Eaton RF Mesh Technical Overview

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Objectives

- Provide technical overview of RF mesh fundamentals
- Provide knowledge of RF Network deployment, formation and dynamic network behavior
- Provide overview of RF Applications

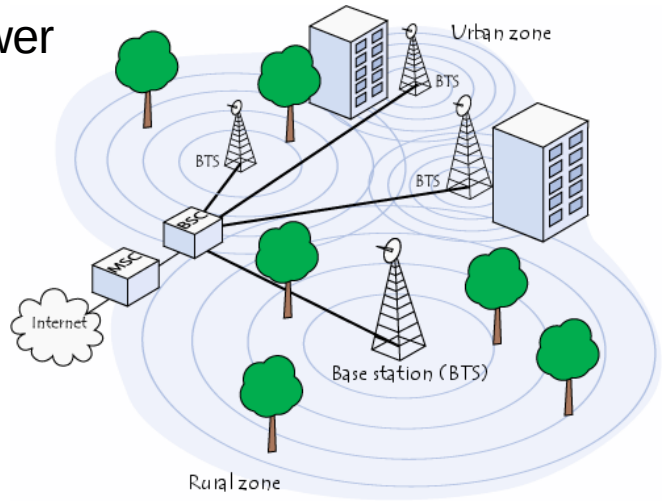
Agenda

- Introduction to Wireless communications
- Eaton RF Mesh Network Fundamentals
- Deployment
- Eaton RF Network Operation
- Q&A

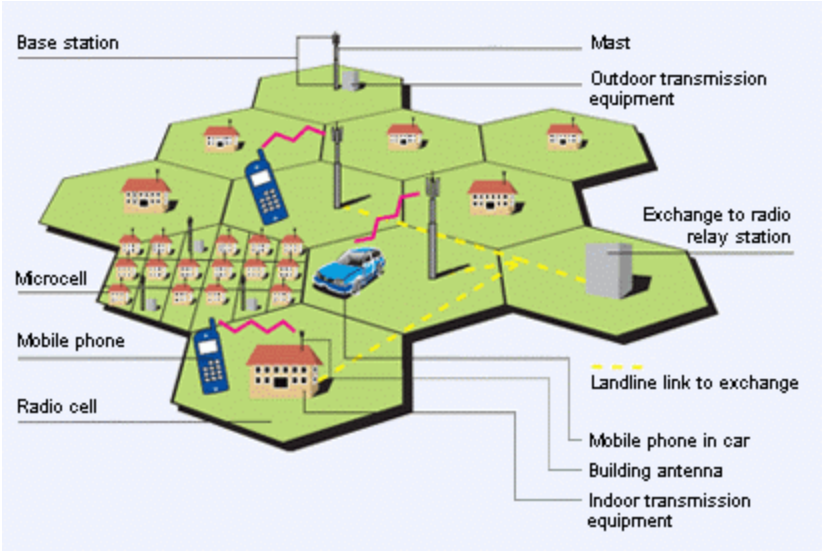
Introduction to Wireless Communications

Network Types

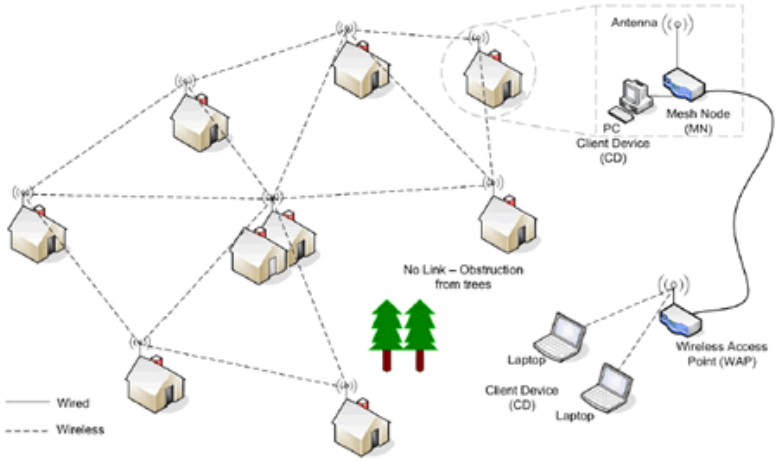
Tower



Cell



Mesh



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Eaton's RF Mesh

- Self-Organizing and Self-Healing
  - No configuring of the nodes at the utility or in the field
  - Nodes independently determine the most efficient method to get to the gateway
  - Nodes automatically identify alternate routes to the gateway when primary communications paths are interrupted
- Easily Expandable/Scalable
  - Easy to add additional gateway when required to expand network
- Secure and Interoperable
  - Mutual authentication and derived encryption keys for each data exchange between nodes
- OTA Firmware Updates
- Single Network
  - A full two way network AND a single Software Platform for Electric, Water, Gas, DR and DA

Eaton's RF Network Specification

- Spectrum
  - ISM bands - 902-928 MHz frequency product (25 MHz available spectrum (50 channels))
  - Frequency Hopping Spread Spectrum (FHSS)
- Throughput
  - Up to 153 kbps data rate with Auto-Optimization
- Variable Power Optimization
  - 125mW to 1W
- Industry Leading Data Transport
  - Up to 96 metric points in the daily report
  - 15 User Defined Interval Data Channels (kWh, voltage, TOU, kVAR/kVARh, etc.)
  - Over 50 different alarms and events
- Security
  - Security built-in to all node-to-node communications. End-to-end security, with mutual authentication and derived encryption keys for each node data exchange.

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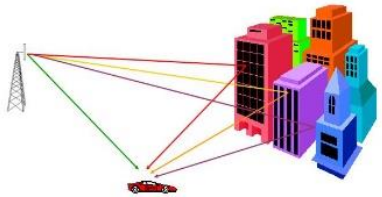
Communications Range

- Communication Range in an RF network is affected by the following factors:
  - Power
  - Receive Sensitivity (Data Rate)
  - Path Loss

Communications Range - Path Loss

- Distance

  Received power goes down by the square of the distance between nodes

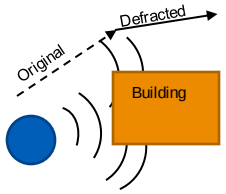


- Obstacles

  Topography (i.e. walls, trees, buildings, hills, mountains…)

- Reflections & Multi-Path

  Reflected radio signals take different length paths and interfere

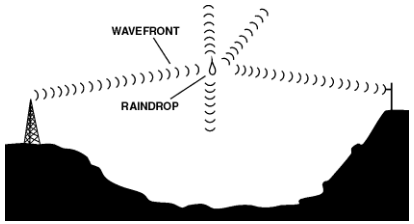


- Diffraction

  Gives the effect that the signal can bend around corners

- Scattering

  Due to small particles, air pollutants and moisture droplets along the path



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Communications Range - Power

- Total Network Communications Range or Distance =

  Node to node distance X number of hops

- Node to node distance is affected by:
  - Transmit Power of Source Node
    - Transmit Power Limited by FCC Regulations
    - Transmit Power Limited by Source of Power (i.e. Battery)
    - Transmit Power Affected by Type of Antenna (Gateway, Relay)

Communications Range - Data Rate

- Receive Sensitivity
  - Measure of how well the receiver performs
  - Defined as the power of the weakest signal the receiver can detect
  - Function of data rate
- Rate vs. Range
  - The lower the data rate, the longer the transmission range
  - The higher the data rate, the shorter the effective range of the transmission
- Rate vs. Throughput
  - Lower data rate = lower throughput
  - Higher data rate = higher throughput

Eaton RF Mesh Network Fundamentals

RF Mesh Components

- Our mesh solution is comprised of the following elements:
  - Yukon/Network Manager
  - Gateway
  - Electric Nodes
    - Single Phase Meters
    - Polyphase Meters
    - DR Switches
    - DA RTUs
  - Battery Nodes
    - Water
    - Gas (New)
  - IP Link Nodes (New)
    - WiFi
    - Cellular (Future)
  - Relays
  - Network Runner

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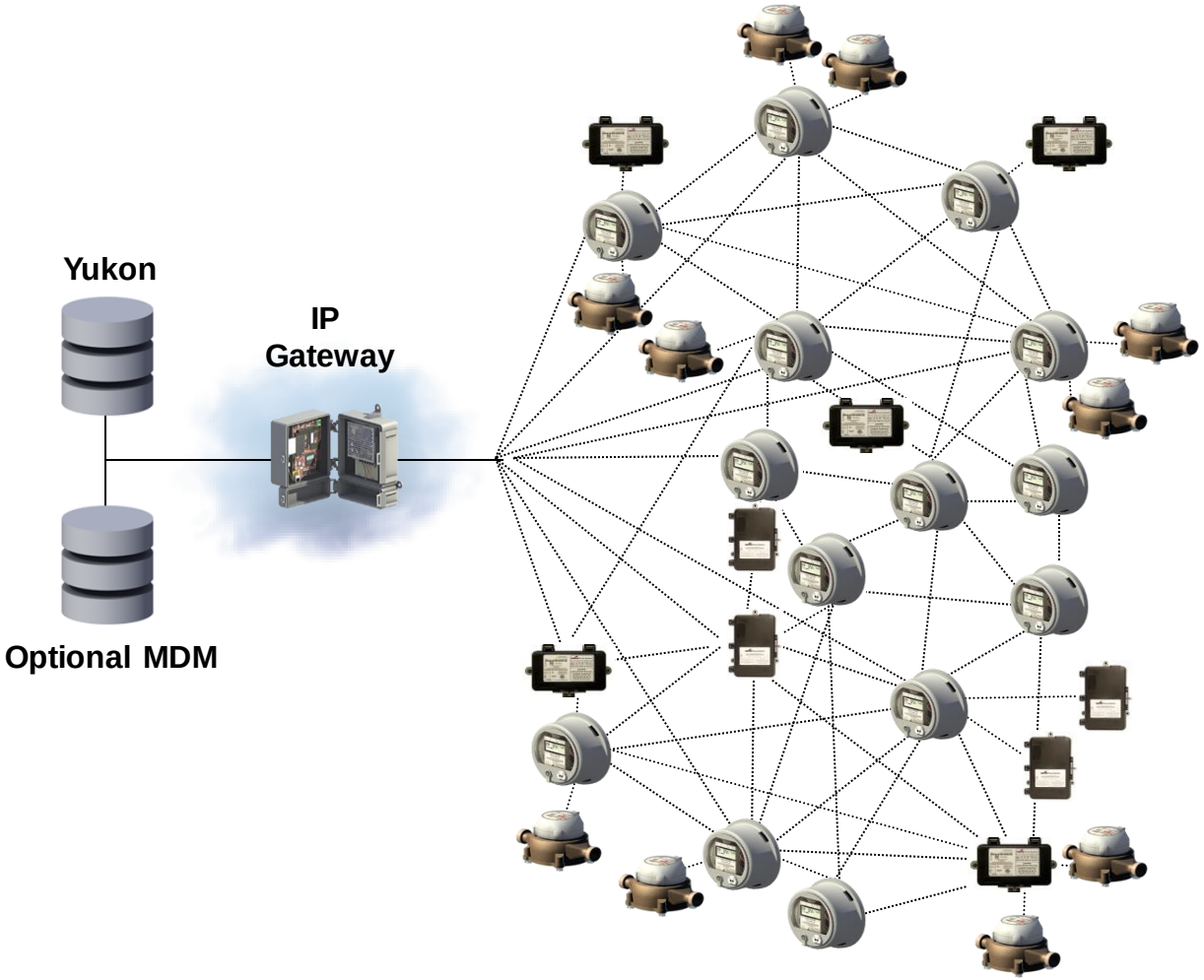
RF Mesh Network Components



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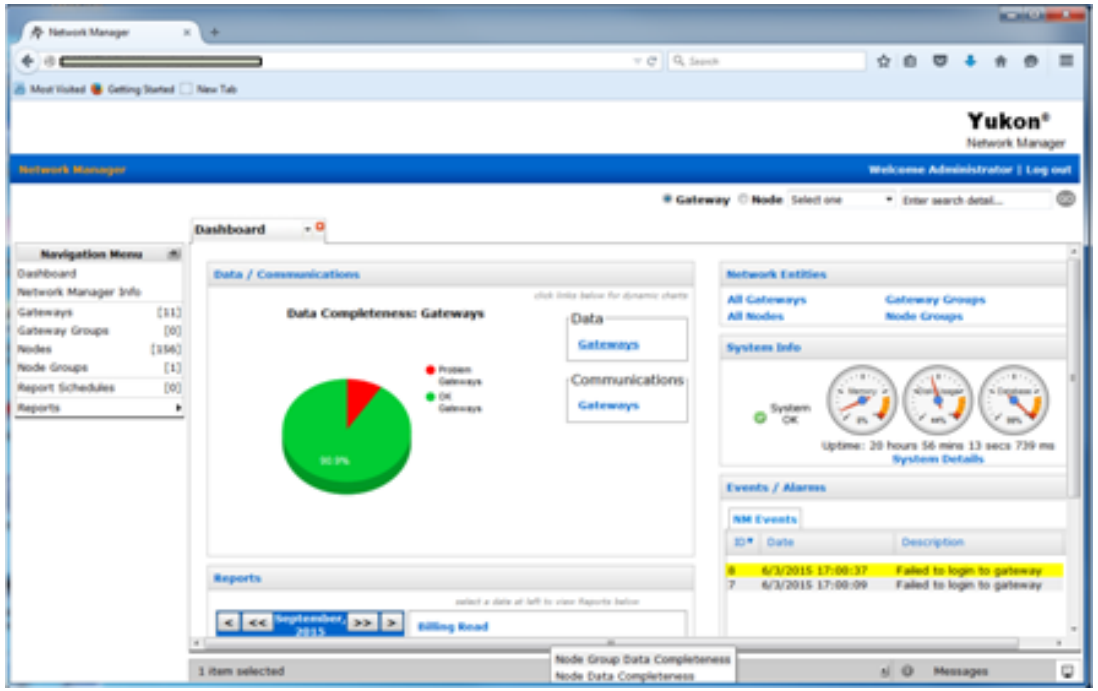
RF Network Manager

- Acts as a middleware between Yukon and Gateway
- Manages the Gateways and performs network monitoring functions
  - Network Flow Control
  - Maintains a Database
- Provides diagnostics for the network and nodes



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RFN Hardware

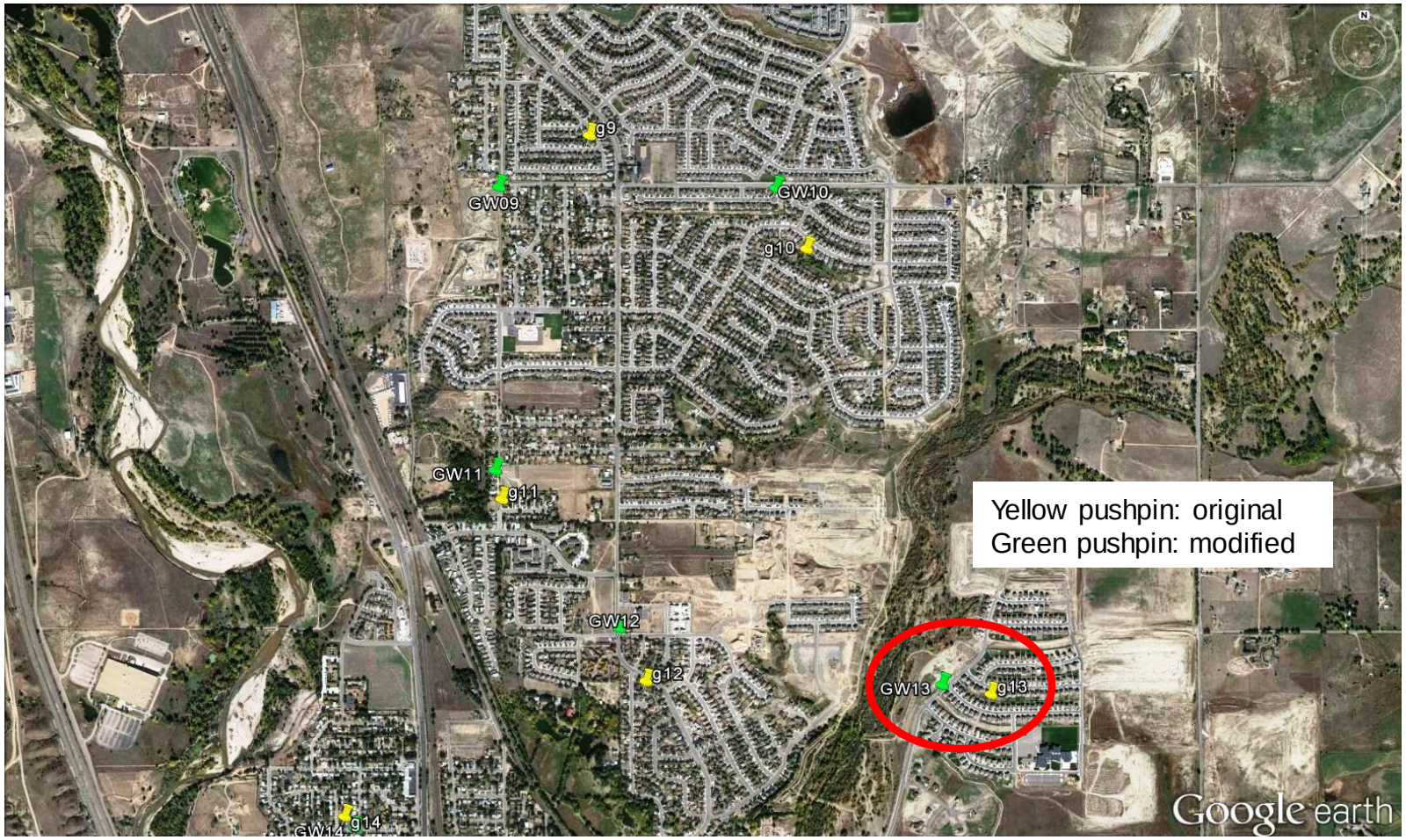
- Gateway - Network Bridge, Collector, between RF wireless mesh and IP wide area network, backhaul support to Network Manager, Yukon
- Powered Nodes - Support two-way unicast and broadcast messaging, Metrology, Events and alarms, …
- Battery Nodes - Support multiple vendor water registers, Gas, OTA updates, …
- Relays - Build out infrastructure to form robust mesh, extend RF communications into rural areas
- IPLink WiFi Node - Meter functions, network bridge between RF wireless mesh and utility network
- Network Runner - Provides configuration and diagnostic field support

Deployment

RF Network Deployment: Gateway Planning

- A propagation study is done as part of initial network design:
  1. Connectivity
  2. Network formation
  3. Capacity
- Gateway locations are proposed as a result of the study
- Final gateway locations are decided upon based on initial proposed location and the constraints imposed by back-haul locations

Modifications for Constraints



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RF Network Deployment: Backhaul planning

- Backhaul is critical to system performance
  - Always available 2-way communication
    - IT infrastructure is setup correctly for access to:
      - NM and Yukon servers
      - NTP server that was configured at Gateways
  - At least 128Kbps of backhaul capacity per gateway
  - MTU size of 1500 bytes
- Unreliable backhaul can affect:
  - Data completeness of interval data
  - Remote Connects and Disconnects
  - On Demand Reads
  - Demand Response events

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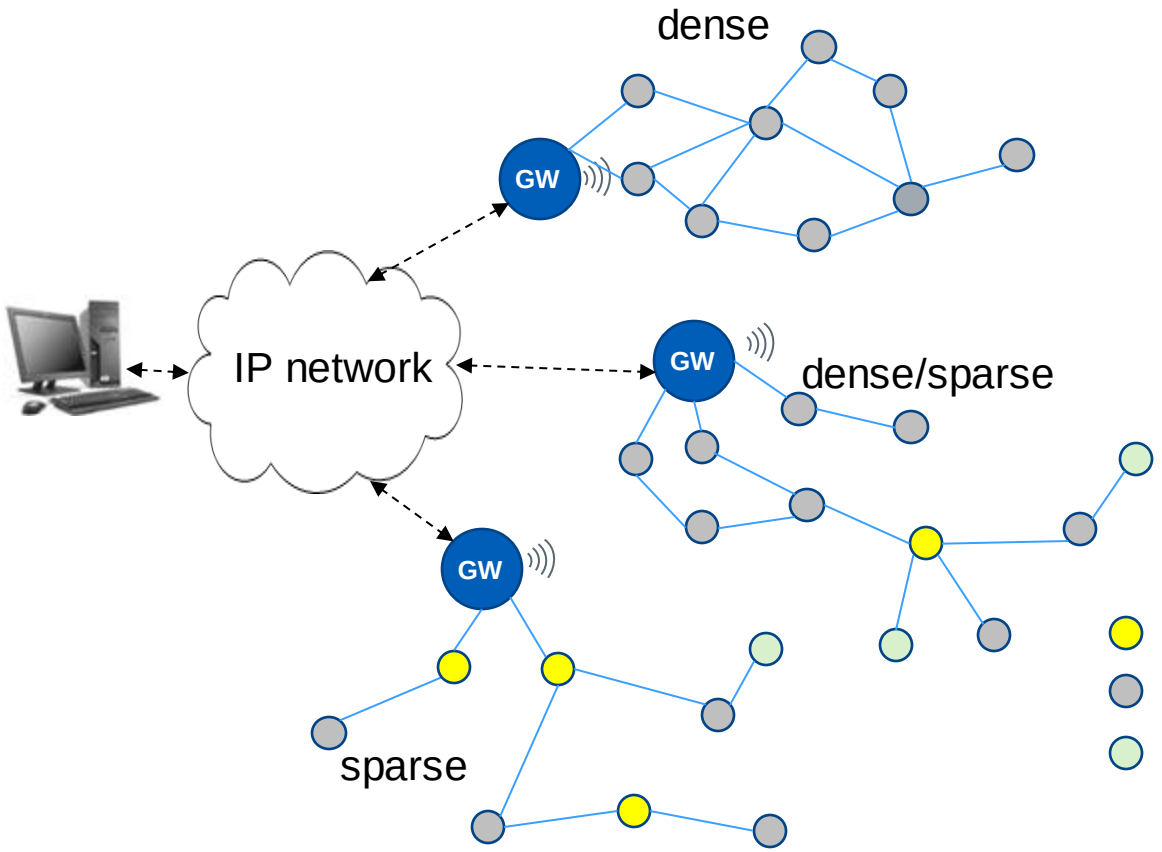
RF Network Deployment

- The order in which the elements that comprise the RF network are deployed is CRITICAL to how quickly the RF network forms
- Order of recommended installation and deployment
  - Yukon and RF Network Manager installation should be planned first
  - Install Gateways
    - Backhaul considerations (wired, wireless)
    - Configure the gateways and setup backhaul communications with RF Network Manager
  - Install recommended relays starting closest to the gateway
  - Install electric nodes outwards from gateway
  - Revisit network coverage after network is discovered and install additional relays or gateways as needed
  - Install battery nodes (water, etc.)

RF Network Deployment

- Install and setup Yukon/NM
- Install gateways and configure backhaul



- Install relays
- Install electric nodes outwards from gateway
- Add additional relays as needed
- Add Battery nodes

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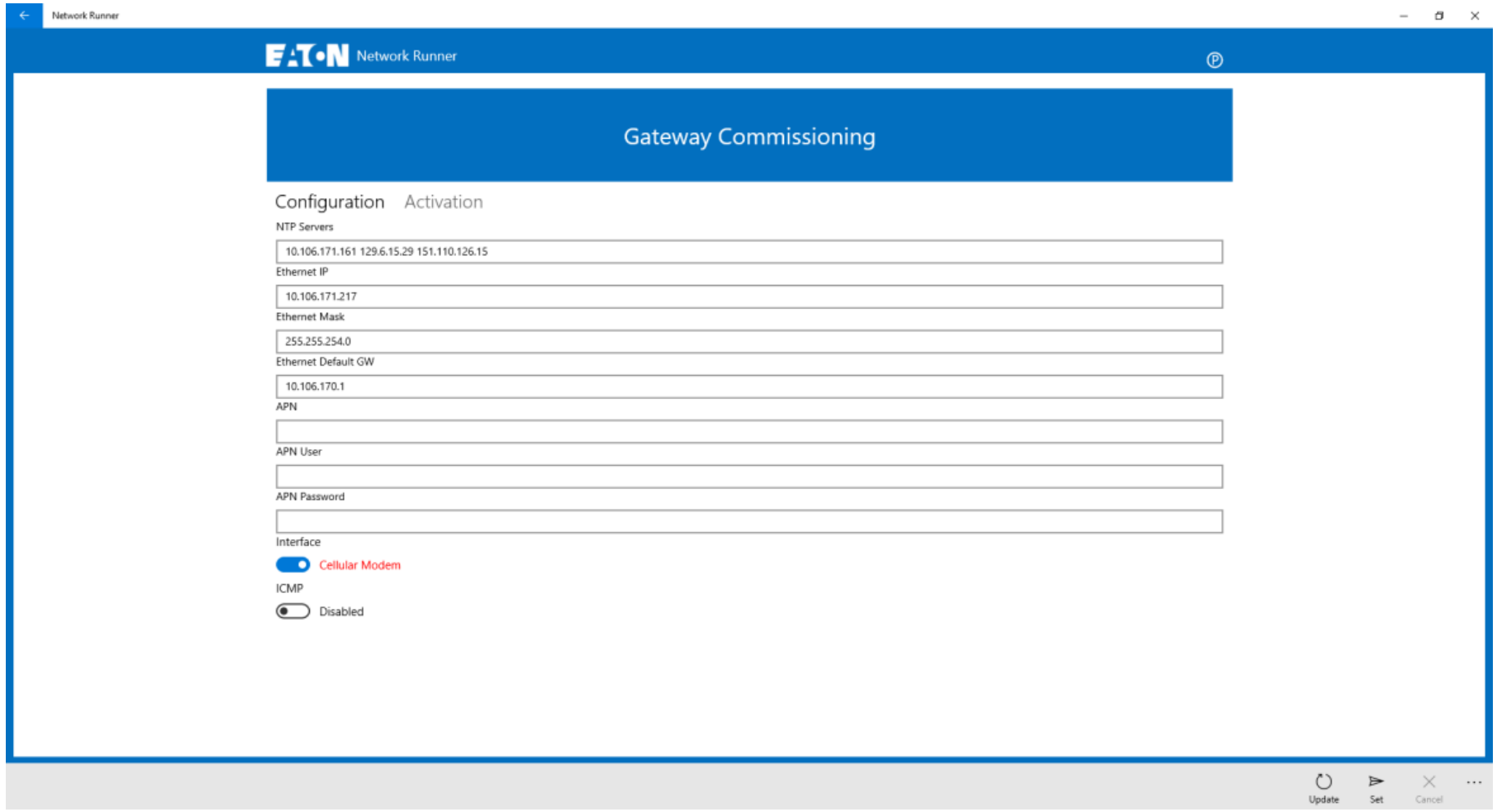
RFN Gateway Configuration

- Requires minimal field configuration
  - Ethernet IP address, NTP Server IP address
  - GPS Coordinates
  - Gateway must be configured using the RF Field Tool via the Gateway Commissioning Workflow

RFN Gateway Configuration



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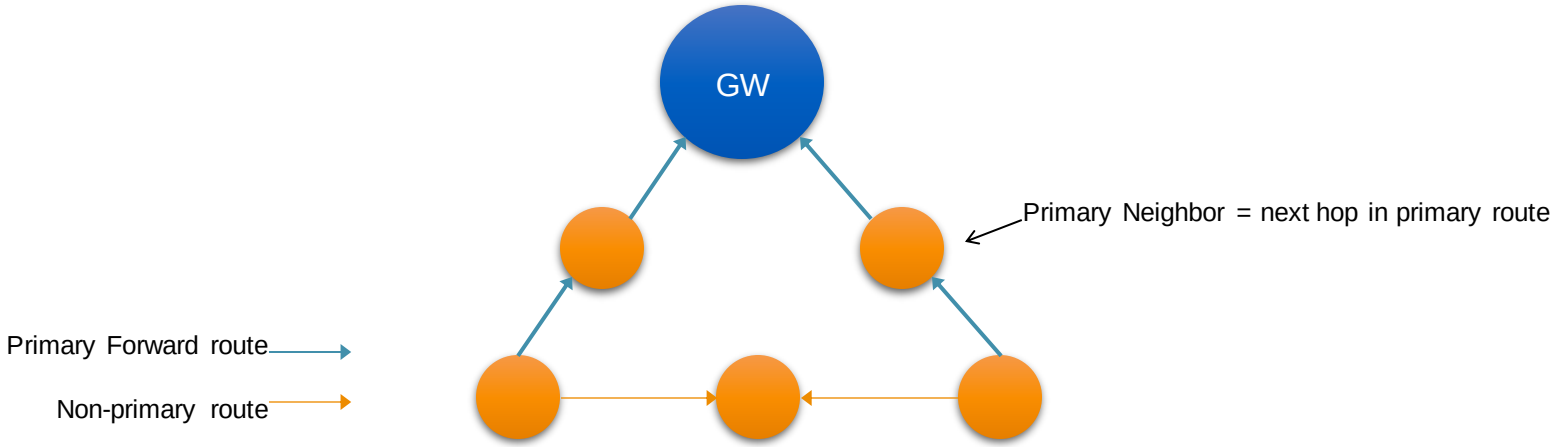
Node Configuration

- Electric nodes configured at production (Plug-n-play)
- New Water nodes configured at production
- WiFi devices require additional configuration
- All devices may be optionally configured with GPS coordinates
  - May also be imported into Yukon

Eaton RF Network Operation

Network Concepts: Routes

- A Route defines the path from one node to another
- Four major components:
  - Destination – the address to be reached
  - Next hop – the next address where the data is forwarded to reach destination
  - Cost – Quantitative representation of the link quality through the route
  - Hop – Number of hops to the destination
- Node objective: Always find the route with lowest cost to Gateway
- The ‘primary forward route’ is the route to the gateway



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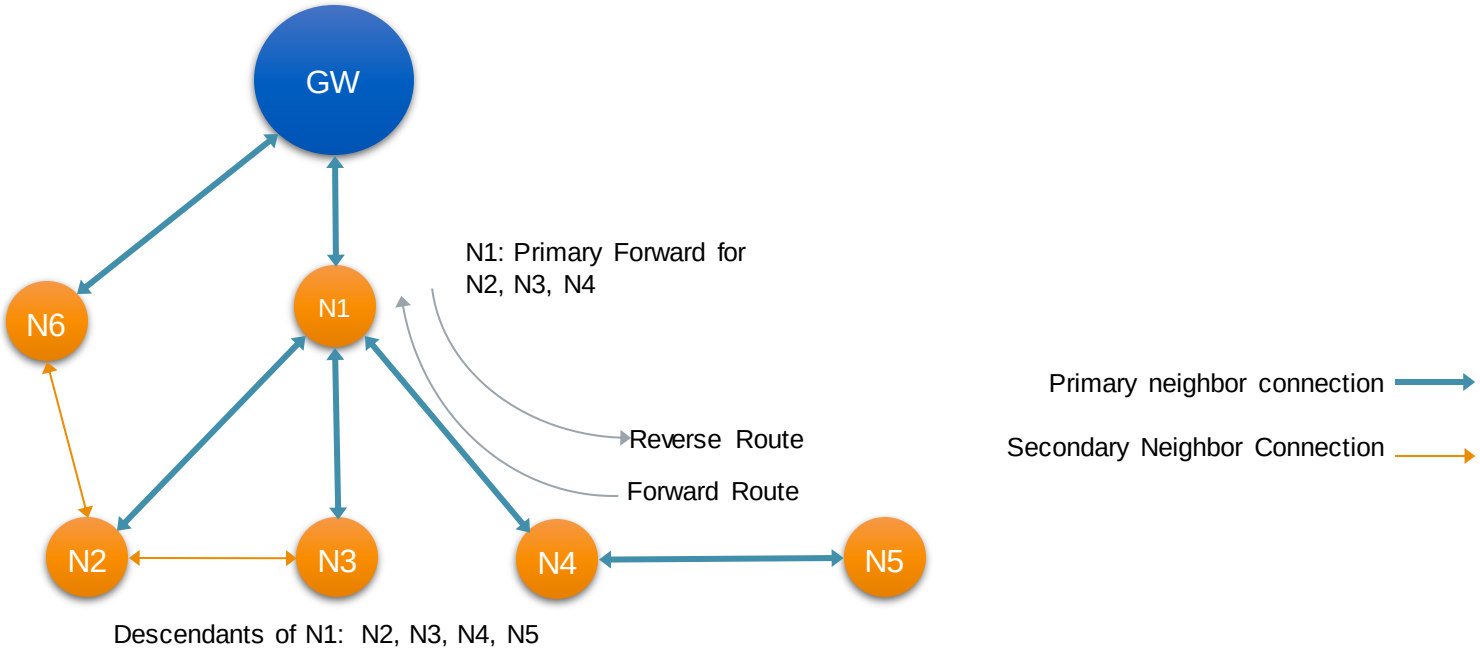
Network Concepts: Neighbors and Route Types

- The next hop node in primary route to Gateway is ‘Primary Forward’ (PF) neighbor
- The next hop node from GW down to a descendant is ‘Primary Reverse’ (PR)
- All neighbors used as next hop for primary routes are ‘Primary Neighbors’
- Neighbors not in primary route are ‘Secondary Neighbors’
- A group of nodes using a node in their forward path are ‘descendants’ of that node



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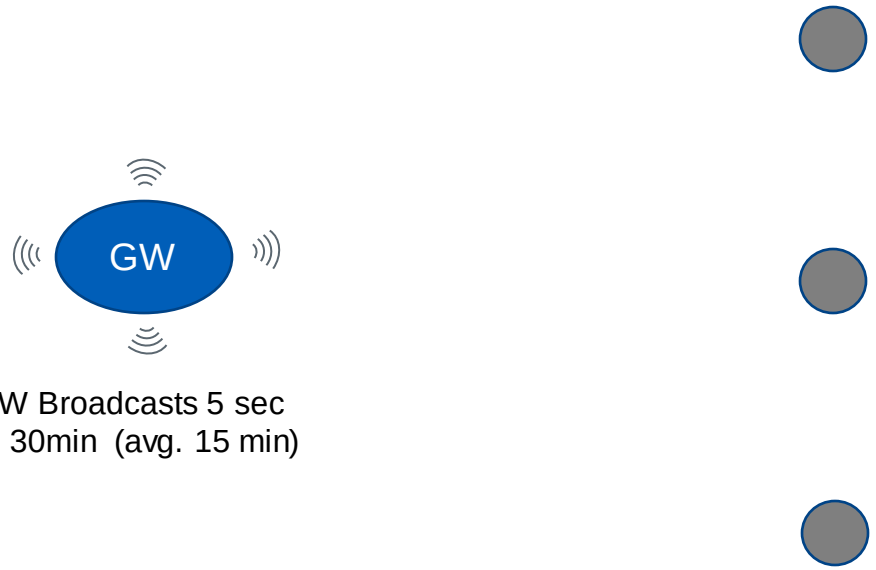
Initial Network Formation: Electric Node

- Upon power up, the Gateway starts ‘visibility’ broadcast
- The new nodes, invisible to the rest of the network, wait for the broadcast containing gateway information.



GW Broadcasts 5 sec
to 30min (avg. 15 min)

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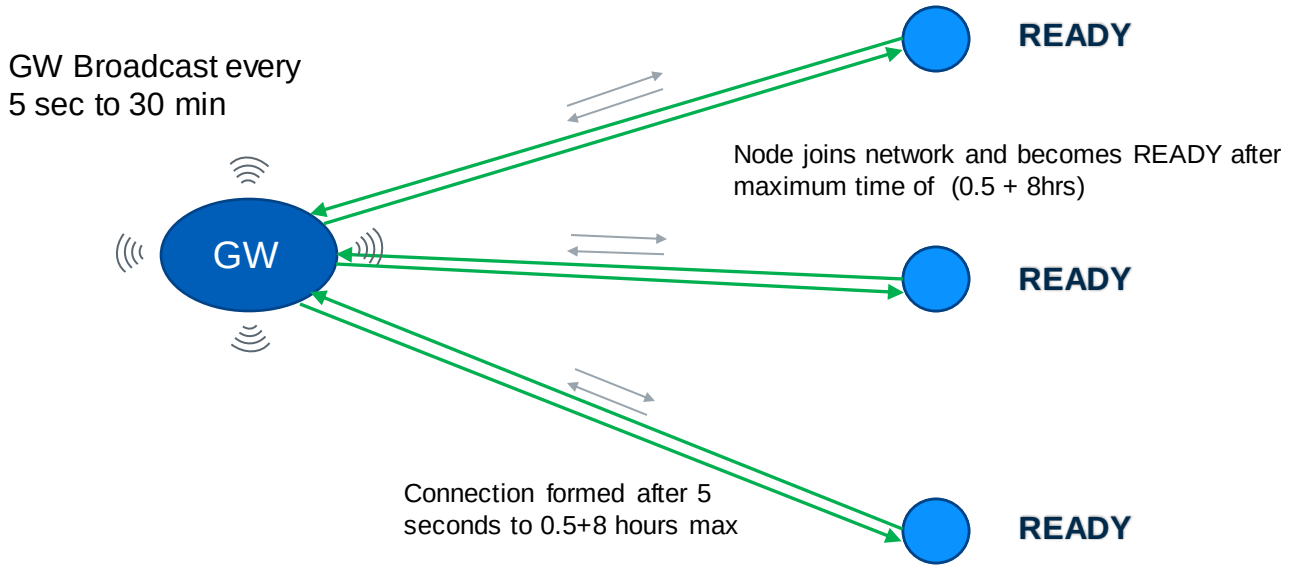
Initial Network Formation: Electric Node

- A node that can hear the broadcast, schedules a connection to the gateway
- During the connection, the node and gateway exchange route information and the Gateway learns the node's information.
- The node will be created in Network Manager and Yukon shortly after the identifying information is received by the Gateway and become ready for communication.



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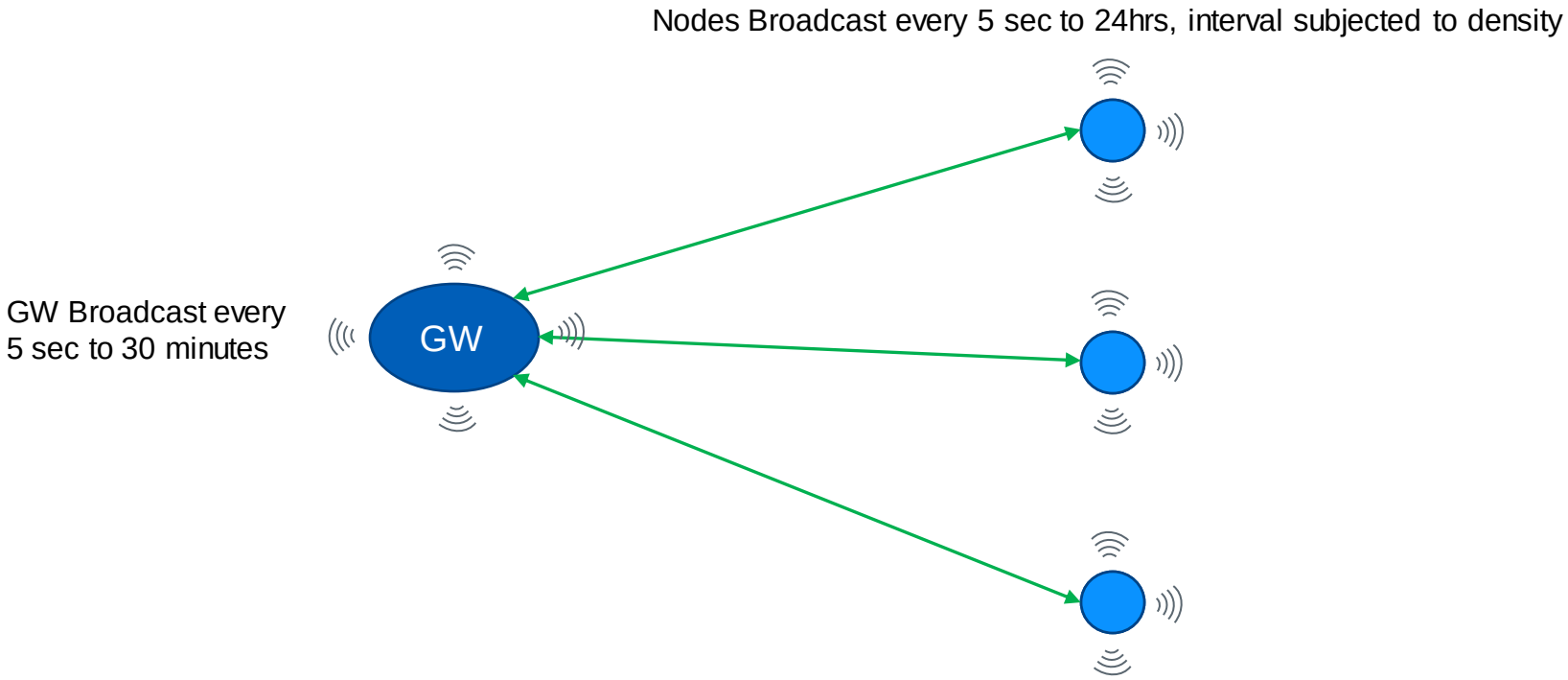
Initial Network Formation: Electric Node

- The node is now a ‘one hop node’ and ‘In Network’
- It starts its own visibility broadcast



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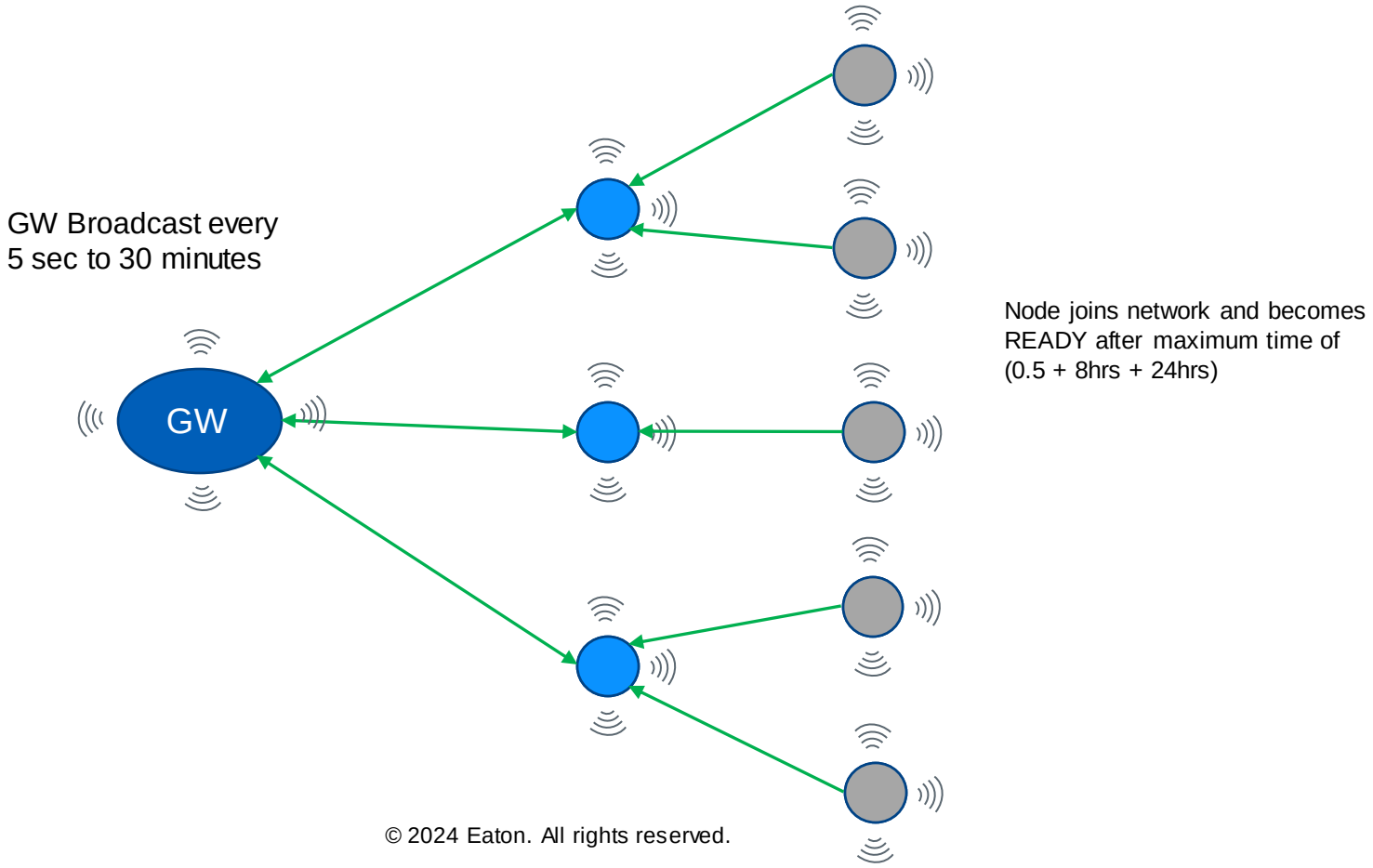
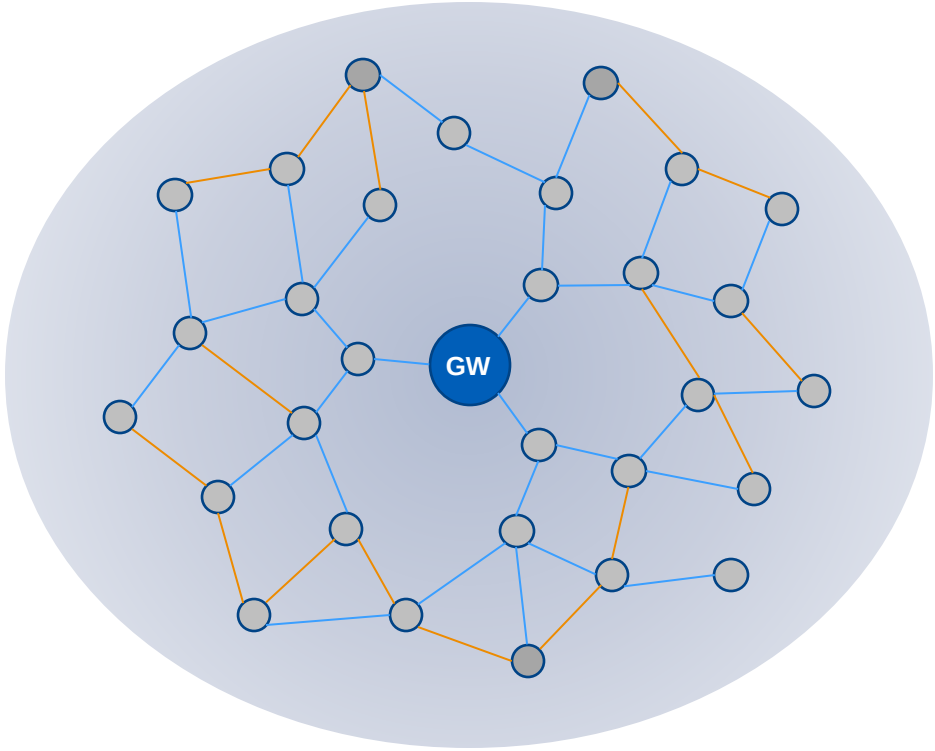
Initial Network Formation: Electric Node

- The nodes that can hear ‘one-hoppers’ join next
- Second hop is formed



Initial Network Formation: Electric Node

- The sequence of broadcast, connection, route discovery follows, more hops are added to the gateway
- Network thus forms outward from the gateway to the leaf nodes



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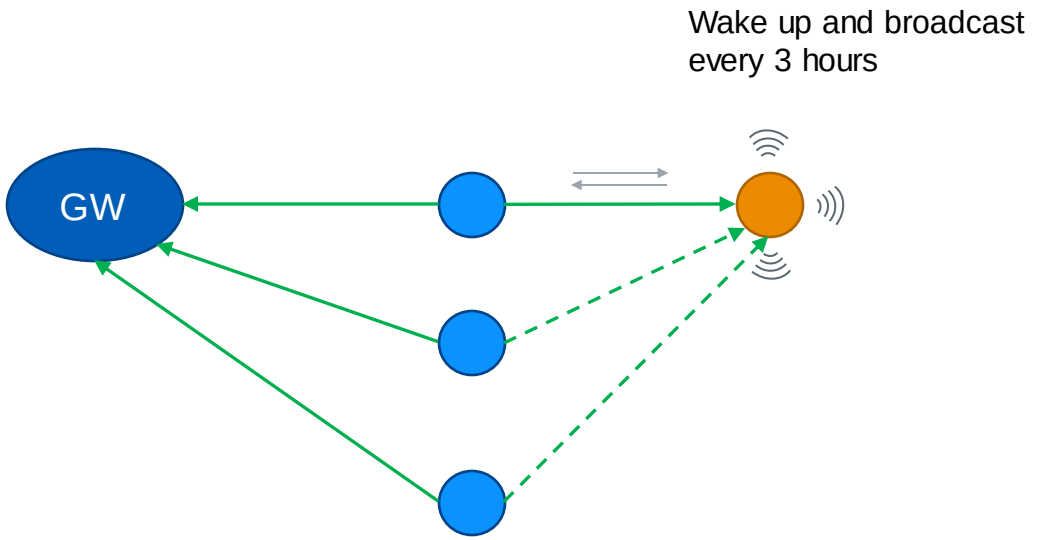
Battery Node Network Formation

- Out of network Battery node broadcasts its presence
- Nearby powered nodes schedule connections
- The first electric node to make a connection negotiates rendezvous time with the battery node
- The battery node joins network and stops broadcasting



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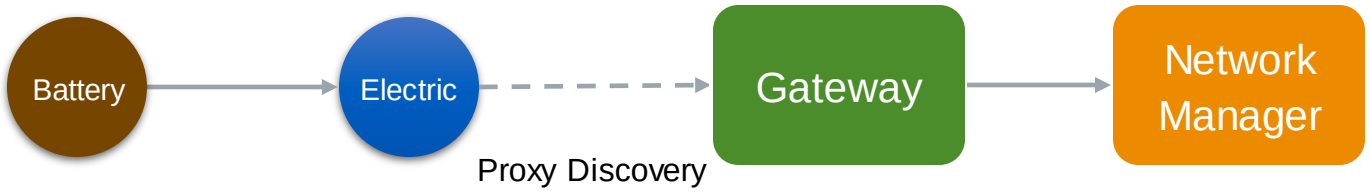
Battery Node Operation

- The battery nodes sleep, except during reporting time (normally once a day).
- Battery nodes do not take part in network formation or routing
- Always associated with an electric peer for daily reporting at a predefined ‘rendezvous’ schedule.
- Electric node forwards battery node data to the gateway
- Electric node generates ‘proxy-discovery’ message for battery node



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Fast Network Join

- RF Field Tool commands a newly installed RF device to join Network immediately
- The new device broadcasts its presence to the network at various power levels
- If an ‘in-network’ node hears the broadcast, it connects to the new device within a minute, does time sync and provides Gateway route information

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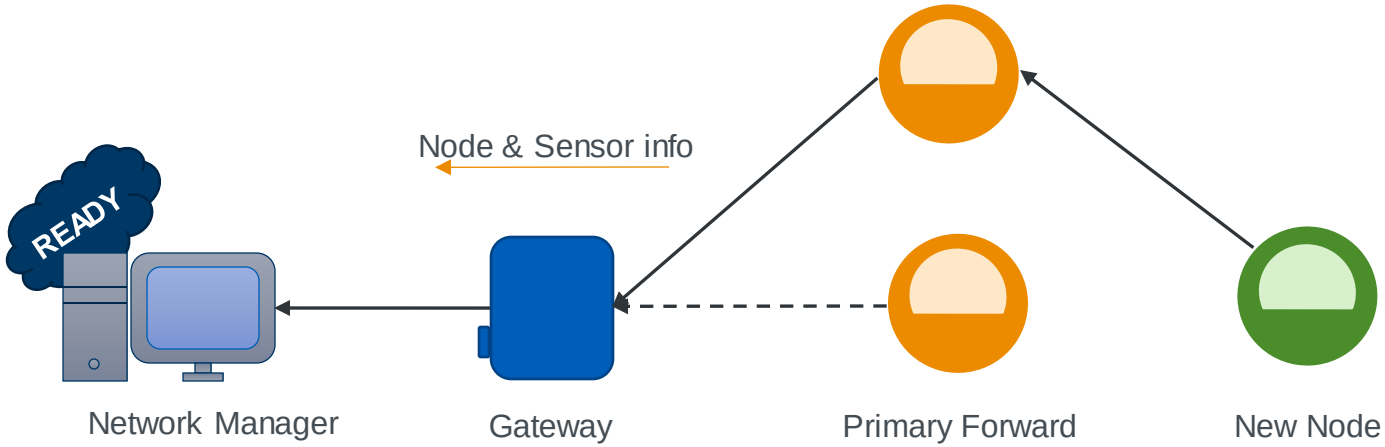
Fast Network Join

- Newly installed node identification and routing path is immediately sent to the Gateway and Network Manager
- Node becomes READY within 5 minutes after Field Tool command.
- Eventually the node may find a more optimal path through dynamic network evaluation.



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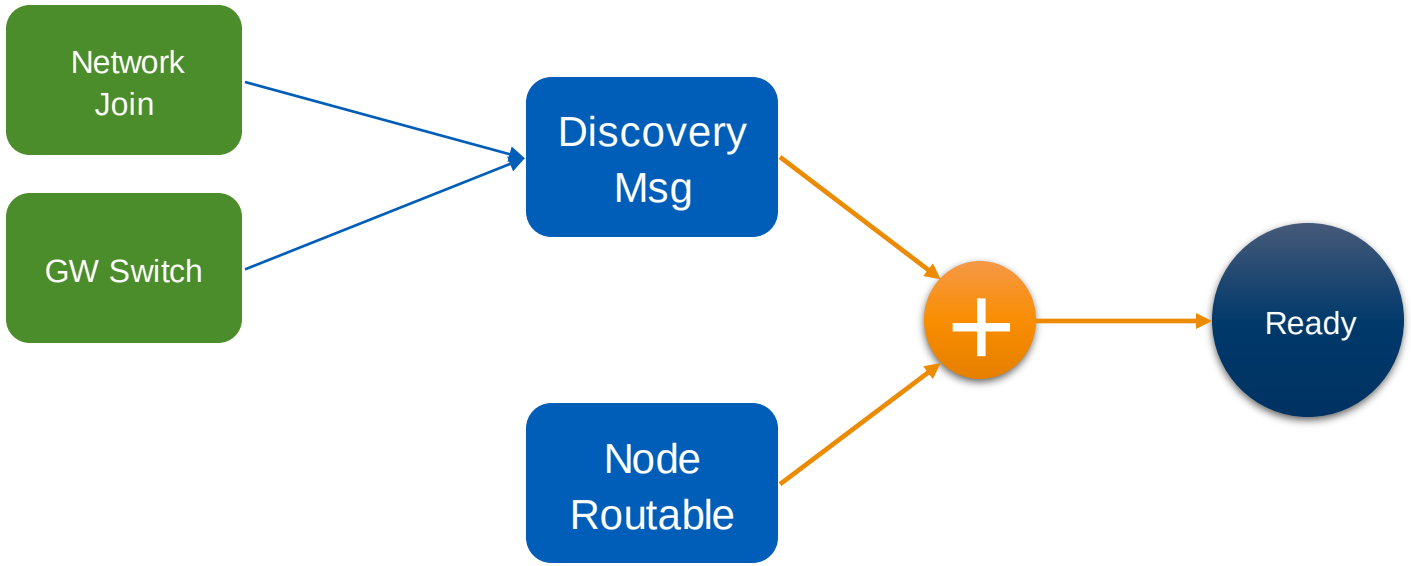
Ready Status

- Node sends discovery message after joining a network
- A node is READY when the gateway receives both the discovery message and the gateway has a route to the node
- Node also sends discovery message when it switches gateways



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Ready Status

- Node is NOT-READY when
  - Gateway receives no route update from the node for 6 hours
  - When there is no route from the gateway to the node, it can't send the node messages
  - Delay when a device is removed before routes expire

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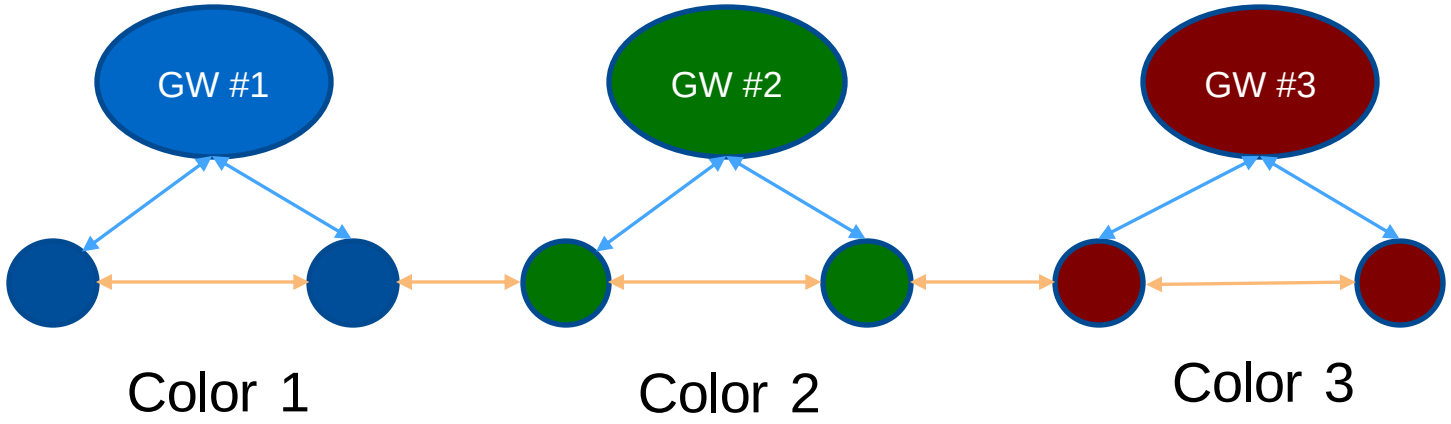
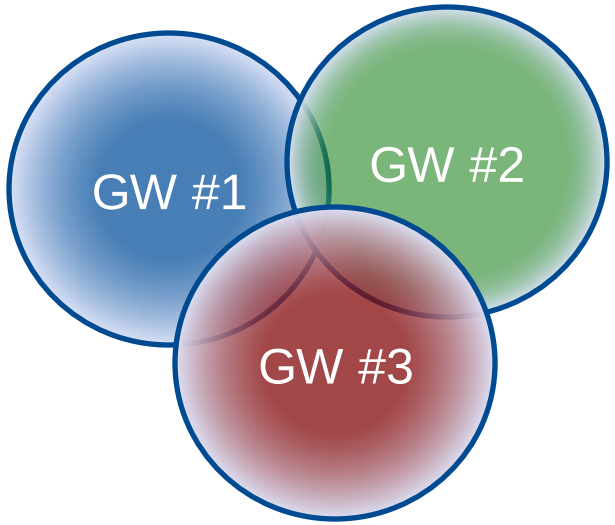
Network Segmentation

- A network is logically divided into Gateway segments
- Segmentation is represented by a unique identifier per deployed Gateway known as Color
- All nodes with the same Color form one network segment
- Segmentation distributes network load among gateways
- Overlapping segments provide network redundancy





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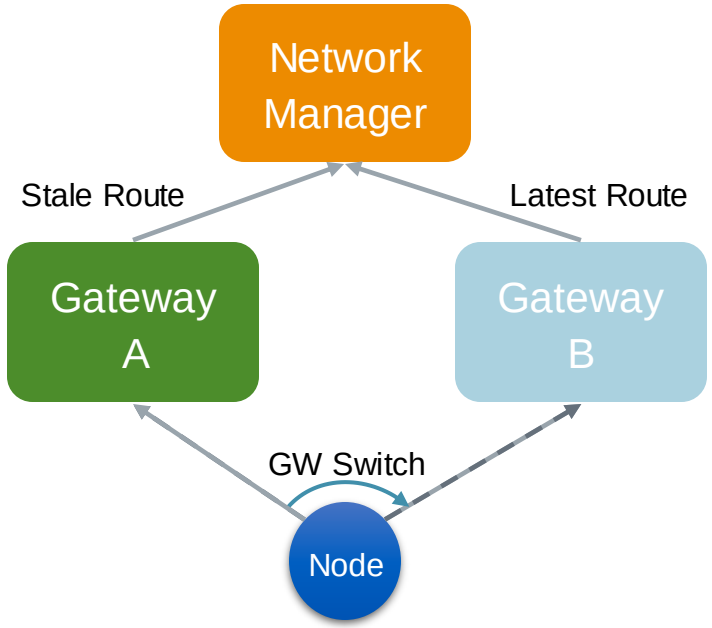
Ready Status: Switching Gateways

- A node is READY under a particular gateway.
- When a node switches gateway, it sends route information to the new gateway.
- Network Manager uses the latest route to update its READY status
- The node eventually times-out at the original gateway



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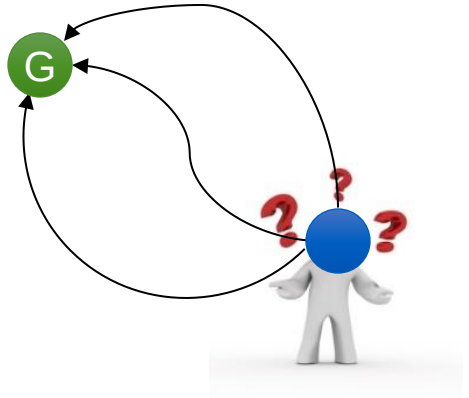
Network Steady State Operation

Network Optimization

- Once the network is formed it goes through an optimization process
  - Network is designed to find the ‘lowest cost’ path to the gateway
- The nodes continue to evaluate paths.
- The essence of mesh networking:
  - Option to choose the best path
  - Multiple path redundancy = resilience



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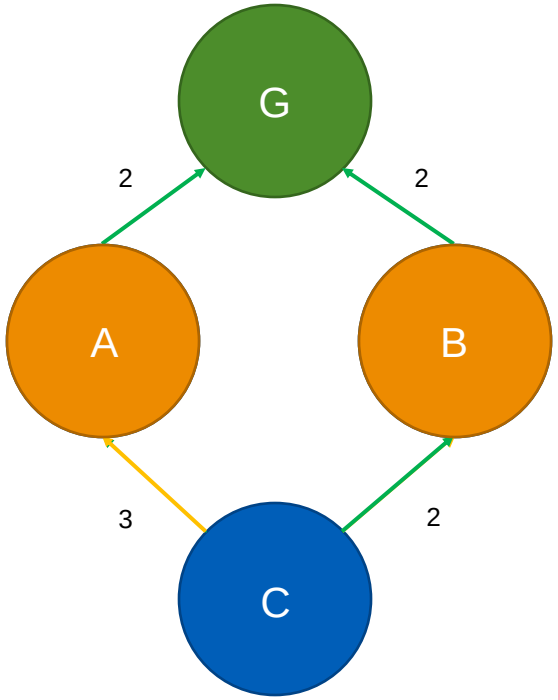
Network Optimization (cont'd)

- A node starts with a 'primary forward neighbor', its next-hop to the gateway.
- Path cost to the gateway is based on link quality of the hops.
  - Nodes exchange routes and gateway path costs with each other
  - Nodes evaluate link cost when they connect to their neighbors
- When a node finds a better path, it switches its 'primary'



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Link Cost Evaluation

- Patented RF mesh link quality measurement technique
- Node to node link quality is measured by
  "Expected Transmission Count" or ETX
- Raw ETX = average retransmissions of a single frame
- Higher ETX => More retransmissions => worse link

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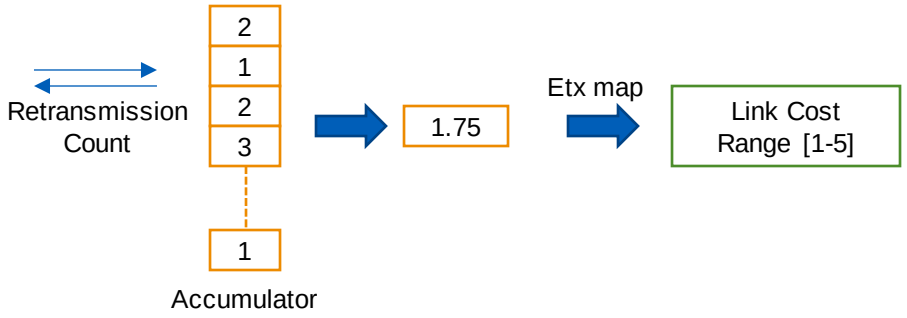
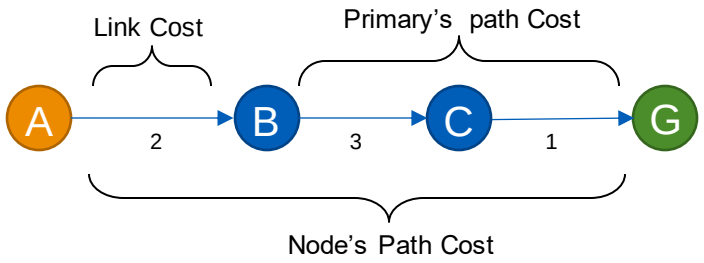
Link Cost Evaluation

- The raw ETX is mapped in to ETX bands 1-5, aka link cost.



- Node's path cost = Total cost to gateway =
  Normalized link cost to its primary + Primary's path cost.



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Multirate and Cost Normalization

- The link cost between node and its peer is normalized based on rate
- Lower rate = Lower Throughput = Higher Cost
- Supported rates = 1/8x, 1/4x, 1/2x, 1x, 2x
  [9.6, 19.2, 38.4, 76.8, 153.6 Kbps]
- Normalization factor = rate throughput ratio

Data Rate	Data Rate (Kbps)	Throughput ratio
1/8x	9.6	1
1/4x	19.2	2.5
1/2x	38.4	5
1x	76.8	10
2x	153.6	20

Rate	Bandwidth Factor	Cost Multiplier
9.6	1	5/1=5
19.2	2.5	5/2.5=2
38.4	5	5/5=1

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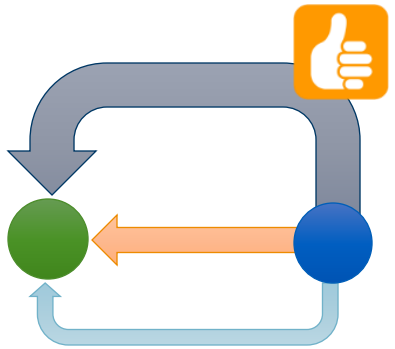
Rate Adaption

- Patented rate/power adaption algorithm
- The ‘common control rate’ is identical for the whole network
- The connection rate is adaptive
  - Higher link cost → Lower Rate
  - Lower link cost → Higher Rate

  Lower rate when the link is bad

  Raise rate when link is good

- The convergence is designed to maximize throughput.



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Rate Adaption

A typical sparse network configuration may look like

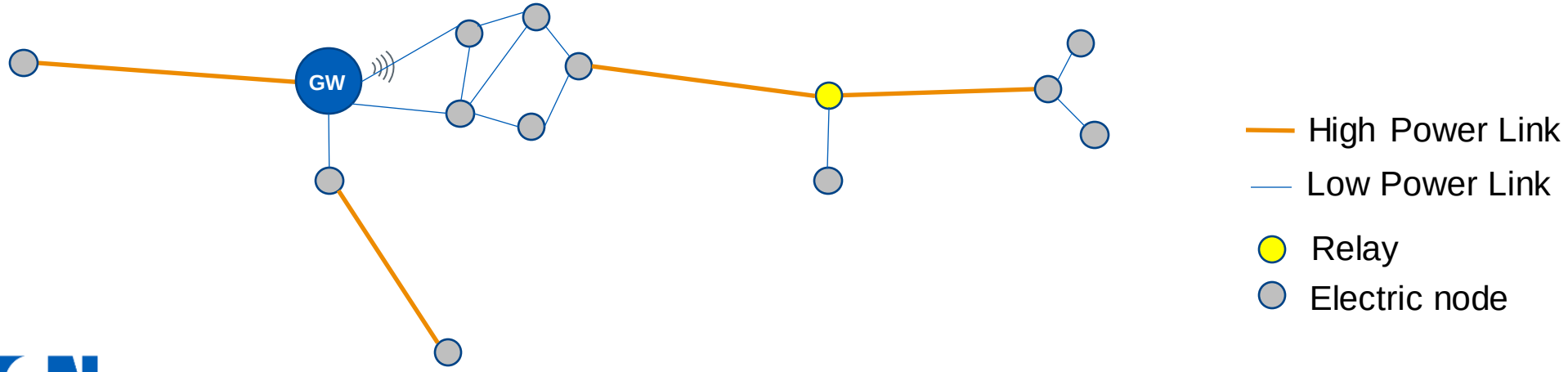
- MR-C := {R0 = 9.6}
- MR-E := {R0 = 9.6, R1 = 19.2, R2 = 38.4}

A dense network typically has a configuration that looks like

- MR-C := {R0 = 38.4}
- MR-E := {R0 = 38.4, R1 = 76.8, R2 = 153.6}

Power Adaption

- Power level starts with neighbor density
  - ½ Watt for dense neighborhoods, 1 Watt for sparse.
- If a link can adapt to the highest rate, nodes will begin sampling lower power levels
- 4 power levels available (Release 9.5)
- Lower interference generally in dense areas while retaining the capacity to use higher power for longer distance when needed



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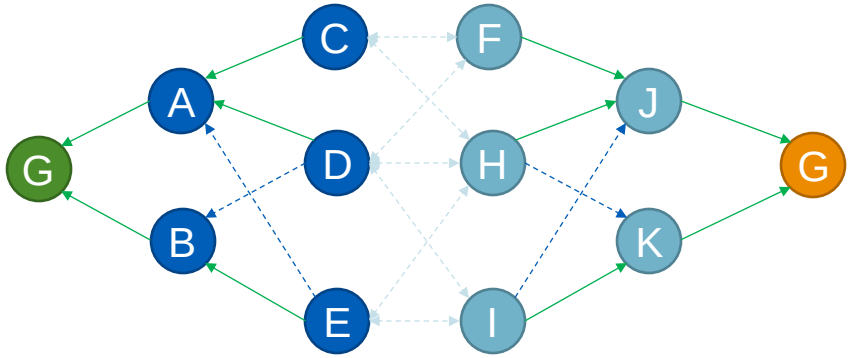
Network Redundancy

- Node maintains an alternate primary with similar cost for traffic forwarding and load balancing.



- Node maintains two sets of suitable neighbors that offer paths to current gateway and an alternate gateway.

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Primary Path Failure Detection

- Node connects to its primary at least once every 2 hours.
- If connection fails, node retries (at least 25) for at least 30 minutes
- If all retry attempts fail, node declares a link failure.

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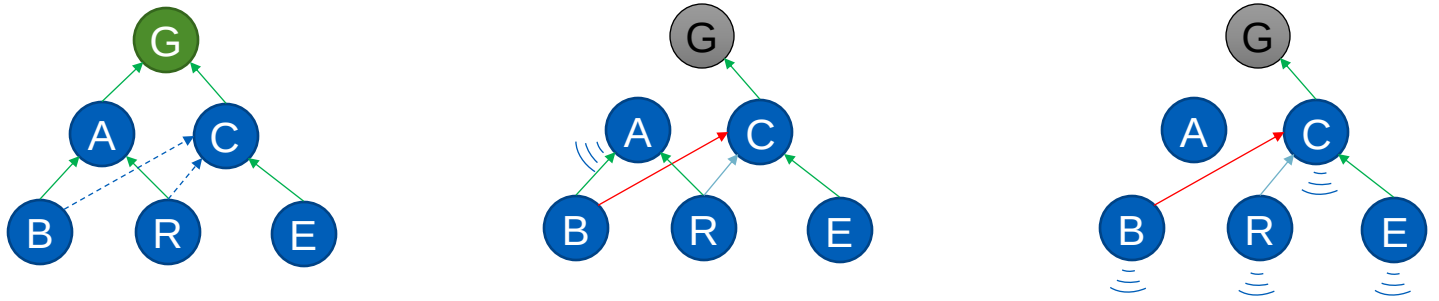
Primary Path Failure: What follows

- A node switches its primary path if it:
  - Has an alternate path to the gateway…. AND
  - Detects primary path link failure…. OR
  - Receives a broadcast message from some other node informing about its primary failure

Primary Path Failure: What follows

- When node has no suitable primary or secondary to use, it broadcasts its own primary failure to alert its descendants
- The primary path failure is thus propagated hop by hop



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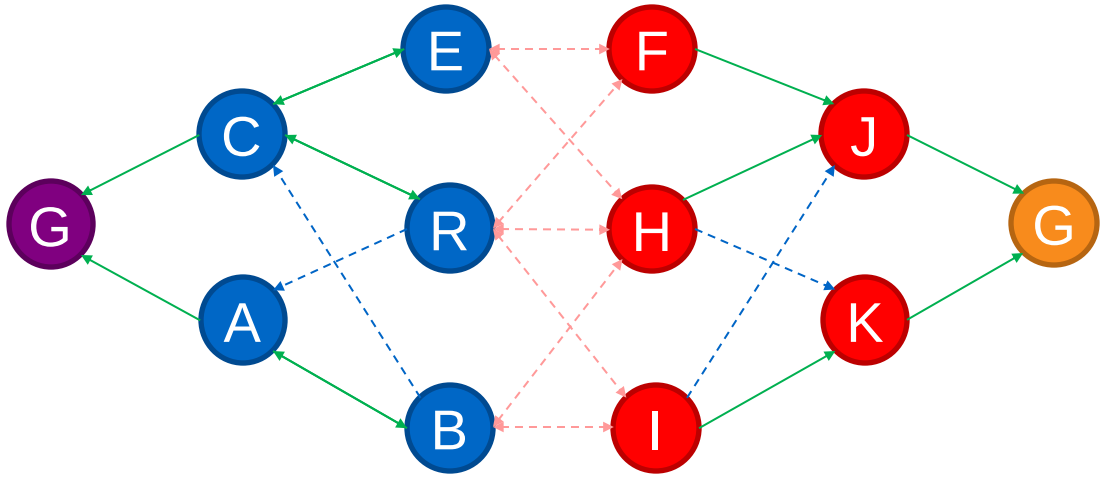
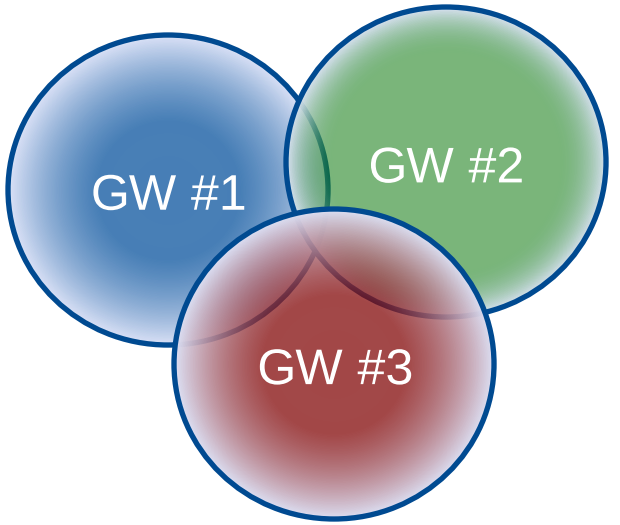
Gateway Failure: What follows

- Gateway failure information is propagated throughout the segment.
- The nodes in overlapping segments switch primaries first
- Other nodes follow hop by hop
- The whole segment gradually points to an alternate gateway within 24 hours.





- Segment overlap is therefore essential

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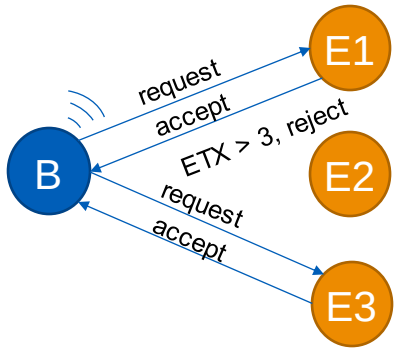
Battery Association Convergence

- The battery association is renewed at every rendezvous.
- If link cost > threshold, the electric node rejects the association.
- Battery node starts broadcasting again looking for a partner
- Last partner does not respond, allowing new partners to connect
- Process continues until a good link-partner is found.



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QUESTIONS?

"I had to quit drinking coffee. It keeps me awake during presentations."

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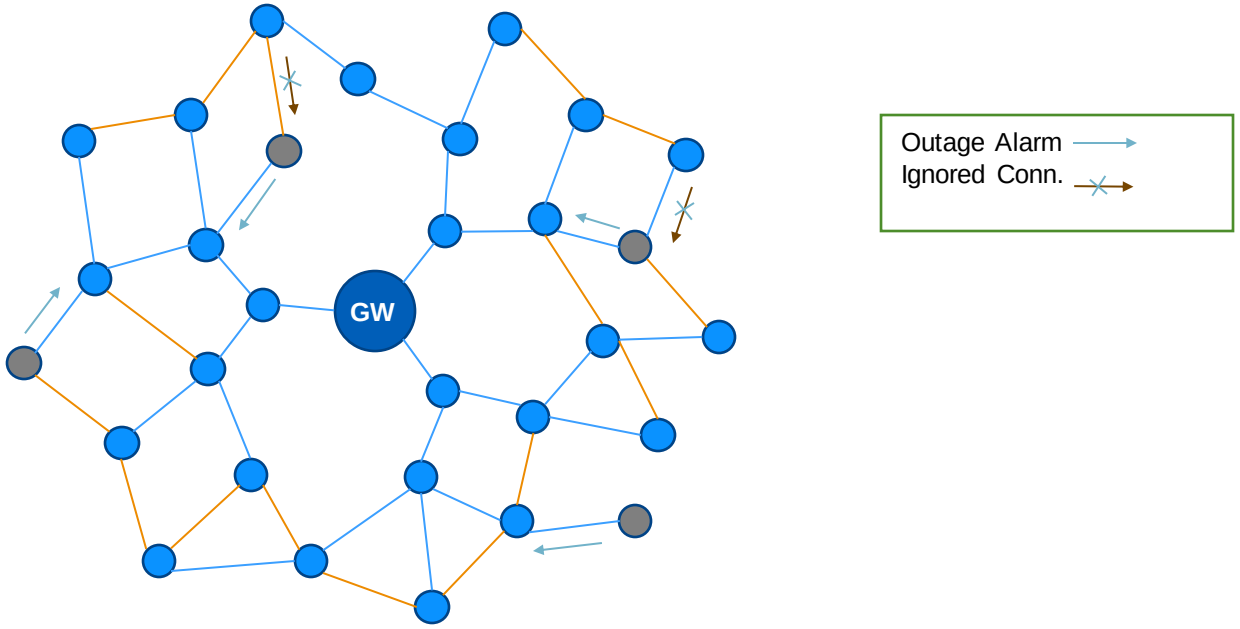
Applications

Outage and Restore: Network Response

- A node in outage can run up to 4 min on backup power
- An outage node does not participate in any connections. Except when:
  - It needs to send an outage alarm
  - Incoming connection is carrying an outage alarm



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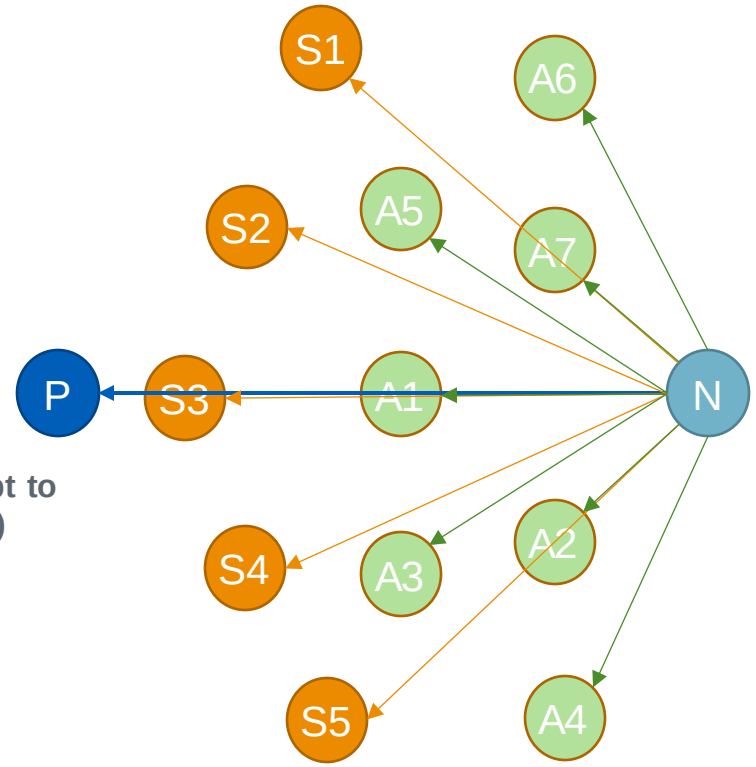
Outage Delivery



Delivery Attempt to Primary (5 tries)

Delivery Attempt to 5 best Secondaries

Delivery Using Anycast: Any neighbor with equal or less hops
Rank by: a. Path cost b. RSSI c. Charge Left

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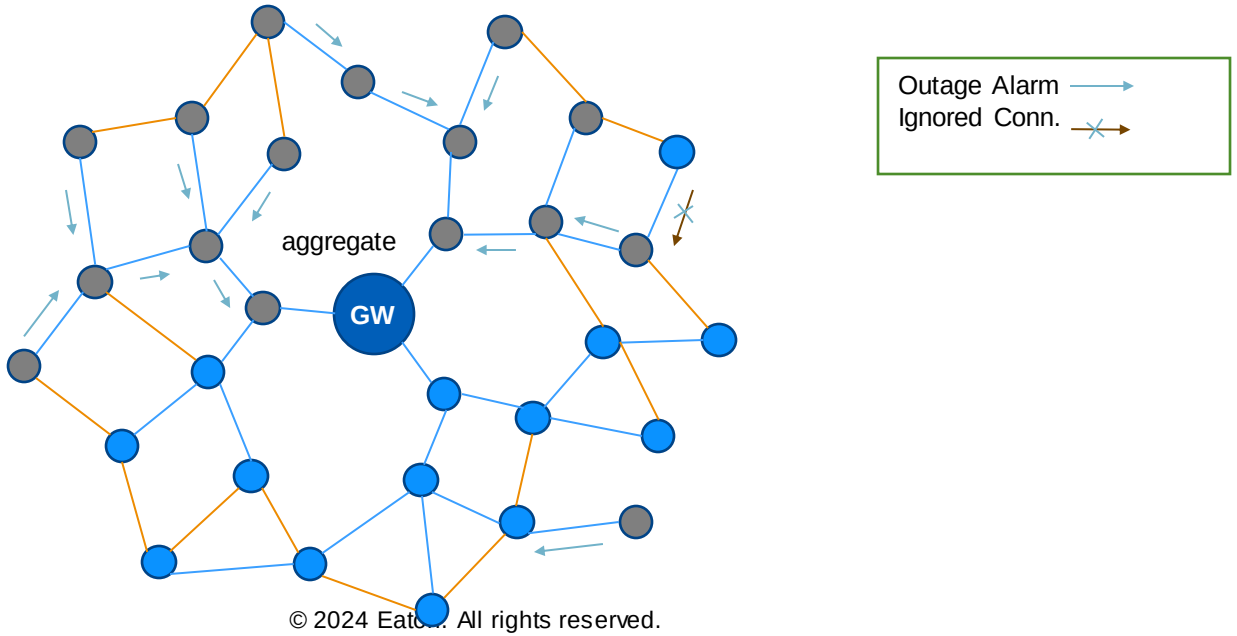
Outage and Restore: Network Response

- Large scale outage event -> alarms not guaranteed to reach GW
- Outage alarm delivery improvements:
  - Aggregate outage alarms prior to sending its own
  - Connect only when outage alarm message is to be delivered
  - Employ connection back-off at the powered node, when it receives an outage message



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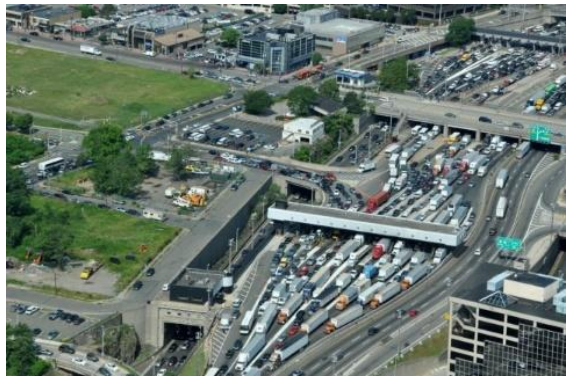
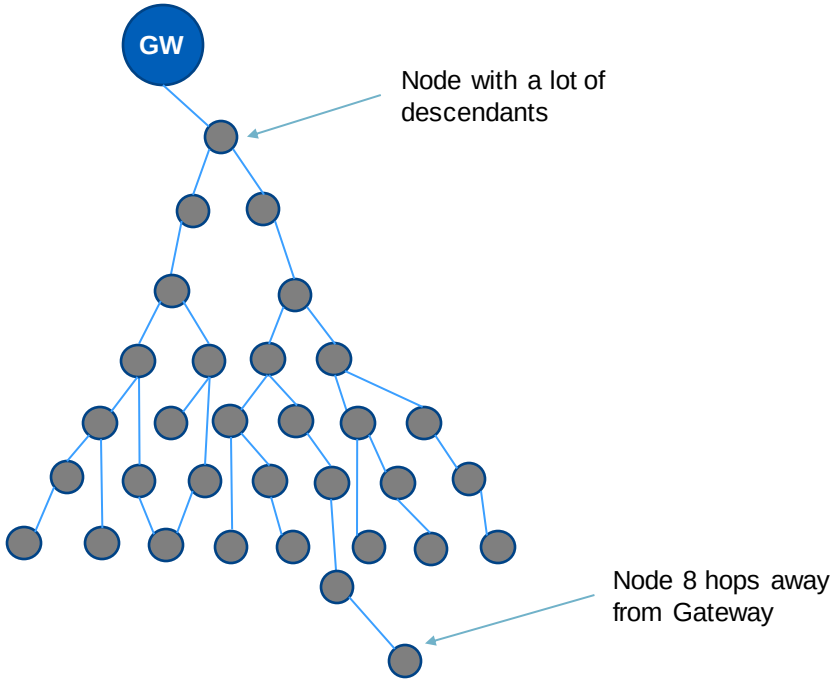
Outage and Restore: Network Response

Outage Response is constrained by Network Topology

- A single node or relay carrying a lot of descendants may reduce chance.
- A message has less probability of reaching gateway if it originates many hops away





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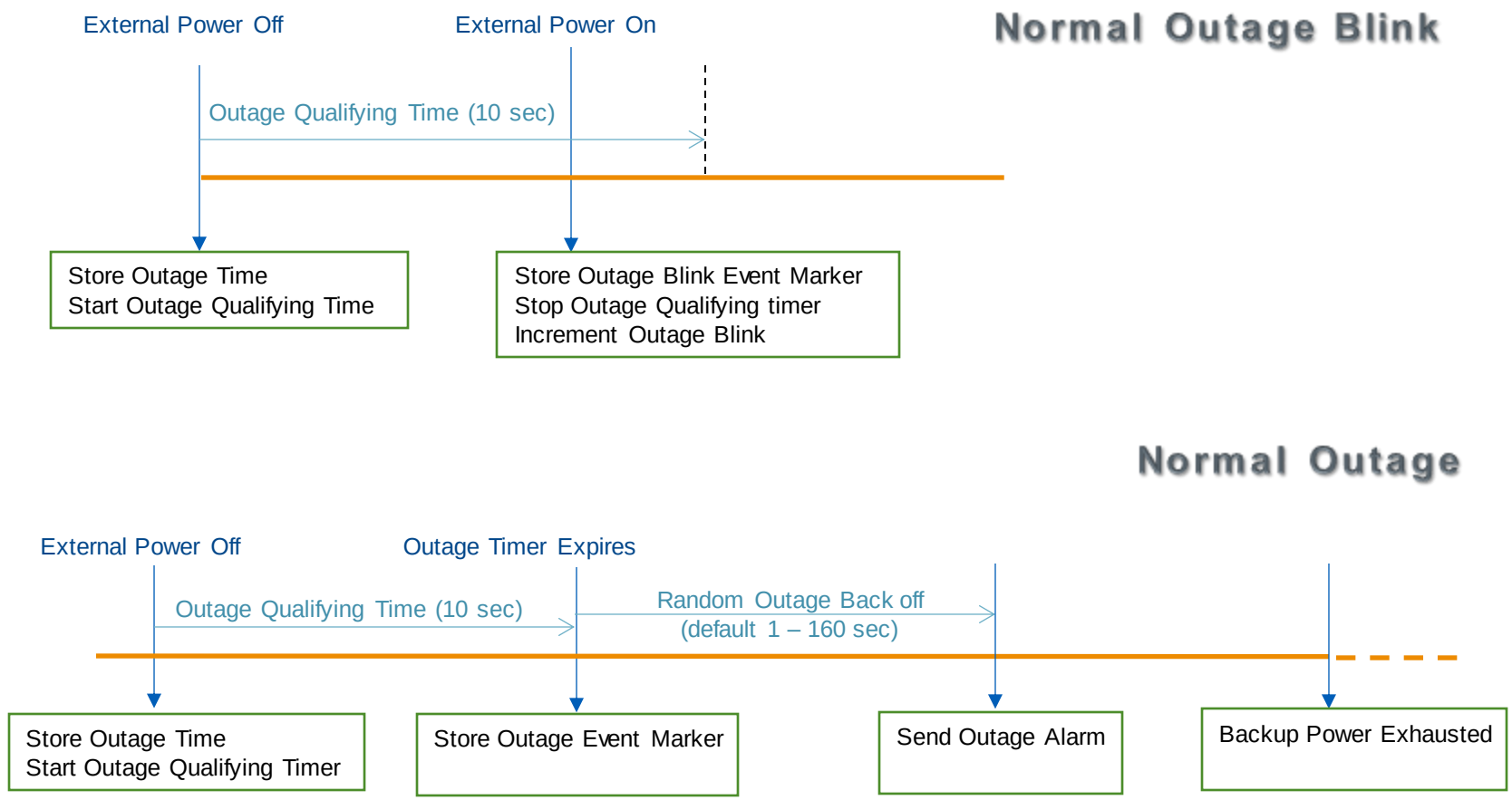
Outage Detection

- RFN Outage and Blink Determination
  - Blink is defined as loss or restoration of power for less than 10 seconds (Release 9.0)
  - Outage is loss of power for 10 or more seconds
  - Restore is after power has been back on for 60 seconds or more

Outage Detection

Outage Detection and Reporting Steps



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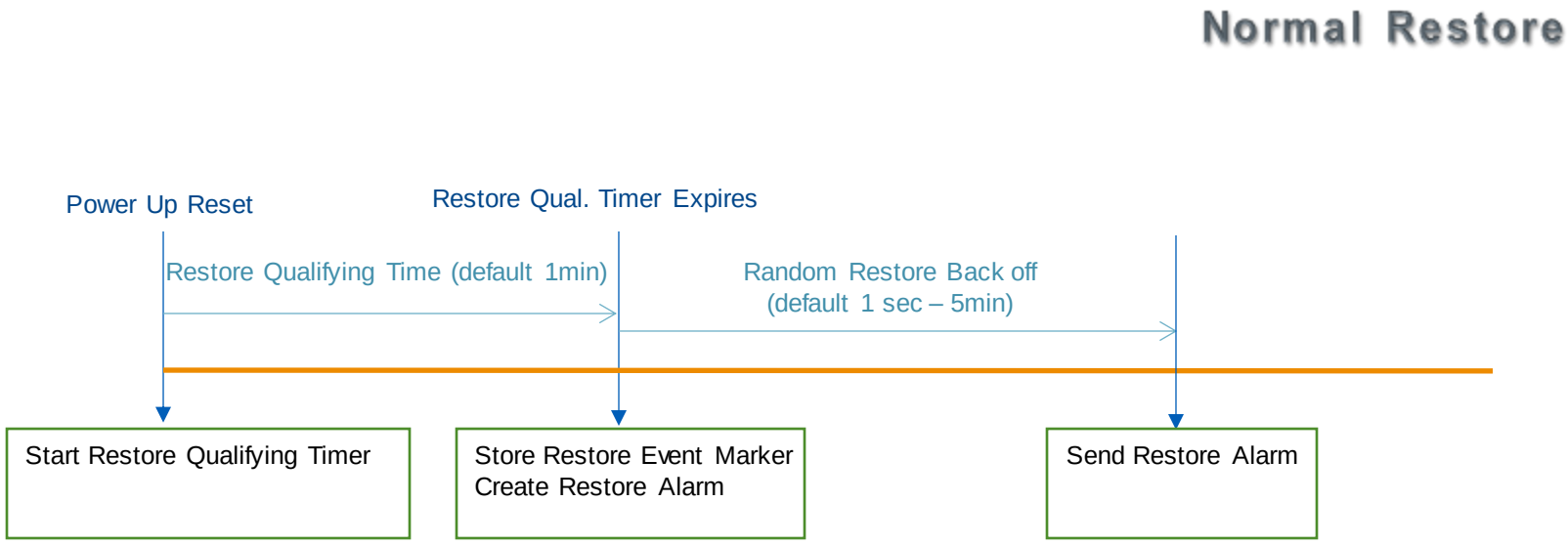
Outage Detection

Restoration Reporting Steps



Firmware Upgrade

- RF system can deliver new features for all RF devices through firmware upgrades
- All RF upgrade images are created with a RSA signature and authenticated before being accepted by a node
- Firmware upgrade mechanism relies on neighbor topology to “spread” the new images down and across the network
- The upgrade mechanism is capable of upgrading any RF node unless it has poor link connectivity to the network
- New design facilitates traffic efficient upgrades resulting in minimizing effect to network traffic

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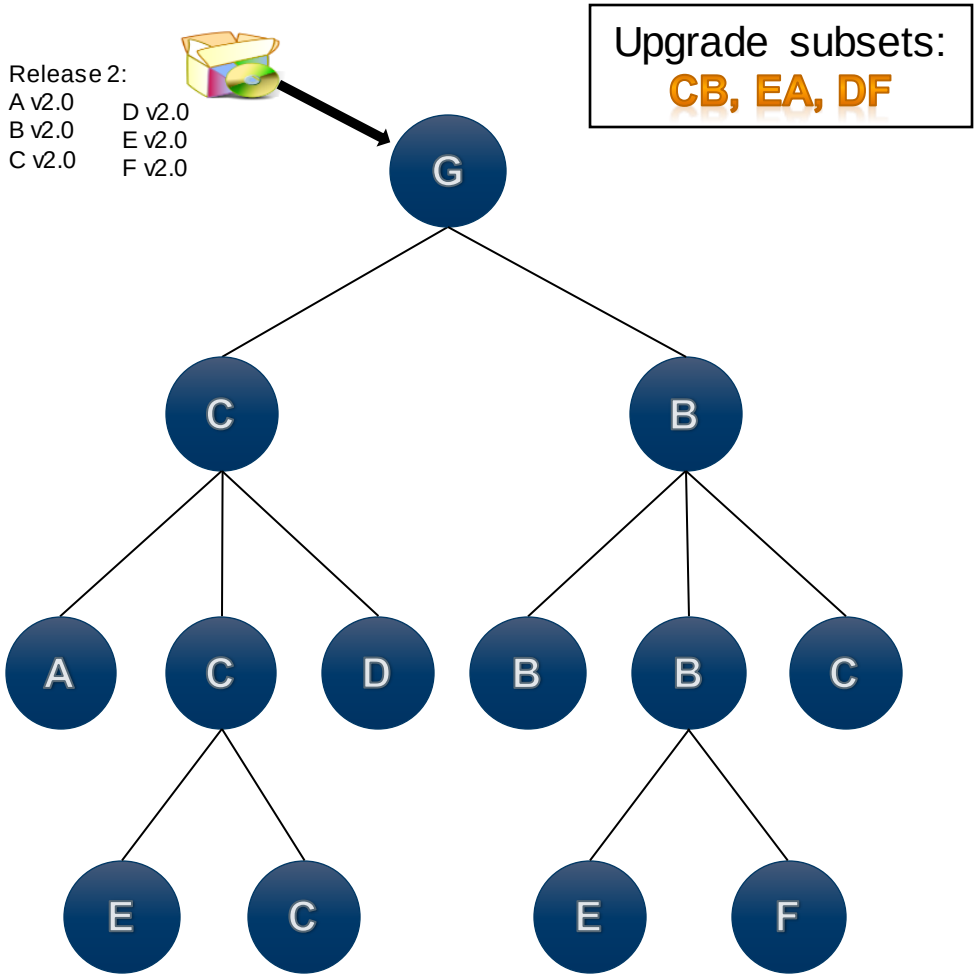
Firmware Upgrade – Gateway



- Upgrades are initiated at the Gateway
- Controlled traffic event
- Gateway sends only a subset of all images into network at anytime
- A defined period of time is given for images to propagate into the network
- Nodes apply updates and send version information to Gateway
- Gateways stop sending images when 99% of nodes have been updated or the defined period of time has elapsed
- Nodes will continue to upgrade each other as needed

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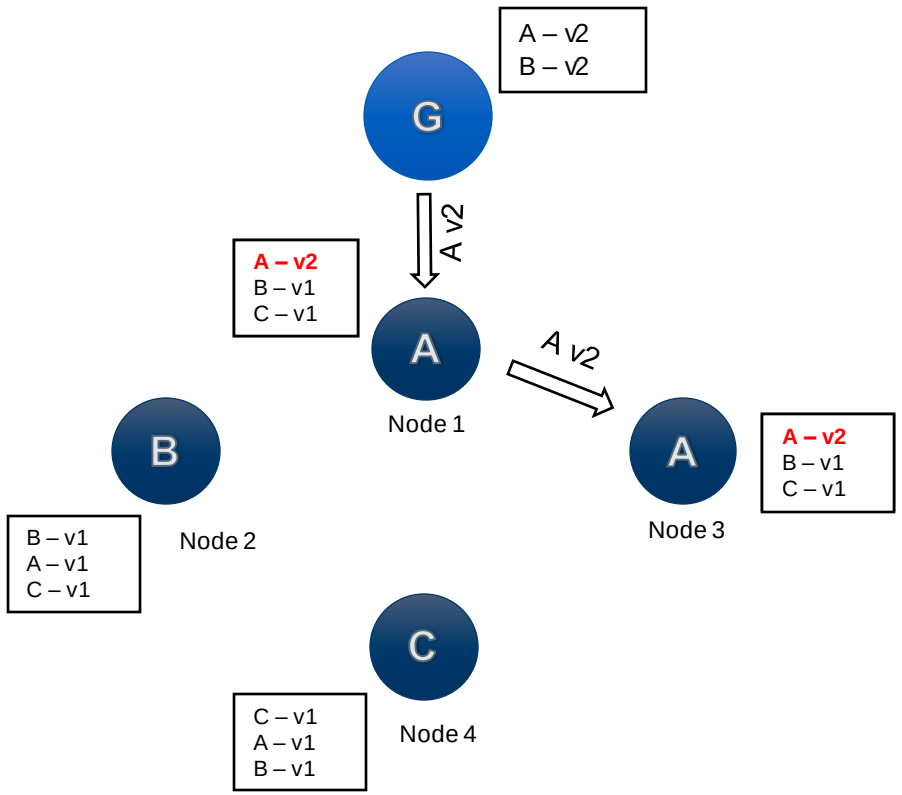
Firmware Upgrade – Node Upgrade



- A node receives new firmware from one of its neighbors
- Neighbors connect to each other periodically to send application traffic or to exchange control traffic
- Firmware exchanges are randomized to avoid heavy network traffic: 1/6 – Gateway, 1/3 - Nodes
- All Nodes store their own and images of 2 other types of nodes to facilitate faster spread through the network
- A node will send the newer version of any of its stored firmware to its neighbor

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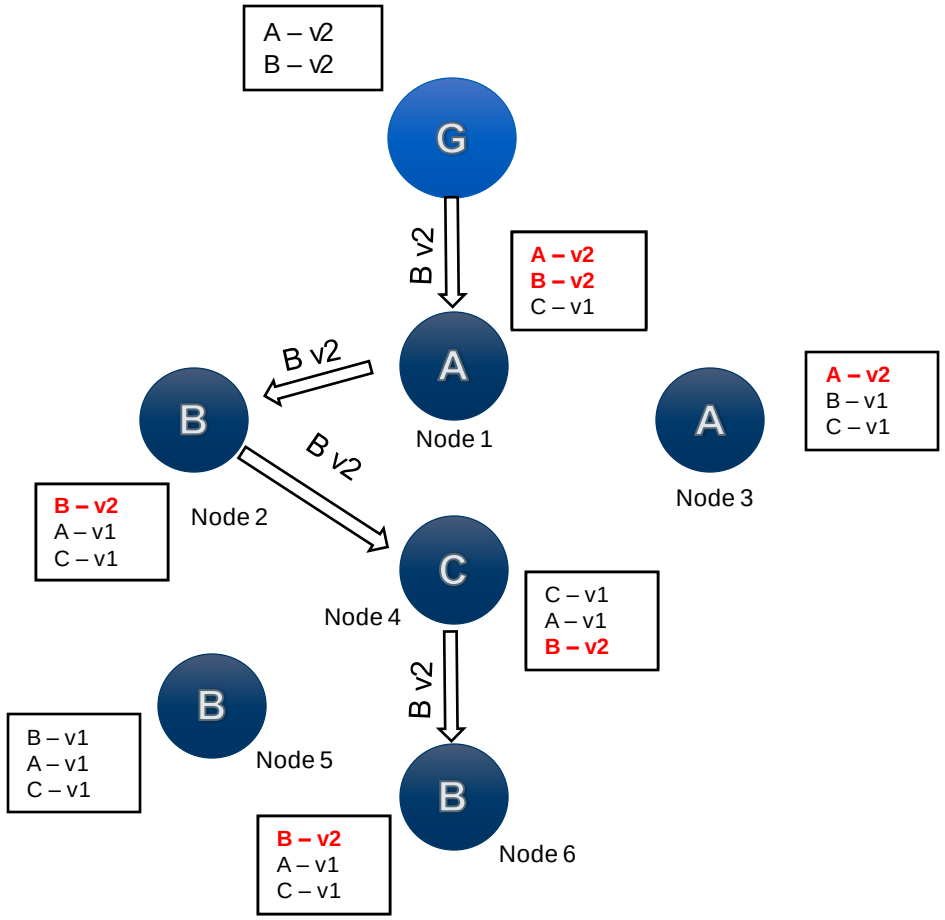
Firmware Upgrade – Node Upgrade



- Nodes of different types can send an upgrade to each other from their stored images
- Nodes sent updated firmware version to the Gateway
- A node that gets newly installed will receive updated firmware if its available from one of its neighbors

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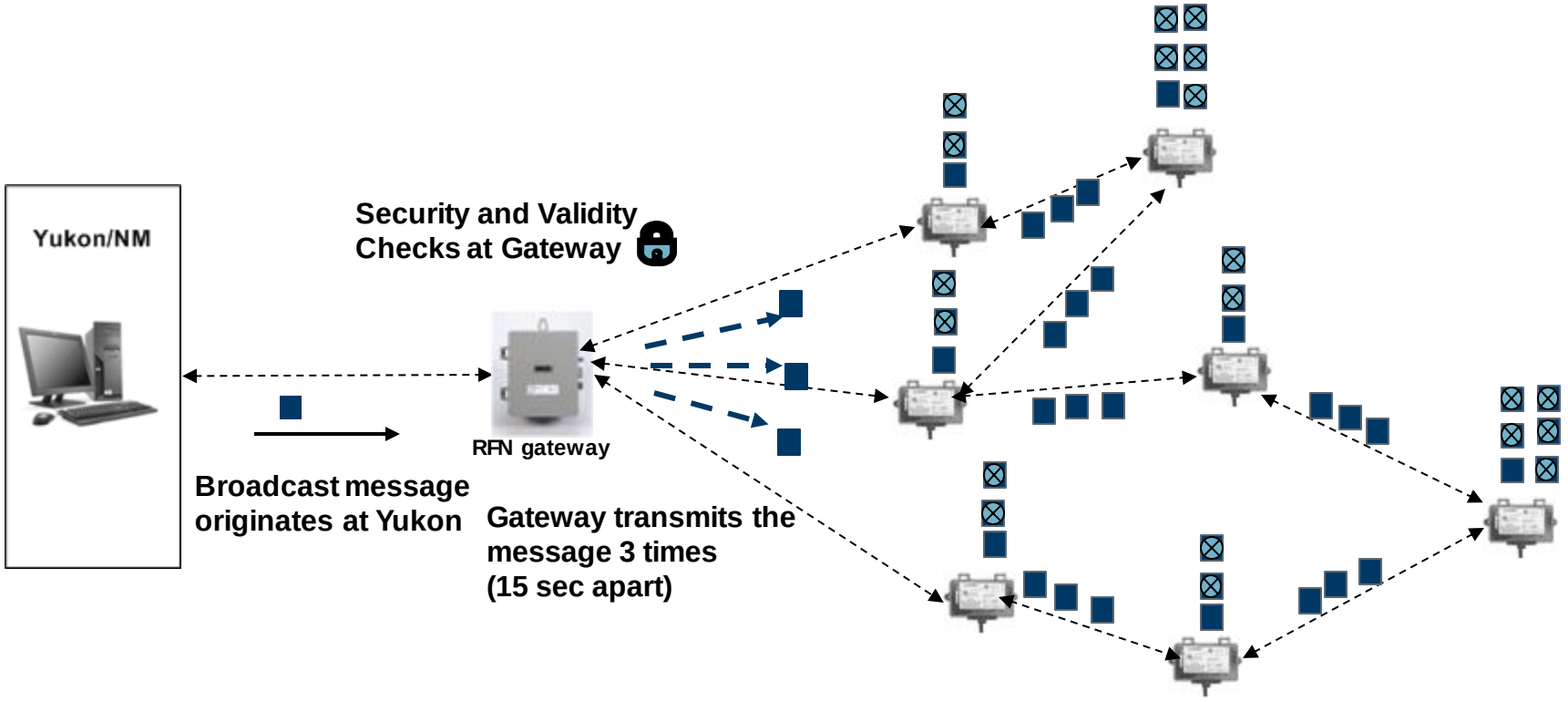
RFN Broadcast Summary

- RFN Broadcast is a controlled flooding mechanism where the message frames are repeatedly broadcast from node to node
- Uses the link layer and it works independent of the network routing connectivity
- Limits the number of broadcasts as well as the period of transmission in order to reduce the impact on any unicast messaging
- Supports authentication and data encryption as well as delay and replay protection
- Uses security keys independent of the unicast transmission
- Supports real-time and non-real time delivery

Broadcast (Real-time message delivery)



- Original message
- Repeated message 1
- Repeated message 2
- Dropped Repeated message

All nodes within reach receive same messages but drop duplicates and expired messages.
Transmit 3 times.
Randomized 0-10 seconds

Message expires in 15 minutes (Validity time)

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RFN Broadcast Summary

- Supports mainly Demand Response (DR) application. DR messages are broadcast as real-time/high-priority messages
- Originates at the Yukon DR Application
- NM implements flow control into the network
- RFN Gateways and Nodes implement message security, validity time and priority as the messages pass onwards into the RF mesh network

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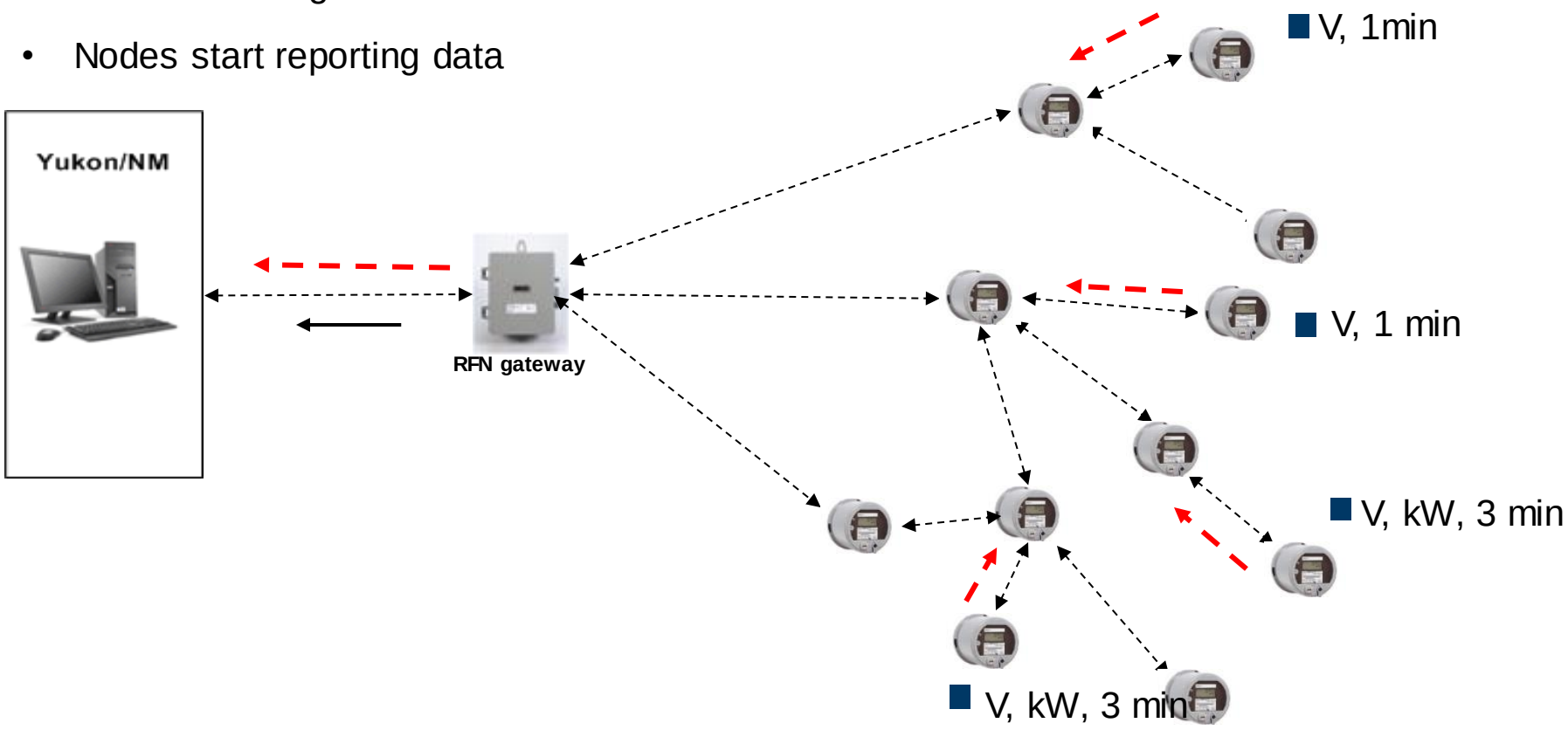
RFN Data Streaming

- Near-real time monitoring of selected meter data mainly aimed for voltages but supports other meter data points (KW, VA, VAR)
- Uses a new RFN connectionless transport layer messaging with low latency, shorter data payloads. Supports up to 8 data points per message. Not recorded nor gap filled.
- Security and validity checks at each node and the gateway
- 1, 3, 5, 15 and 30 minute configurable reporting intervals
- End-to-end configuration and management and data interface to the customer management system are provided by Yukon
- Capacity is managed by Yukon and allows data streaming on a subset of meters.

RFN Data Streaming

- Yukon enables and select channels for Data Streaming
- Nodes start reporting data



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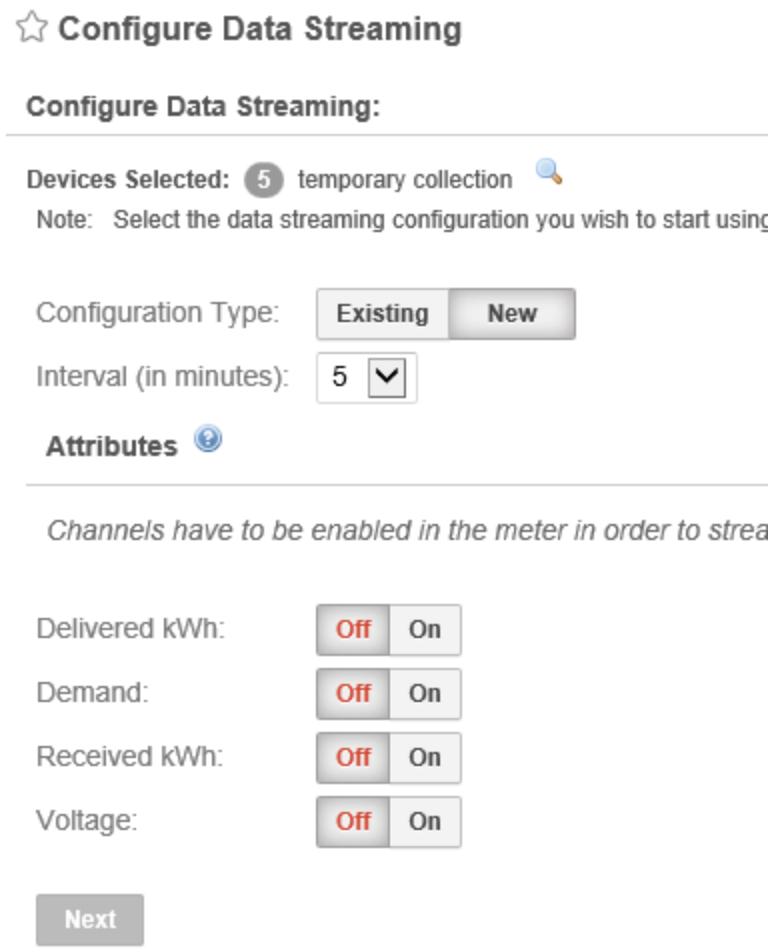
Data Streaming: Yukon Configuration



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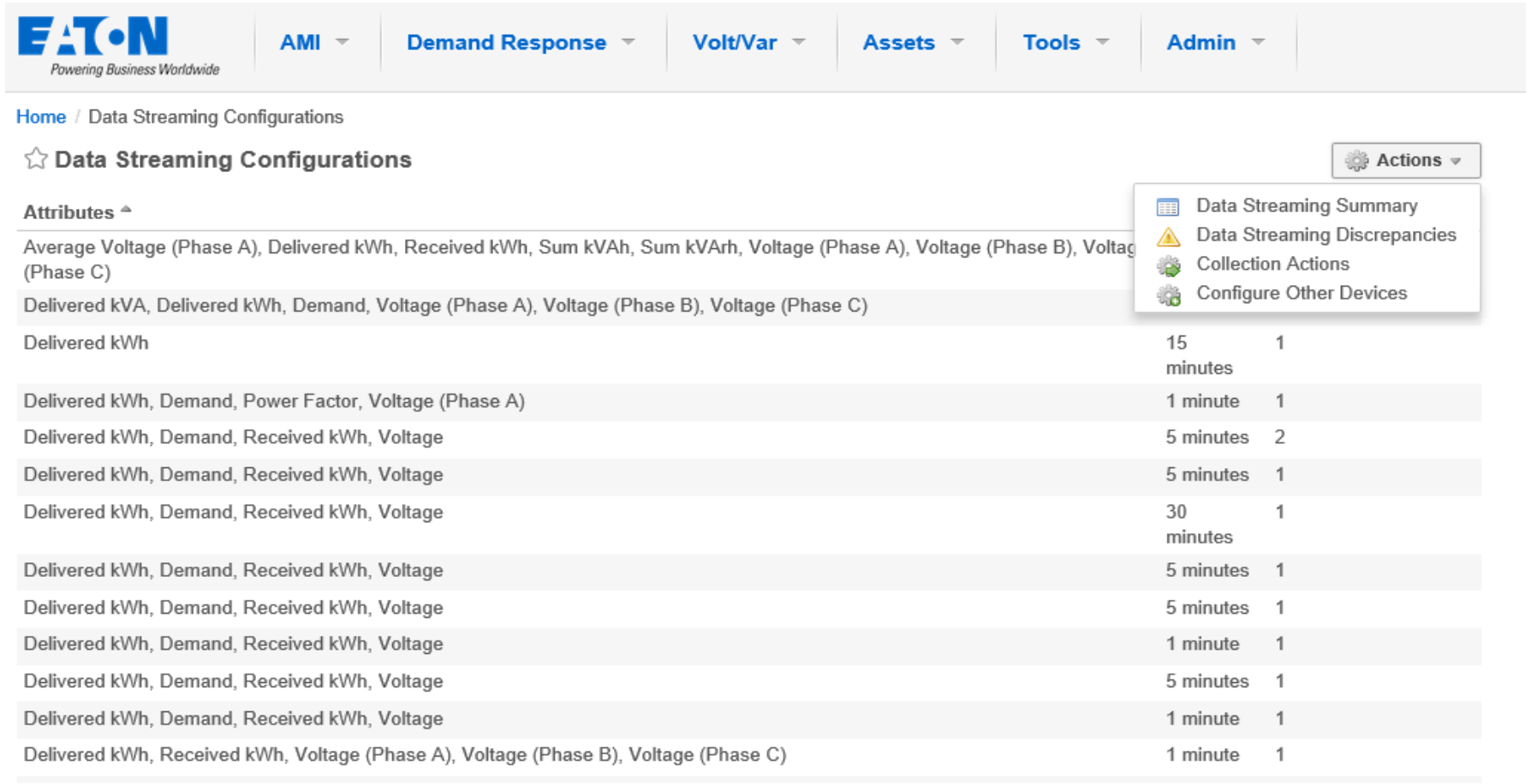
Data Streaming: Yukon Configuration



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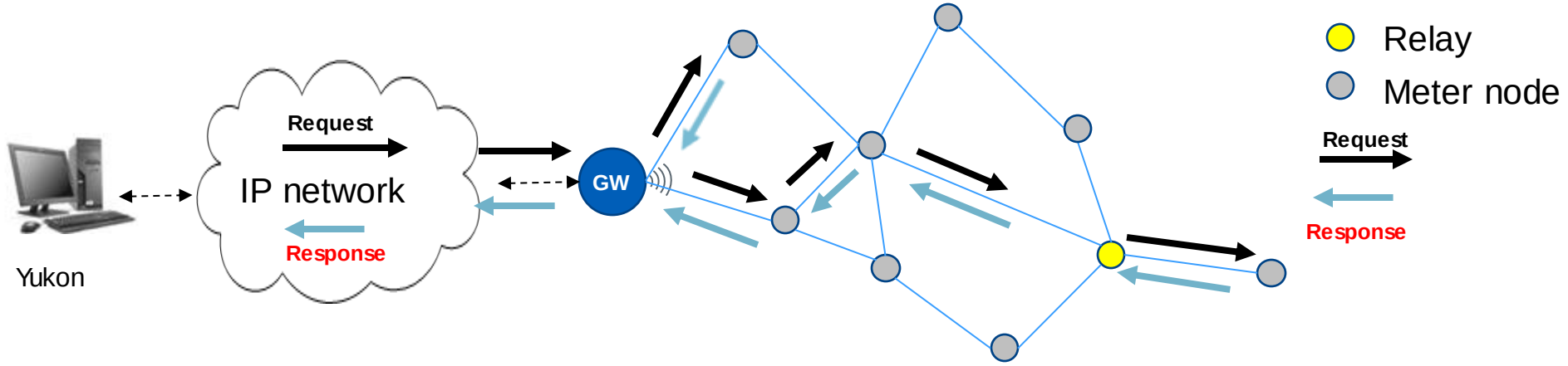
On-Demand Reads

- On-Demand reads (current meter reading) can be initiated from Yukon/NM to a node
- Average time is about 2-3 seconds per link but it can be more depending on many factors
  - How busy the gateway and nodes are at the time of on-demand
  - Link quality
  - Data Rate



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New/Recent Features (Release 9.3-9.9)

- WiFi IPLink Meter (9.3)
  - Acts as network bridge for the RF Network to utility backhaul using WiFi
  - Based on the C2SX meter
- Power Adaptation (9.5)
- Remote Meter Programming
  - Supports meter configuration for Elster A3 and LG S4
- Gas Meter (9.7)
- On-demand performance improvements (9.7, 9.8)
  - Routing optimizations
  - Average connection duration reduction
  - Cumulatively, large improvement in 2-way performance across multiple hops and in dense networks
- Time of use, seasonal (9.9)
- KYZ pulse support (9.9)

Q & A

- Questions?

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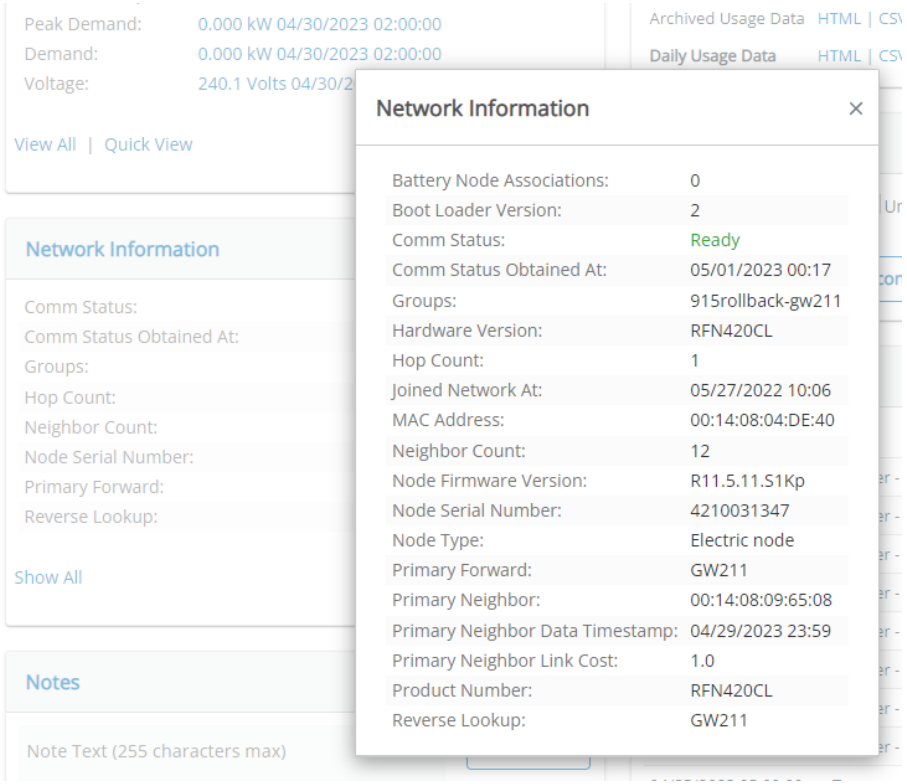
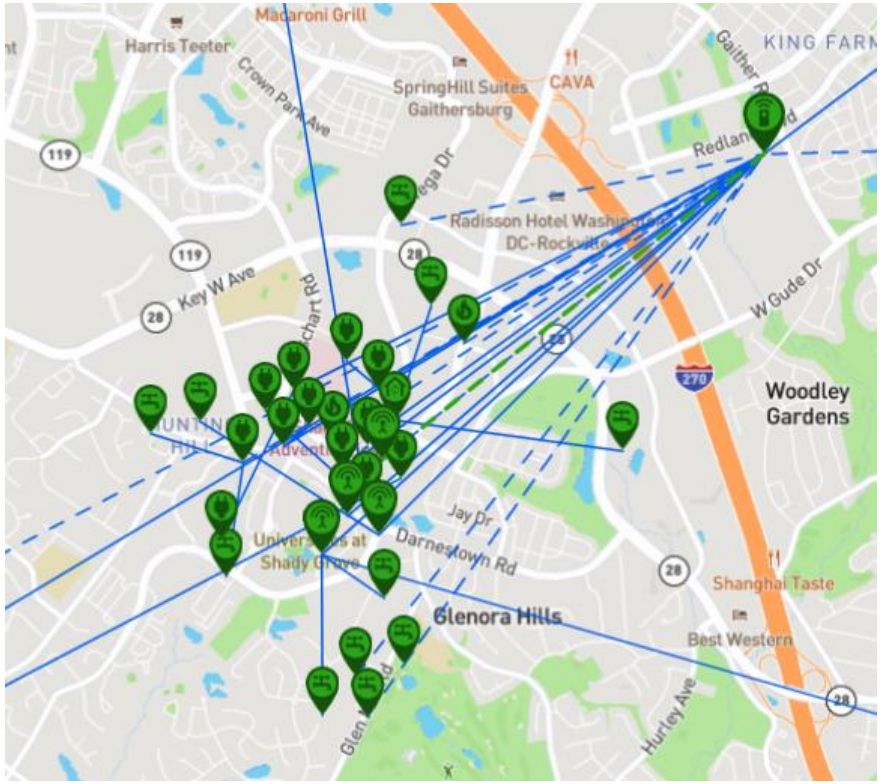
Eaton RF Mesh Network Troubleshooting

RF Network Troubleshooting

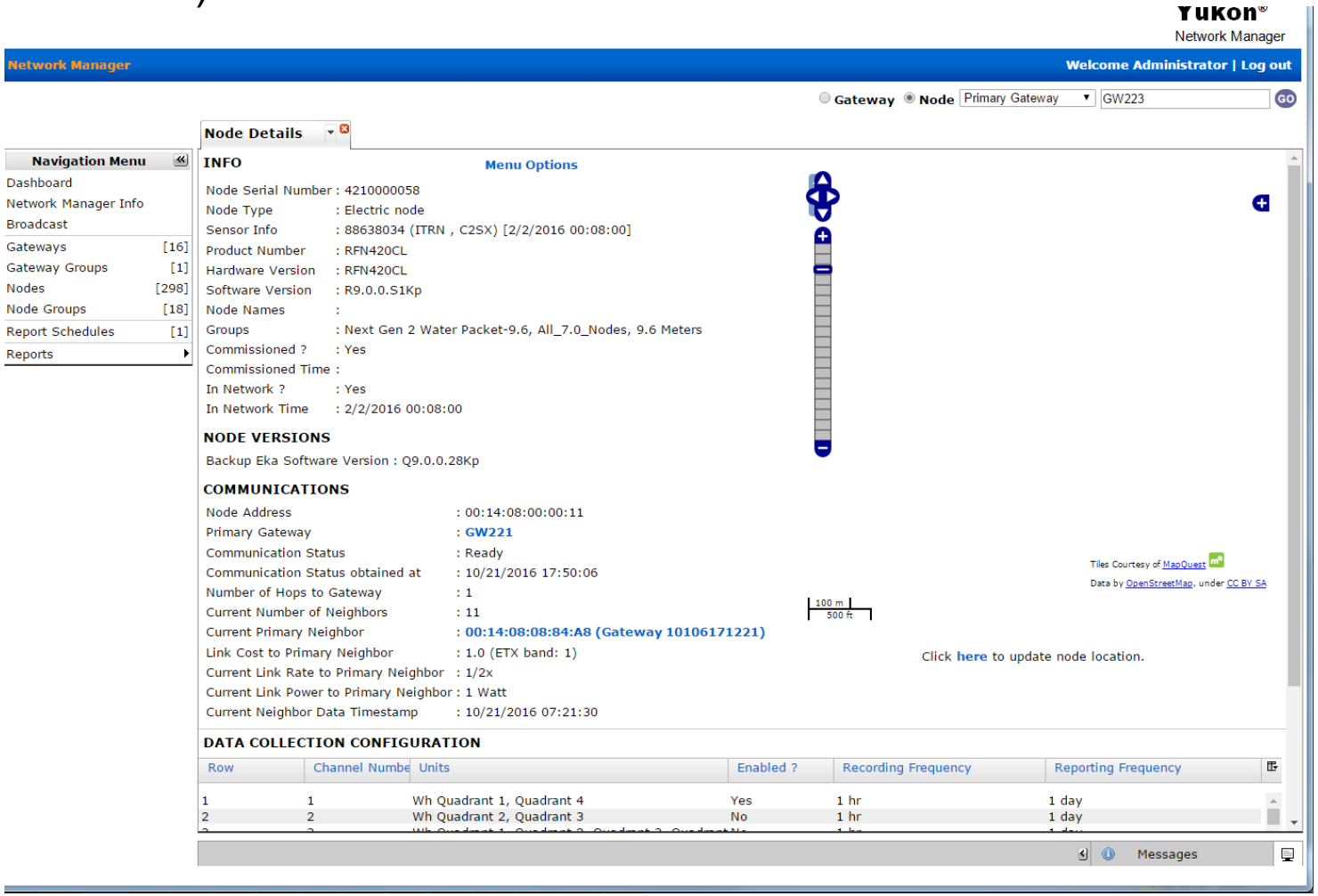
- Yukon has added features to display Network Information.
- If provided with GPS Coordinates, Yukon also provides mapping of the network topology overlaid on the physical location.





RF Network Troubleshooting

- Node Details screen gives a lot of information about the node (Node S/N, fw version, comms status, link cost, power, data rate…)



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RF Network Troubleshooting: Neighbors

Gateways | Search Results | Search Results | **Neighbors**

Row	Data Timestamp ▼	Neighbor Address	Link Cost	ETX Band	Current Rate	Current Power
4110000028						
1	4/29/2014 15:51:16	00:14:08:03:B0:38	1.2	2	1x	0.5 Watt
2	4/29/2014 15:51:16	00:14:08:04:B6:6B	1.0	2	1x	0.5 Watt
3	4/29/2014 15:51:16	00:14:08:04:08:60	1.0	2	1/2x	0.5 Watt
4	4/29/2014 15:51:16	00:14:08:04:5E:D1	1.0	2	1/2x	0.5 Watt
5	4/29/2014 15:51:16	00:14:08:04:03:58	1.0	2	1/2x	0.5 Watt
6	4/29/2014 15:51:16	00:14:08:01:DB:E7	1.0	2	1/2x	0.5 Watt
7	4/29/2014 15:51:16	00:14:08:04:60:19	1.0	2	1/2x	0.5 Watt
8	4/29/2014 15:51:16	00:14:08:03:4C:5F	1.0	2	1/2x	0.5 Watt
9	4/29/2014 15:51:16	00:14:08:06:4A:70	1.0	2	1x	0.5 Watt
10	4/29/2014 15:51:16	00:14:08:04:00:95	1.0	2	1/2x	0.5 Watt
11	4/29/2014 15:51:16	00:14:08:03:4C:B3	1.0	2	1/2x	0.5 Watt
12	4/29/2014 15:51:16	00:14:08:02:3F:F3	1.0	2	1/2x	0.5 Watt
13	4/29/2014 15:51:16	00:14:08:05:30:02	1.0	2	1x	0.5 Watt
14	4/29/2014 15:51:16	00:14:08:03:4C:67	1.0	2	1/2x	0.5 Watt
15	4/29/2014 15:51:16	00:14:08:03:5E:84	1.0	2	1/2x	0.5 Watt
16	4/29/2014 15:51:16	00:14:08:03:5F:A5	1.0	2	1x	0.5 Watt
17	4/29/2014 15:51:16	00:14:08:04:03:EC	1.0	2	1/2x	0.5 Watt
18	4/29/2014 15:51:16	00:14:08:04:1A:98	1.0	2	1/2x	0.5 Watt
19	4/29/2014 15:51:16	00:14:08:01:D2:E5	1.0	2	1/2x	0.5 Watt
20	4/29/2014 15:51:16	00:14:08:01:49:18	1.0	2	1x	0.5 Watt
21	4/29/2014 15:51:16	00:14:08:05:2F:F9	3.6	2	1x	0.5 Watt
22	4/29/2014 15:51:16	00:14:08:03:5E:8D	1.0	2	1/2x	0.5 Watt
23	4/29/2014 15:51:16	00:14:08:03:46:BA	1.0	2	1/2x	0.5 Watt
24	4/29/2014 15:51:16	00:14:08:03:47:CA	1.0	2	1/2x	0.5 Watt
25	4/29/2014 15:51:16	00:14:08:01:49:11	3.6	2	1x	0.5 Watt
26	4/29/2014 15:51:16	00:14:08:03:E2:A5	1.0	2	1x	0.5 Watt
27	4/29/2014 15:51:16	00:14:08:01:96:22	1.0	1	1x	0.5 Watt
28	4/29/2014 15:51:16	00:14:08:05:30:00	1.0	2	1x	0.5 Watt
29	4/29/2014 15:51:16	00:14:08:04:50:17	1.0	2	1/2x	0.5 Watt
30	4/29/2014 15:51:16	00:14:08:03:44:62	1.0	1	1x	0.5 Watt

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RF Network Troubleshooting: Routes

Gateways | **Routes**

Row	Data Timestamp ▼	Dest. Address	Next Hop Address	Hop Count	Cost	Flags
40	4/8/2014 22:33:52	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	2	PF,VR
41	4/8/2014 02:26:33	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	2	PF,VR
42	4/7/2014 22:32:04	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	2	PF,VR
43	4/7/2014 02:27:27	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	2	PF,VR
44	4/6/2014 22:31:05	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	2	PF,VR
45	4/6/2014 02:33:04	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	1	PF,VR
46	4/5/2014 22:31:32	00:14:08:03:5F:A5	00:14:08:03:5F:A5	1	1	PF,VR
47	4/5/2014 02:24:53	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
48	4/4/2014 22:29:43	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
49	4/4/2014 02:29:10	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
50	4/3/2014 22:34:08	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
51	4/3/2014 02:24:24	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
52	4/2/2014 22:34:45	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
53	4/2/2014 02:23:17	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
54	4/1/2014 22:26:40	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR
55	4/1/2014 02:22:53	00:14:08:03:44:62	00:14:08:03:44:62	1	2	PF,VR

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RF Network Troubleshooting

Issue: Meter not joining the network

- Multiple step process:
  1. Perform a current meter reading Over The Air (OTA) using Field Tool to verify the meter is individually operational
  2. Retrieve neighbor table of node using Field Tool
  3. Check if this node appears as a neighbor of a nearby node that's already in the network. If not go to Step 6
  4. Verify ETX Band for this node at all neighbors
  5. If ETX Band is 4 or above with all neighbors, go to Step 6
  6. Reinforce infrastructure for this node

RF Network Troubleshooting

Issue: Node reporting Communications Status “Not Ready”

- Backhaul connection may be down
- Not Ready may be a temporary condition because a node is in the process of switching to a new Gateway OR a firmware upgrade is in progress
- If node continues to be Not Ready for 24 hours or more:
  - Check Node logs:
    - If data reports are being sent, node is able to communicate with its neighbors
    - Original route to Gateway is reforming or has an issue

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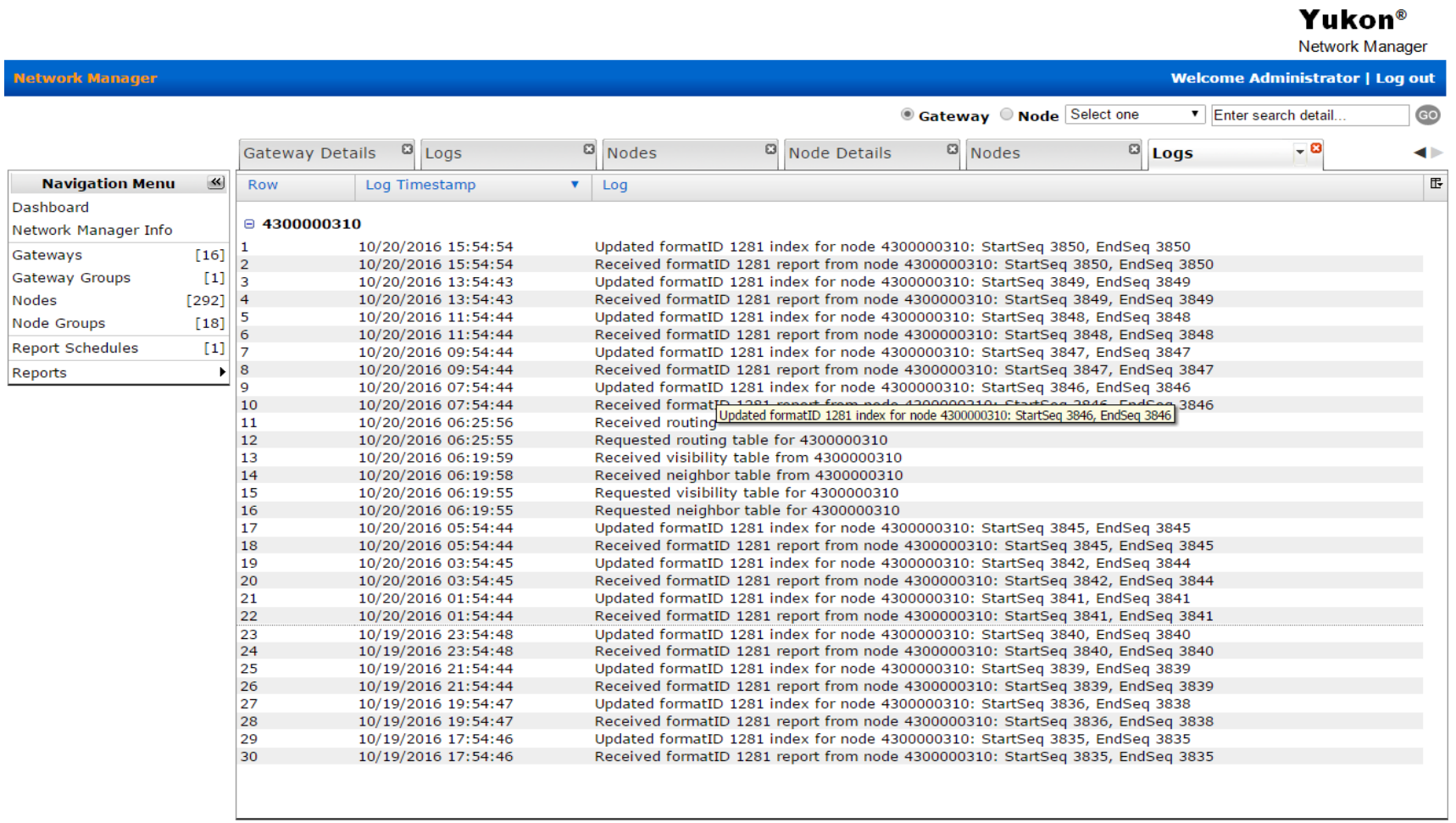
RF Network Troubleshooting

- Node logs



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RF Network Troubleshooting

Issue: Node reporting Communications Status “Not Ready”

- If there are no data reports from the node for 3 days:
  - Check Routing table of Node to determine last known Primary Forward Node
  - Locate the Primary Forward in the node’s neighbor table and check its link cost.
  - Review the link cost history of this node in the Primary Forward node’s neighbor table
  - If the link cost has degraded, the node may be in the process of switching to another Primary Forward.
  - Review the problem node’s neighbor table to verify link costs with other neighbors
  - If all neighbors have degraded link cost, visit the node to verify OTA with Field Tool

RF Network Troubleshooting

Issue: Node data intervals not received

- Nodes report their interval data periodically (usually every 24 hours) with each Interval Record (usually 15 minutes)
- Data points can be seen from the Network Manager Node Details -> Data Points for a selectable date range
- If the node is in “Ready” state and interval data is received with missing dates (i.e. gaps)
  - Network may be busy and RFN Gateway may be gap filling. It will catch up and fill the missing intervals

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RF Network Troubleshooting

Issue: Node data intervals not received (cont'd)

- If the node is in "Ready" state and no reports are received for more than several days then it should be diagnosed for other root causes:
  - Check the NTP configuration at the Gateway. Nodes will not report interval data if they haven't received time sync from the gateway
  - RF Network manager and gateway communications can be checked from NM
- If the node is in "Not Ready" state then diagnose the "Not Ready" cause

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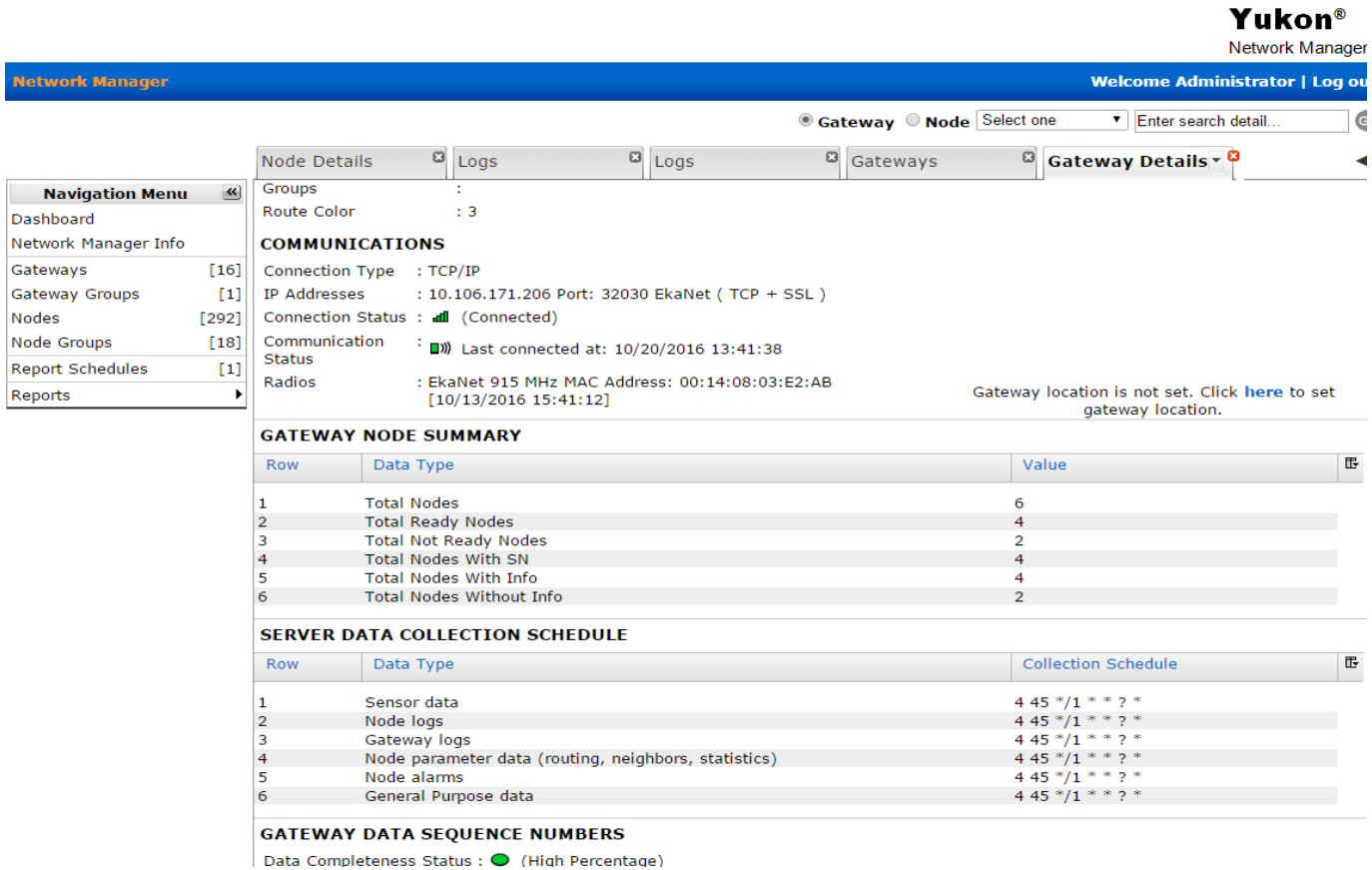
RF Network Troubleshooting

Issue: All of the above (Node not joining, NOT-READY, missing data)

- Check if Gateways are running within capacity
  1. From NM, list nodes under the a gateway and verify that the total number of nodes is not too close to its maximum capacity (configured parameter during deployment. Ask Customer Service for your network's setting)
  2. Gateway logs in NM having too many entries of 'Received Message from Unknown Node' – is another indication of Gateway running out of capacity
  3. If gateway capacity issue is verified, evaluate infrastructure, and decide on gateway addition or relocation.

RF Network Troubleshooting

- Node list under a gateway



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Support Slides

Acronyms

AMI Advanced Metering Infrastructure	**OS** Operating System
APN Access Point Name	**OTA** Over The Air
DA Distribution Automation	**PLC** Power Line Carrier
DR Demand Response	**QoS** Quality of Service
ETX Expected Transmission Count	**RF** Radio Frequency
E2E End-to-End	**SG** Smart Grid
EV-DO Evolution Data Optimized	**RFN** RF Network
HSPA High Speed Packet Access	***TCP*** Transmission Control Protocol
GW Gateway	**UDP** User Datagram Protocol
IP Internet Protocol	
LCR Load Control Relay	
M&C Monitoring and Control	

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RFN Gateway

- Network Bridge between RF wireless mesh and IP wide area network
- Automatic RF mesh node registration and discovery
- Temporary repository and gap filling for delayed or missed mesh network data for reliable communications

- RF mesh network time synchronization
- RF mesh node firmware upgrade management
- Secure SSL communications
- Wired and wireless backhaul support
  - 10/100 Ethernet
- Onboard backup power for Outage
- Optional enclosure with UPS

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RFN Electric Nodes

- AMI: Landis+Gyr, Itron, Sentinel, Elster (and others)

- Demand Response: LCR-6200, LCR-6600, LCR-6700

- Distribution Automation: RFN-1200

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RFN Electric Nodes

- Up to 1 Watt power
- Multiple data rates (9.6, 19.2, 38.4, 76.8, and 153.6 kbps)
- Secure communications
- Protocols (C12.18, C12.19, Itron blurt, DR and DA protocols)
- Support two-way unicast and broadcast messaging
- Advanced Metrology Support
- Event and alarms
- Voltage profiling
- OV/UV alarms
- Blink Count, Outage
- Remote Disconnect
- Secure RSA signed Over The Air (OTA) firmware upgrades

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RFN Battery Nodes

- Power 100mW to ¼ Watt
- Support multiple water registers (Badger, Elster, Itron, Neptune, Master, Mueller, Sensus, Zenner, Metron Farnier)
- Support for multiple gas registers (Honeywell, Sensus, etc)
- Connect to the network through nearby Electric or Relay node
- OTA firmware upgrade

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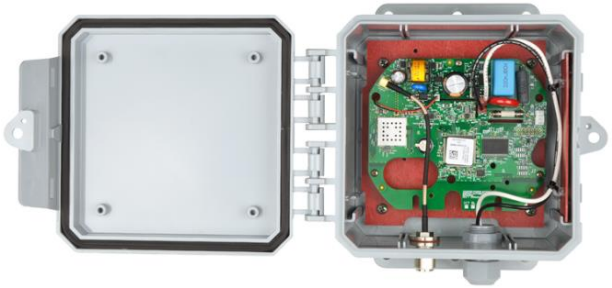
RFN Relays

- Used to build out infrastructure to form robust mesh
- Extend RF communications into rural areas
- Build out communications network for DR, C&I or water metering before residential AMI meters are installed
- Large ultra-capacitor for outage support
- Currently 4 versions
  - RLY-806: 120-480VAC, attached external antenna or remote external antenna
  - RLY-851: 120-277VAC, internal antenna for quick deployment
  - RLY-853: 12VDC, solar energy harvesting relay
  - RLY-856: 120-277VAC, attached external antenna or remote external antenna



RLY-806

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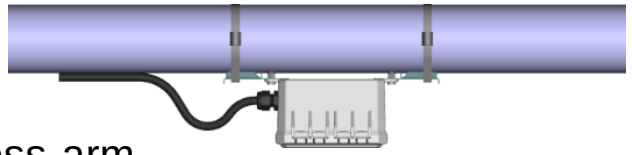
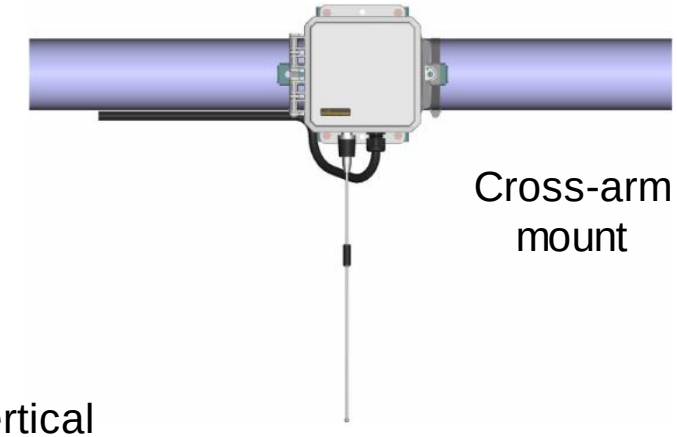
RFN Relays

- Various mounting options



Cross-arm mount

Pole vertical mount



Cross-arm mount

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RFN WiFi Node

- Connects over IP to a service on the backend along with Yukon and Network Manager
- Behaves in the RFN as a 1-hop node to the gateway
- Supports the C2SX meter

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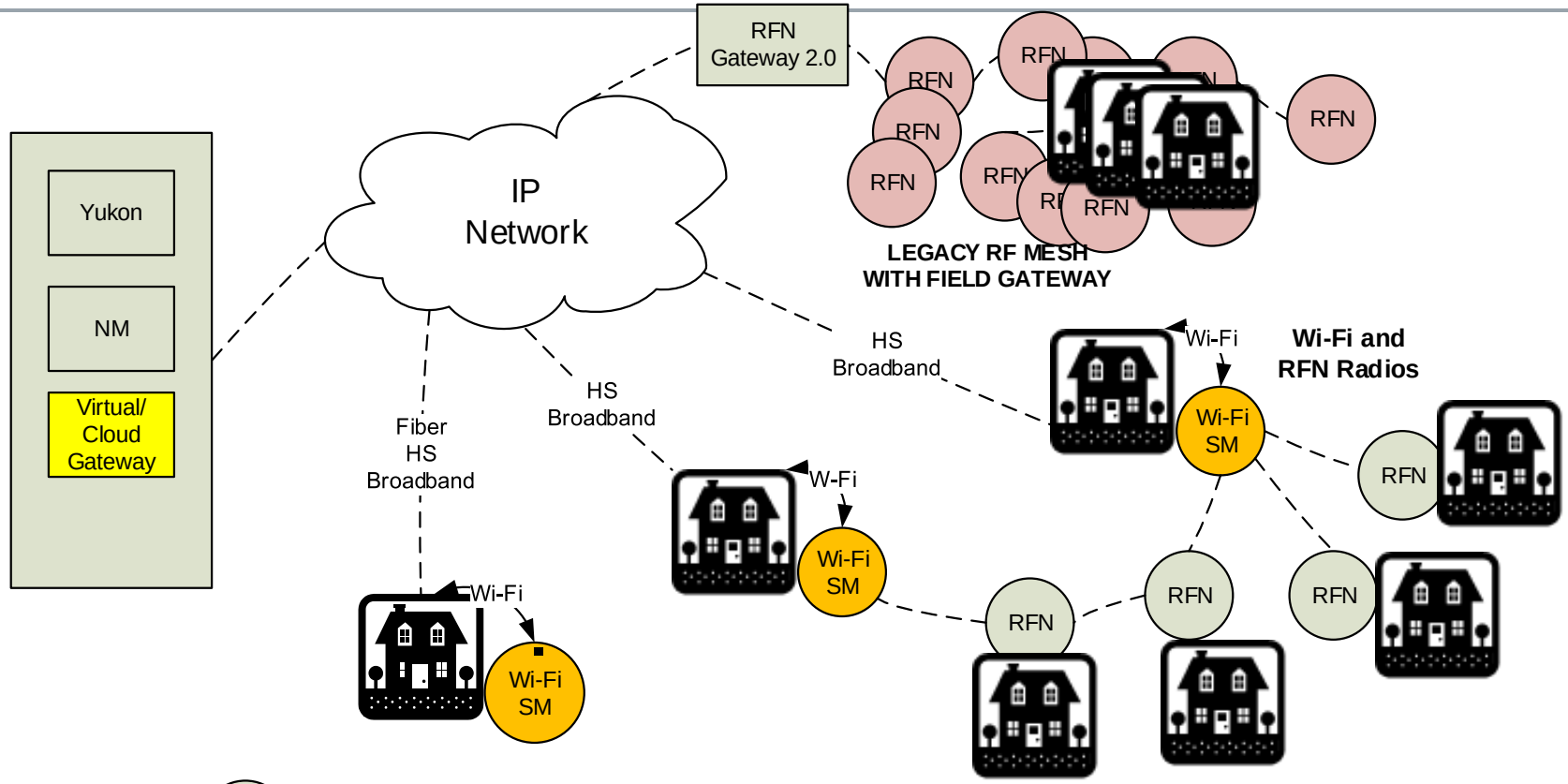
RFN WiFi Node



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RFN Network Runner

- Provides configurations and diagnostics field support
- RF Radio up to 1Watt with multiple data rates (9.6, 19.2, 38.4, 76.8, 153.6 kbps)
- Functions
  - Gateway Configuration
  - GPS provisioning for RF nodes
  - Meter management
  - LCR management
  - Water Commissioning
  - Node Firmware Upgrade
  - Network Diagnostics

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Metrology and Configuration

- Residential Meters with Advanced Metrology
  - Itron C1SX, C2SX & L&G Focus
  - Advanced Metrology provides additional features to inexpensive residential meters
    - Demand calculation based on consumption
    - TOU recording with configurable schedules
    - Capability to configure TOU schedules and demand interval from Yukon
- C&I ANSI meters
  - Elster A3, Itron Sentinel & L&G S4X (future)
  - RFN Node reads configuration from meter

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Meter Configuration

- Factory Configurable Items
  - Time Zone & DST
  - Recording and Reporting Intervals
  - Outage Reporting Parameters
  - C1SX & C2SX Display configuration
    - Metrics, # of digits, display cycle & disconnect state
  - Focus AL Display configuration
    - Metrics, # of digits, display cycle
  - TOU Schedules (Advanced Metrology only)
  - Demand Calculation Interval (Advanced Metrology only)

Yukon Meter Configuration

- Device Configurations are used to assign sets of configurable items to groups of meters
- Be careful when changing or assigning device configurations to large groups of meters
- Yukon Configuration Items
  - C1SX and C2SX Display configuration
    - Select metrics to display
    - # of display digits
    - Display cycle time
    - Disconnect status (C2SX only)
  - Focus AL display configuration

Yukon Meter Configuration

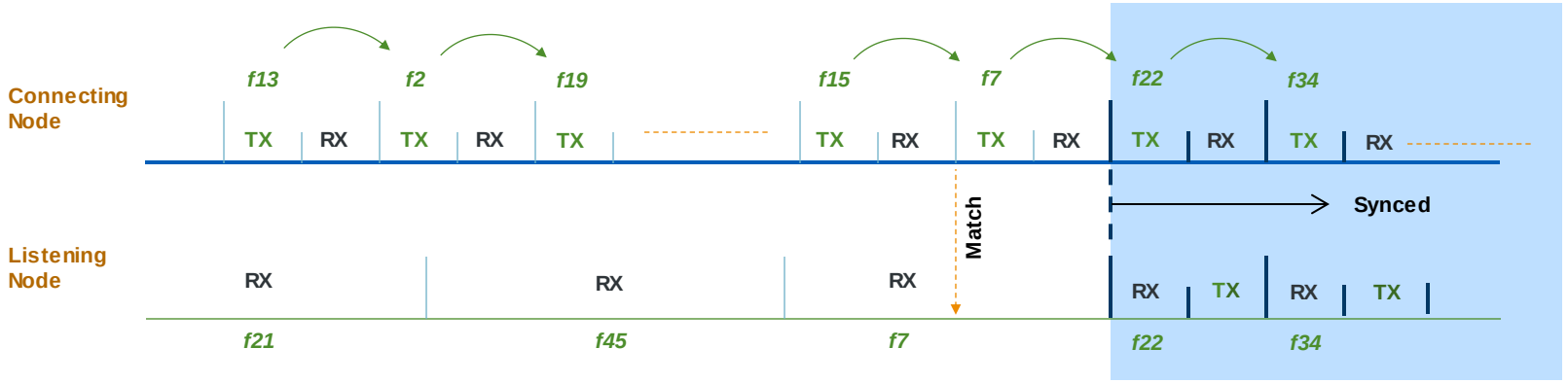
- Set demand interval (C1SX, C2SX, Focus)
- Set TOU schedules (C1SX, C2SX, Focus)
- Set remote disconnect configuration (C2SX & Focus AX)
- Set demand freeze date
- Metric Channel Configuration
  - Select metrics for interval recording
  - Select metrics for daily recording
  - Select interval recording and reporting time
- Set temperature alarm configuration
- Set OV/UV configuration
- Set voltage profile configuration

Remote Disconnects

- Disconnect Modes
  - On-Demand Disconnect
    - Disconnect, Arm and Reconnect
  - Load Limiting Disconnect
    - Delayed Reconnect and Immediate Reconnect
  - Cycling Disconnect
    - Off Cycle Time Can Be Different Than On Cycle Time

Frequency Hopping

- Frequency hopping enables the co-existence of multiple networks
- Hopping reduces interference due to reflection, noise and other environmental factors
- Hopping is an FCC requirement for operation on unlicensed band at 1 watt.
- The method transmits radio signal across multiple channels in a pseudo-random sequence known by the sender and receiver



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Frequency Hopping (cont'd)

- Suitable to cover larger areas where numerous co-located systems are needed
- Eaton's RF mesh nodes use 50 hopping channels per second. Uses algorithm for generating pseudo-random channels
- Eaton's RF mesh radios improves connection time using Knuth shuffle algorithm and other patented techniques such as predictive synchronization

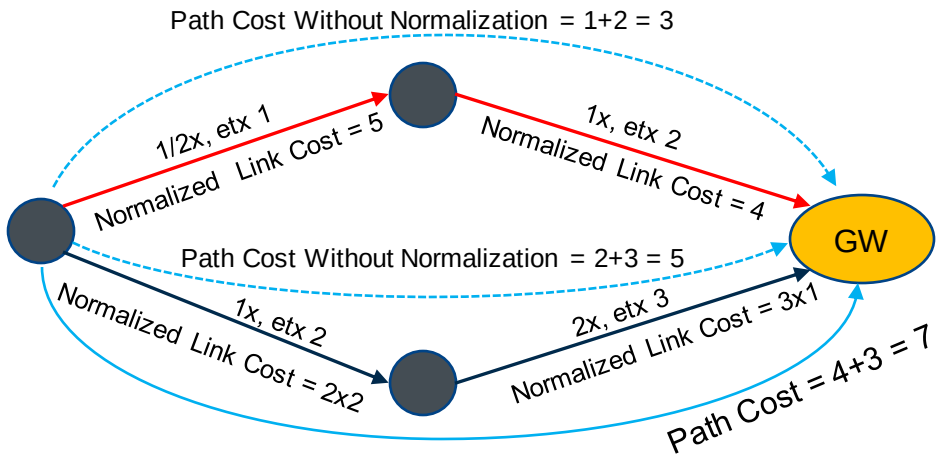
Communications Range: Link Budget

- Combining all of the above factors -> Link Budget
  - Way of quantifying the link performance or effective range
  - TX power - (- RX Sensitivity) – Path losses = Link budget
  - Traditionally, a link budget has some amount of margin (extra capacity)

Multirate and Cost Normalization

- The link cost between node and its peer is normalized based on rate
- Supported rates = 1/8X, 1/4X, 1/2X, 1X, 2X
  [9.6, 19.2, 38.4, 76.8, 153.6 kbps]
- Lower rate = Lower Throughput = Higher Cost
- Normalization factor = rate throughput ratio

Example: In a system where 2X rate is available, the link cost at 1X rate is multiplied by 2 for normalization.



Throughput Ratio	
2x:1x	2.0
1x:1/2x	2.5
2x:1/2x	5.0

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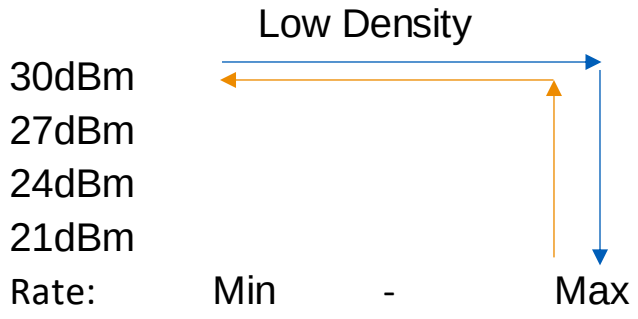
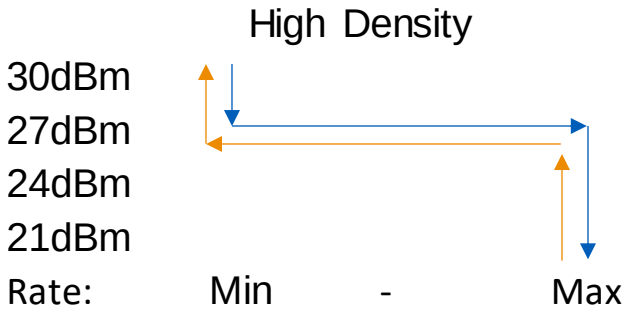
Power Adaptation

- Typically support 4 power level for electric meters and relays
  - 21dBm, 24dBm, 27dBm, 30dBm
- Depends on network/device configuration
- Samples candidate power on each neighbor to evaluate the link independently
- Uses the highest power level only at the minimum rate in a high density environment
- Adjusts density based on number of surrounding devices it can receive broadcasts from





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Network Simulation

- Allows the network interaction across a large population of devices to be simulated
  - Up to ~40,000, shortly simulating over ~100,000
- Varies topology to produce different loading
- Memory monitoring and address sanitization
- Future efforts include link simulation and importing network topology for simulation

Neighbor Table Flags

- **PF** – Primary Forward
- **PR** – Primary Reverse
- **S1** – Secondary neighbors, serving GW
- **S2** – Secondary neighbors, alternate GW
- **F** - Float Neighbor
- **BN** – Battery neighbor
- **IN** – Ignored neighbor (Field- tool)

Visibility Table Flags

- **S1** – Secondary neighbors, serving GW
- **S2** – Secondary neighbors, alternate GW
- **V1** – Visible neighbors, serving GW
- **V2** – Visible neighbor, alternate GW