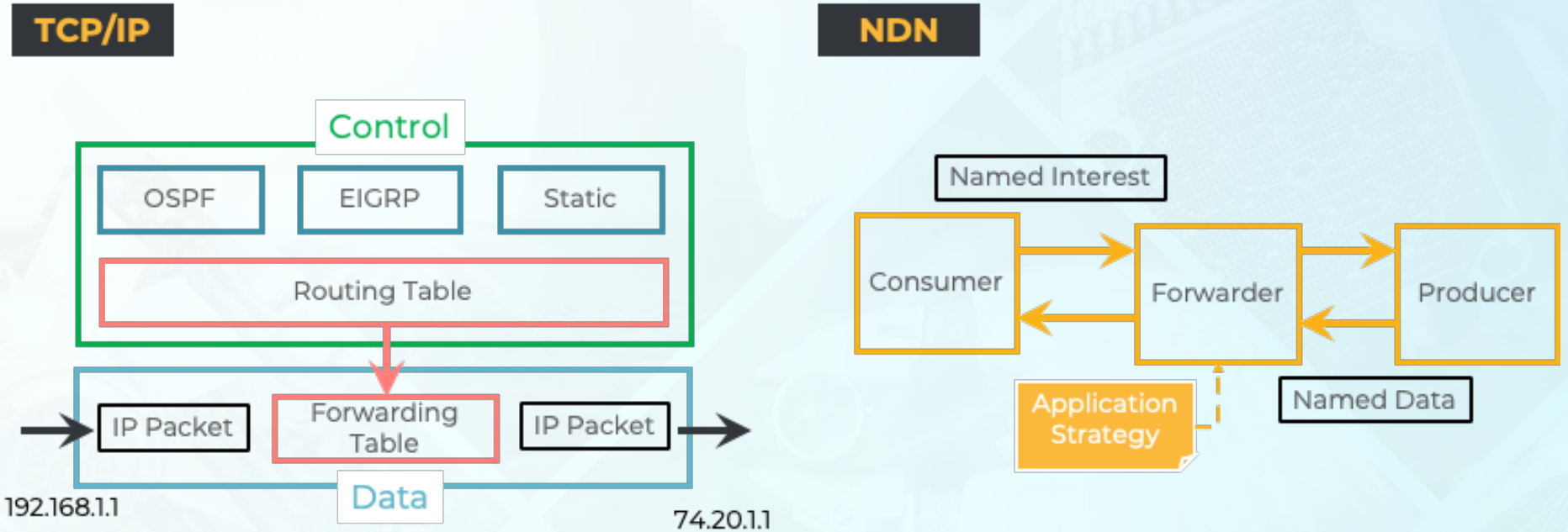
Project Overview - Motivation

- Predictive maintenance sensors are needed to extend nuclear plant lifetime, but extreme construction standards make these efforts challenging
- Wiring has been found to be the largest cost barrier; wireless connectivity is thus of interest
- Operant's networking software uniquely enables extreme range wireless technology (LoRa) in an end-to-end cybersecure **mesh** topology
- This mesh can extend the range of low cost commercial LoRaWAN sensors while adding cybersecurity and resilience
- Could this technology even be used with previously off-limits Critical Digital Assets?



Project Overview - Technology

- The underlying technology is Named Data Networking (NDN): a fundamental paradigm shift that solves the most persistent problems in today's networks: resiliency, security, and access control.
- NDN enables secure end-to-end communications without depending on the underlying communication channels; data is always secured regardless of whether it is in flight or at rest.
- Focus on data packets vs traditional link-based approach: each is named, secured, and immutable
- This enables applications to reliably achieve data confidentiality, integrity, and availability (CIA)



Technology - Advantages

Fundamentally, a network just delivers data bits. There are three main advantages in NDN:

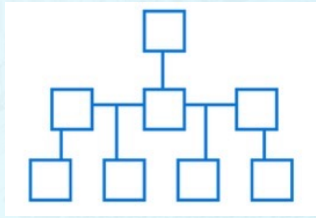
1) Transport Resiliency
   - Synchronizing data vs conversational sessions
2) Routing Flexibility
   - No topological constraints on connectivity
   - Secure use of multicast
3) Improved and Simplified Security
   - Identities are fundamental
   - Attack surface is much reduced

1

Landline vs

Social Media

2



Phone Tree vs

Internet

3

Multiple Temporary IDs vs

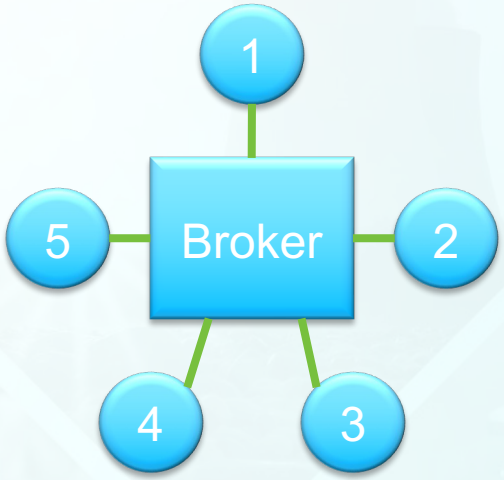
Fingerprint

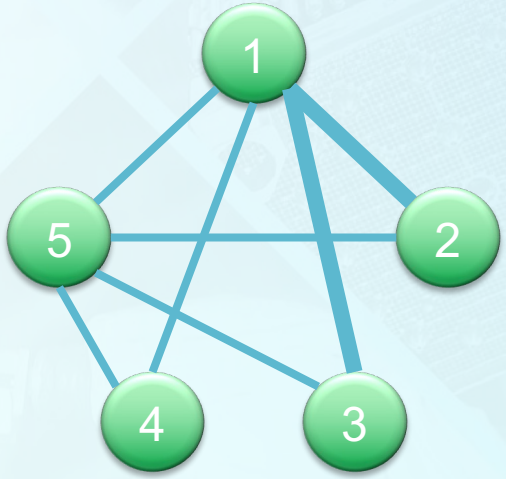
Technology - Advanced Multi-Party Communications

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



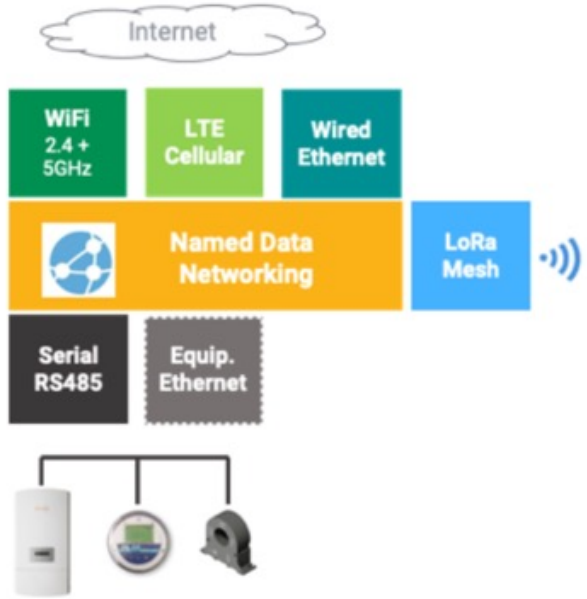


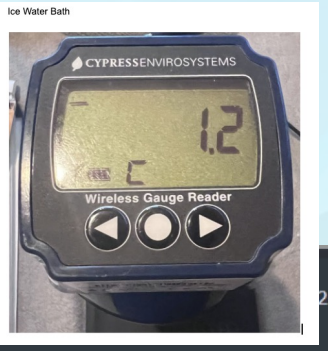
Operant NDN Pub/Sub is fully distributed and efficiently delivers messages over any available link with forwarding and end-to-end cybersecurity assured by design

Phase 1 Results – Lab Experiments

Operant has worked with DOE for five years to develop NDN to interconnect distributed energy assets such as solar, storage, and wind.

- In the course of this work we designed and fabricated an inexpensive NDN-based LoRa/cellular/WiFi/Ethernet gateway with over 100 mile line of sight radio range
- In partnership with Constellation, we realized the potential for nuclear plant sensing
- We utilized this gateway for a Phase 1 demonstration of a LoRaWAN sensor mesh






```
Lora Packet is " b'QMvulAEA4g
Network Session Key is " 27c9
40cbee940100e20201bfe614f13dd
mhdr:  40
DevAddr:  0194eecb
FCtrl:  00
FCnt:  02e2
FCnt:  738
Fport:  01
Payload (encrypted):  bfe614f13dda17611d3c20
Payload Decrypted hex 0107e90300d73f9e9da00f
Payload for the ieee 3f9e9da0
IEEE754 Temperature 1.24 C
```

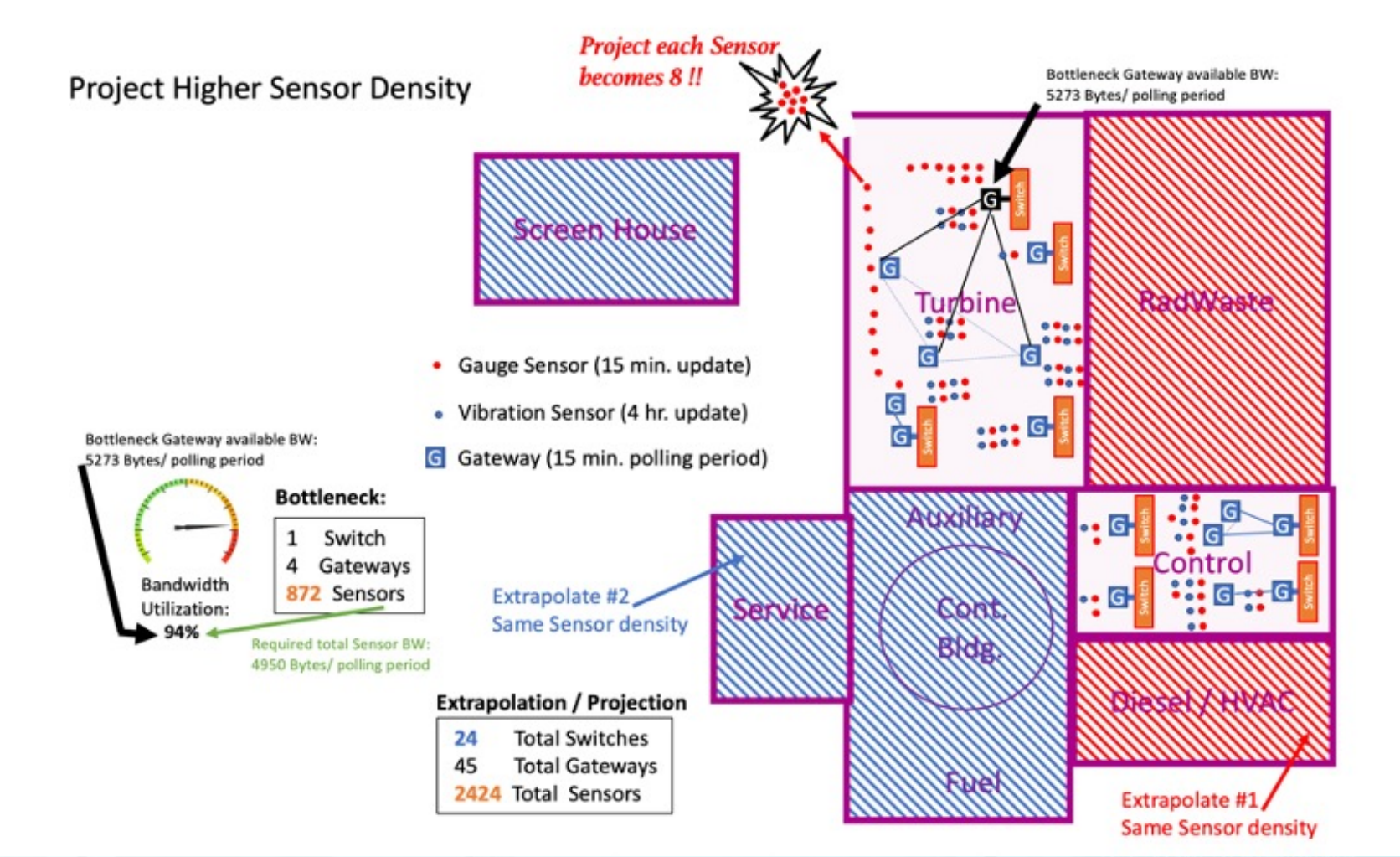
Phase 1 Results - Modeling

Utilizing real world results…

- Solar gateway field trials,
- Measured signal strengths from TMI trials
- Representative sensor data usage information from Constellation

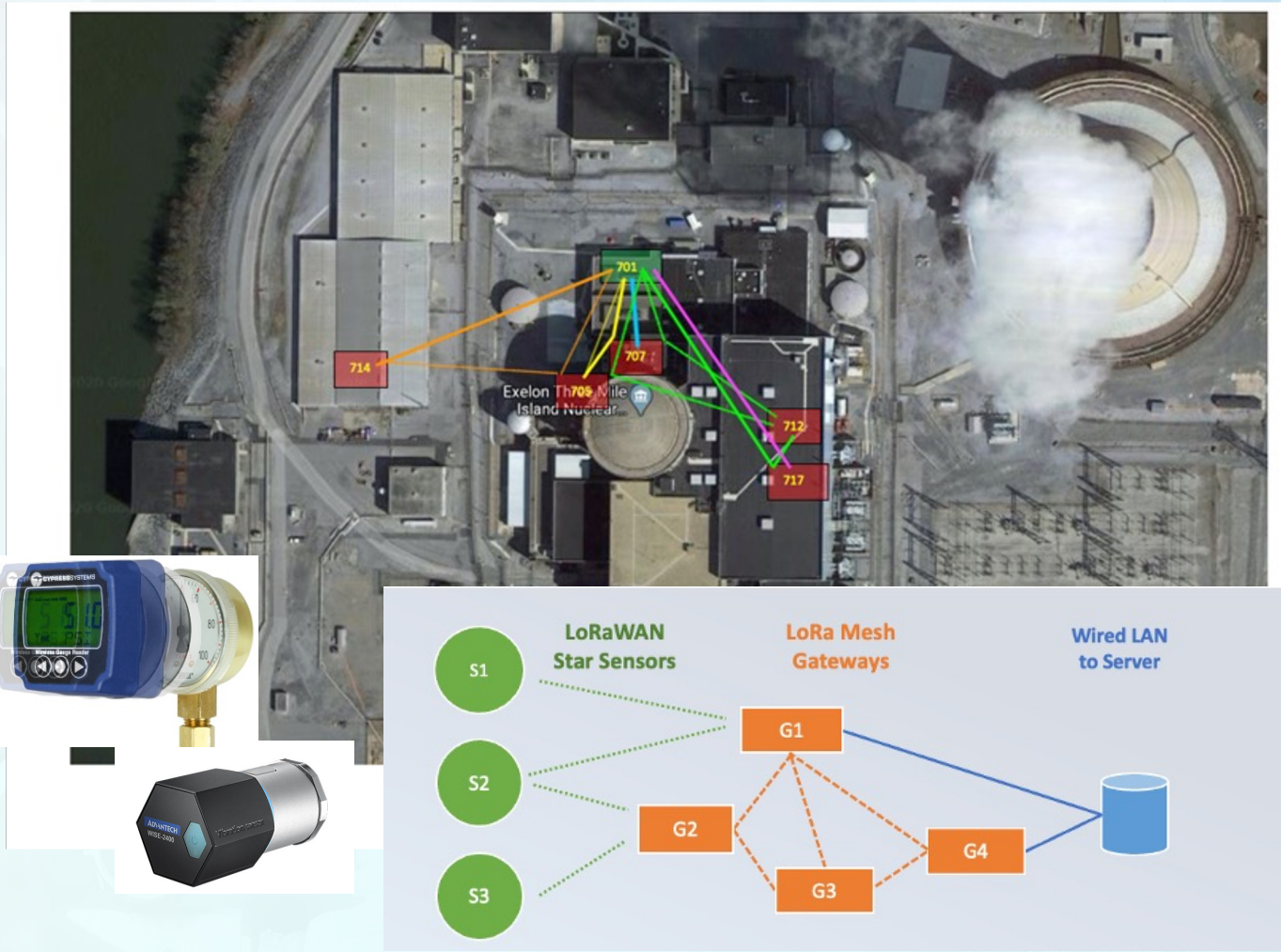
…we developed an integratec economic and technical model

- As many as 2400 sensors could be supported
- Costs could potentially be reduced by 90% over DAS solutions



Technology Impact – Life Extension Through Cost Savings

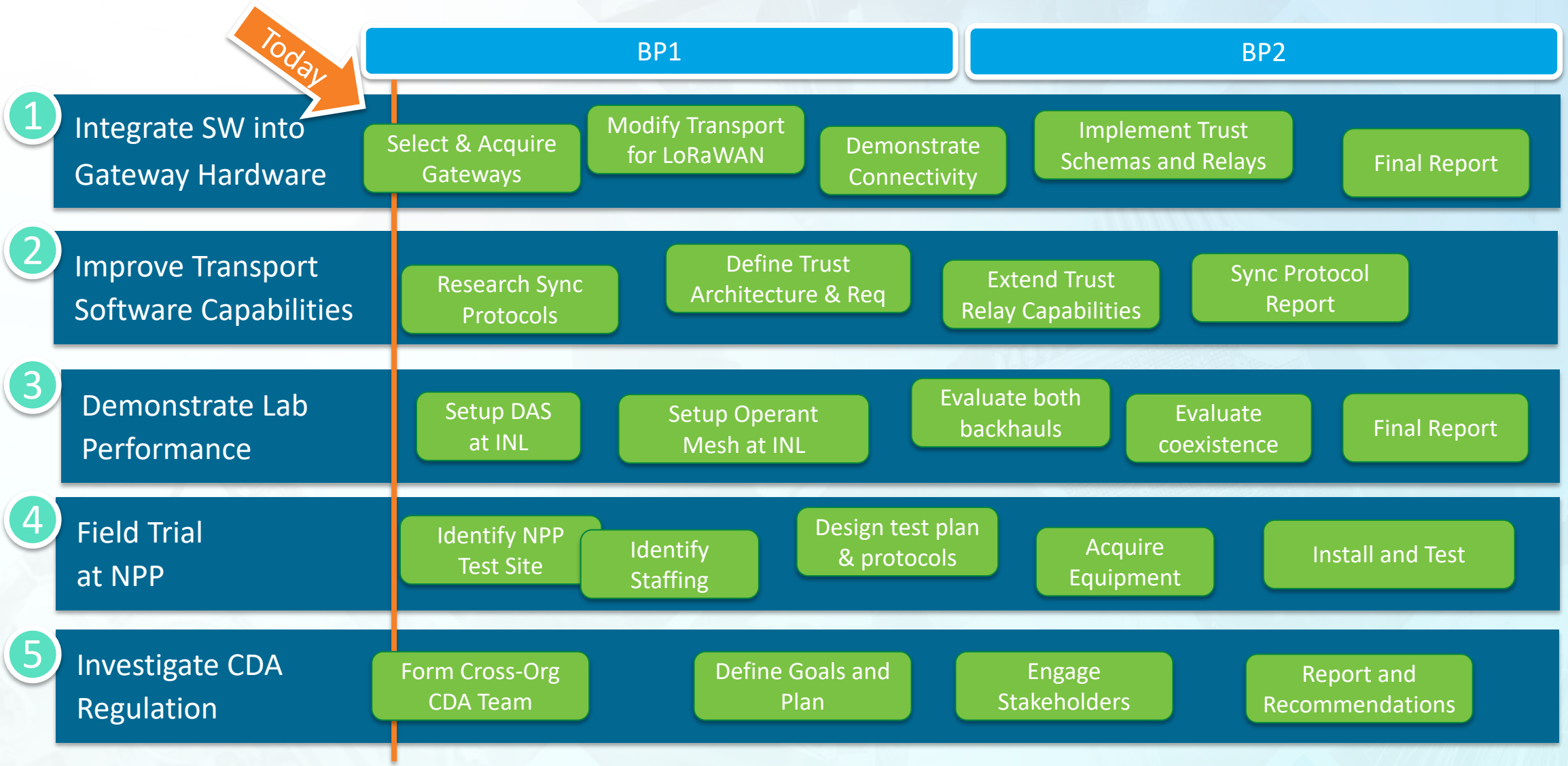
- Operant's Named Data Networking solution will enable the nuclear industry to securely deploy commercial LoRaWAN wireless sensors within nuclear power plants and their immediate environs.
- Inexpensive battery-powered commercial sensors will both retrofit existing manual gauges and provide new measurement capabilities.
- Digitalization projects thus enabled with these cost savings include automation for reducing personnel expenses as well as predictive maintenance to increase up-time and reduce equipment repairs.



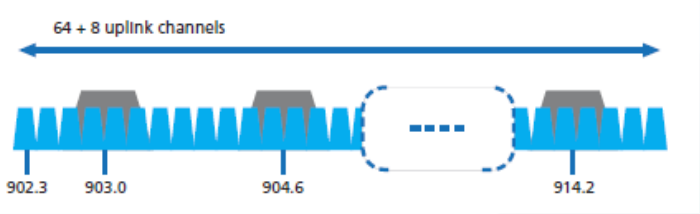
Project Overview – Phase 2 Team

- Operant Networks is an early stage company focused on machine-to-machine communications using a novel networking technology that provides intelligence and security on each and every data packet.
- Constellation Energy, America's largest nuclear power provider, with a fleet providing 22 GW of carbon-free power has deep industry and customer insight into the needs of existing and future NPPs and are thus uniquely capable of validating our communications platform.
- Idaho National Laboratory is the nation's premier nuclear science and technology lab helping the nation maintain and expand its use of nuclear energy. Their ability to provide comparative and coexistence testing of our sensor network with the existing DAS solution is unmatched.
- UCLA Professor Lixia Zhang is the lead PI of the Named Data Networking (NDN) Project, a consortium of universities focused on Named Data Networking.
- Pollere provides extensive real-world expertise in both traditional networking and NDN technologies. Their work on the Data-Centric Toolkit (DCT) is a foundation this current proposal.
- Cypress Envirosystems is a leading provider of wireless sensing solutions to the nuclear industry and will provide valuable commercialization insight during the project period.

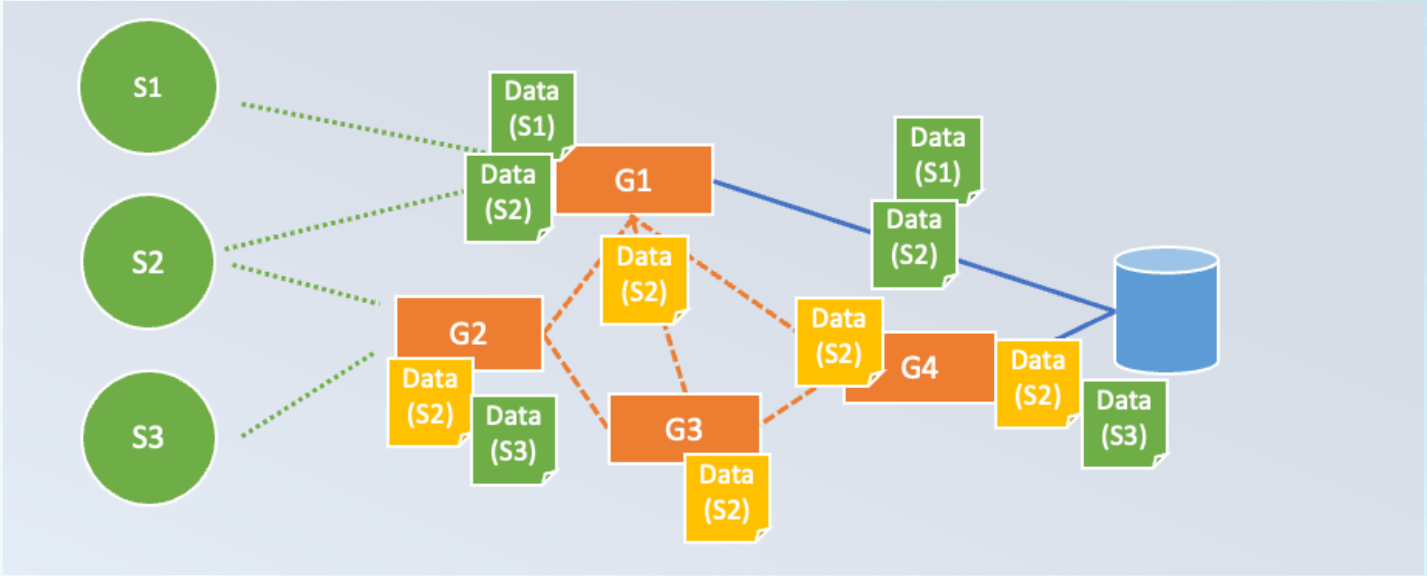
Project Overview - Schedule



Project Goals - Increase Wireless NDN Mesh Throughput



Data Rate (DR)	Spreading Factor (SF)	Channel Frequency	Uplink or Downlink	Bitrate (Bits/Sec)	Maximum User Payload Size (Bytes)
0	SF10	125 kHz	Uplink	980	11
1	SF9	125 kHz	Uplink	1,760	53
2	SF8	125 kHz	Uplink	3,125	125
3	SF7	125 kHz	Uplink	5,470	242
4	SF8	500 kHz	Uplink	12,500	242
5 – 7					
8	SF12	500 kHz	Downlink	980	53
9	SF11	500 kHz	Downlink	1,760	129
10	SF10	500 kHz	Downlink	3,125	242
11	SF9	500 kHz	Downlink	5,470	242
12	SF8	500 kHz	Downlink	12,500	242
13	SF8	500 kHz	Downlink	21,900	242

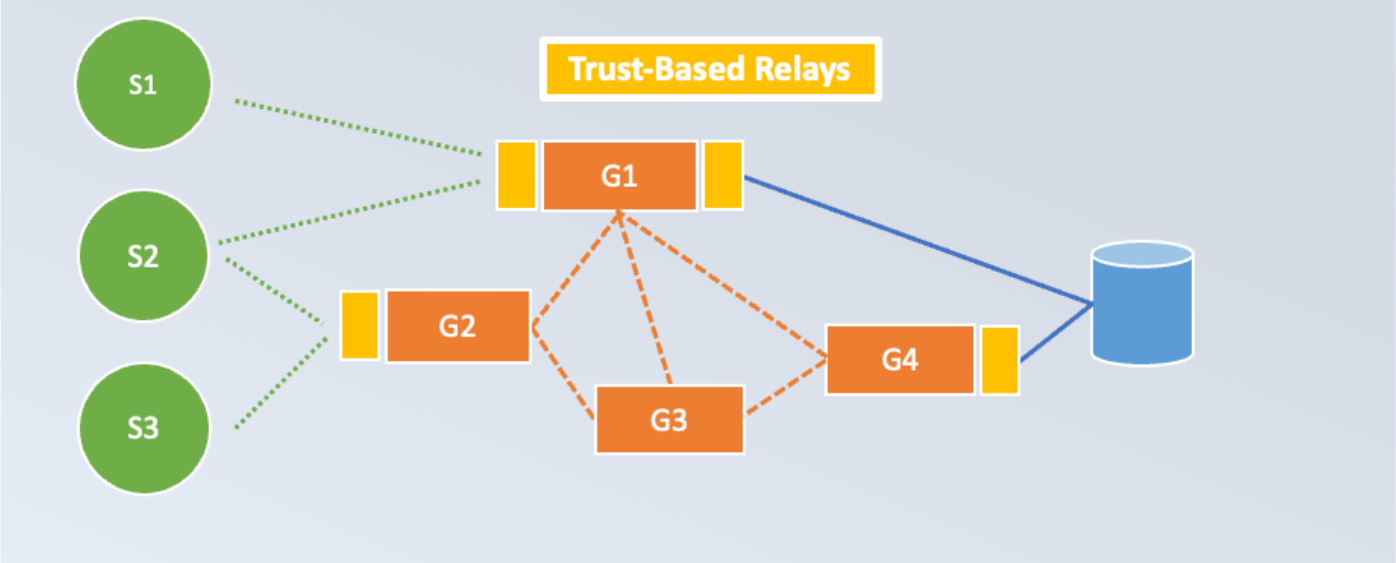


- LoRa is a complex protocol with many degrees of freedom: multiple radio channels, multiple connectivity paths, and multiple digital spreading factors give opportunity for parallel communications but add challenges for mesh communications
- How do you avoid overly-redundant communications utilizing the new capabilities of NDN?

Project Goals - Extend NDN Transport Security Capabilities

- Sensor data flows between the three distinct network segments, each with different security ('trust') expectations, on its path to becoming actionable information.
- The first segment is the LoRaWAN star which utilizes commercially available sensors and has rudimentary security capabilities.
- After reaching the first mesh gateway, the data enters the second network segment served by the DCT-based publish subscribe transport. We there enhance the security of the system significantly.
- Finally, it traverses the wireless mesh network and is delivered to the utility LAN for analysis.

- The NDN-based publish subscribe transport contains 'trust relays' which form network segmented trust zones without the need for traditional physical network isolation.
- Each zone is defined by a particular schema signed by a specific trust anchor



Project Goals - Test and Validate

- Utilizing Idaho National Laboratory's (INL) testing facilities we will demonstrate the performance of the complete system after the improvements of Objectives 1, 2 and 3.
- We will contrast it with the performance of existing Distributed Antenna Systems (DAS)

- Utilizing Constellation's nuclear facilities (site TBD) we will execute a field trial on a real world plant

Project Goals - Possible to Support Critical Digital Assets?

- The high level of security inherent in our NDN communications protocol raises new possibilities in an NPP application: could the well established general prohibition on wireless links in Critical Digital Assets (CDA) applications which affect safety, security, and emergency preparedness ('SSEP') functions be relaxed?
- We envision that as the definitional boundary between air gapped digital CDAs and less restrictive sensing applications comes under economic pressure, a communications technology which can address both securely could have significant impact.
- Constellation, Cypress Envirosystems, and INL have expressed significant interest and capabilities in contributing to this investigation.
- INL, in collaboration with Constellation, will develop an approach to identify critical digital assets (CDAs) and methodology to perform cyber evaluations of both the technologies.
- INL further believes that advanced reactors will also benefit from any potential expanded use of wireless connectivity. Next generation designs will also have CDAs and are currently expected to use the existing communications technologies (such as DAS or LoRa) for wireless connectivity of their sensor systems.

Concluding Remarks

- Operant Networks and our partners remain excited to begin the definitional phase of this new project and believes there is significant industry benefits and commercial value awaiting a successful result.

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Thank You