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The Field Area Network (FAN)

“Smart Grid” second wave brings critical infrastructure for utility communications

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Topics

- Introduction: EPRI, utilities, communications
- Background: legacy and “first wave” applications
- “Second wave”: focus on critical comms infrastructure
- Towards robust unlicensed / lightly licensed systems
- Towards resilient 4G-based systems
- Modeling cost and other practical aspects
- Q&A and discussion

Electric Power Research Institute (EPRI)

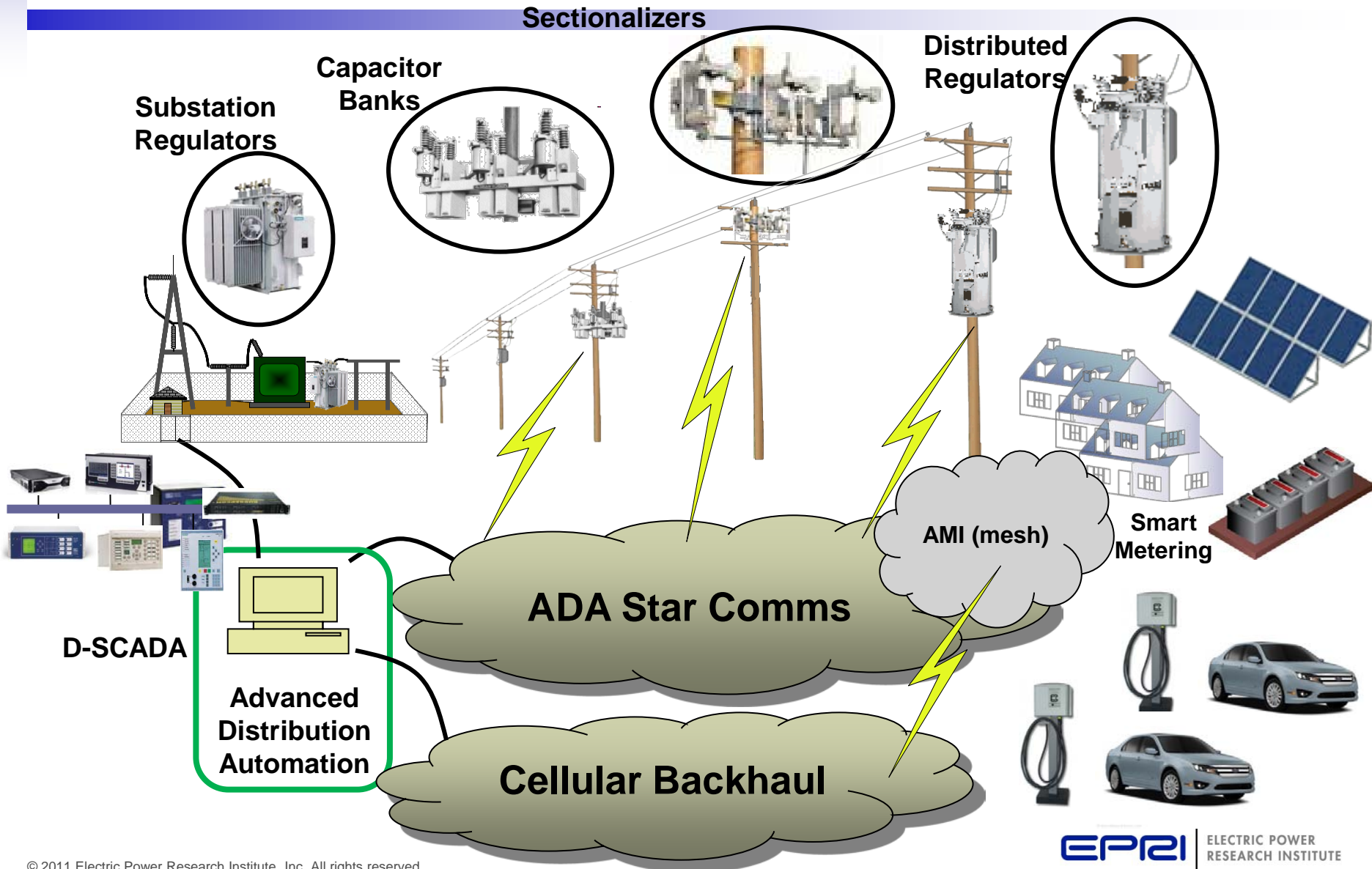
- Founded by and for the electricity industry in 1973 as an independent, nonprofit center for public interest energy and environmental research
 - EPRI utility members represent >90% of electricity generated in the USA
- Collaborative resource for the electricity sector
 - ~\$350M annual R&D funding, ~18% international members, participants in more than 40 countries
 - 470 engineers and scientist, offices in Palo Alto, CA, Charlotte, NC & Knoxville, TN. Labs in Charlotte, Knoxville and Lenox, MA
- Four major R&D portfolios: Nuclear, Generation, Environment, and Power Delivery & Utilization
- Cross-cutting IntelliGrid Program coordinates and manages Smart Grid projects, including comms



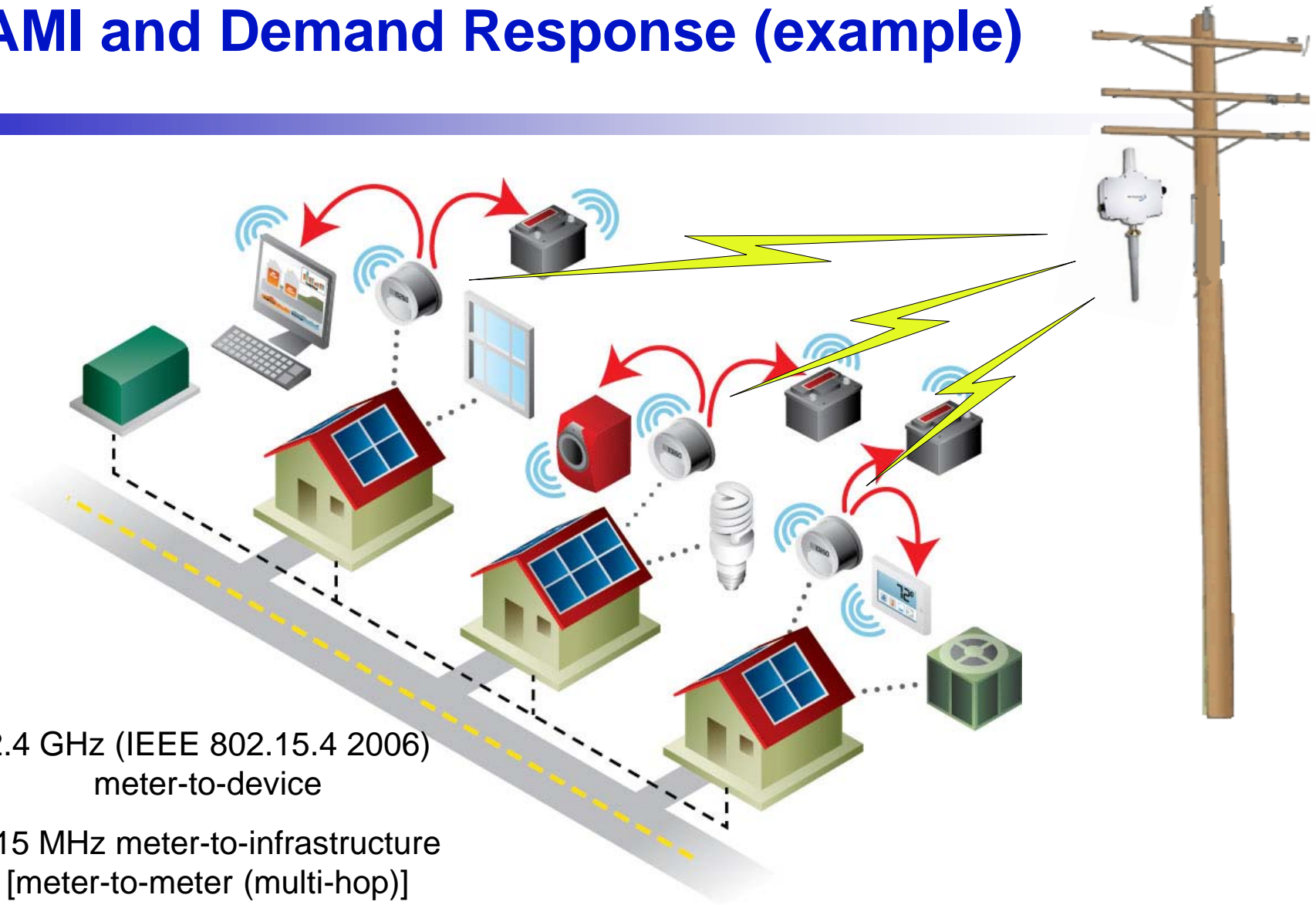
Field Area Network Overview

- Field Area Network - FAN
 - Ubiquitous, broadband wireless resource
 - Meets stringent utility requirements for reliability, resilience
 - Designed to support *all* current and anticipated applications
- Integration of legacy and “First Wave” Smart Grid applications ..
 - Distribution Management Systems – DMS (SCADA)
 - Advanced Metering Infrastructure, Demand Response, Distributed Energy Resources (incl. PHEV charging)
- .. with “Second Wave” Smart Grid applications
 - Advanced Distribution Automation: Fast fault location, recovery, and automated sectionalization; Conservation Voltage Regulation; Volt/Var control; Power Quality controls; etc.
 - Fine grained load profiling and control of Distributed Energy Resources, including roaming DERs (EV charging)
 - Integrated field operations and support, mobile data, voice (VoIP)

Background: legacy & “first wave” applications



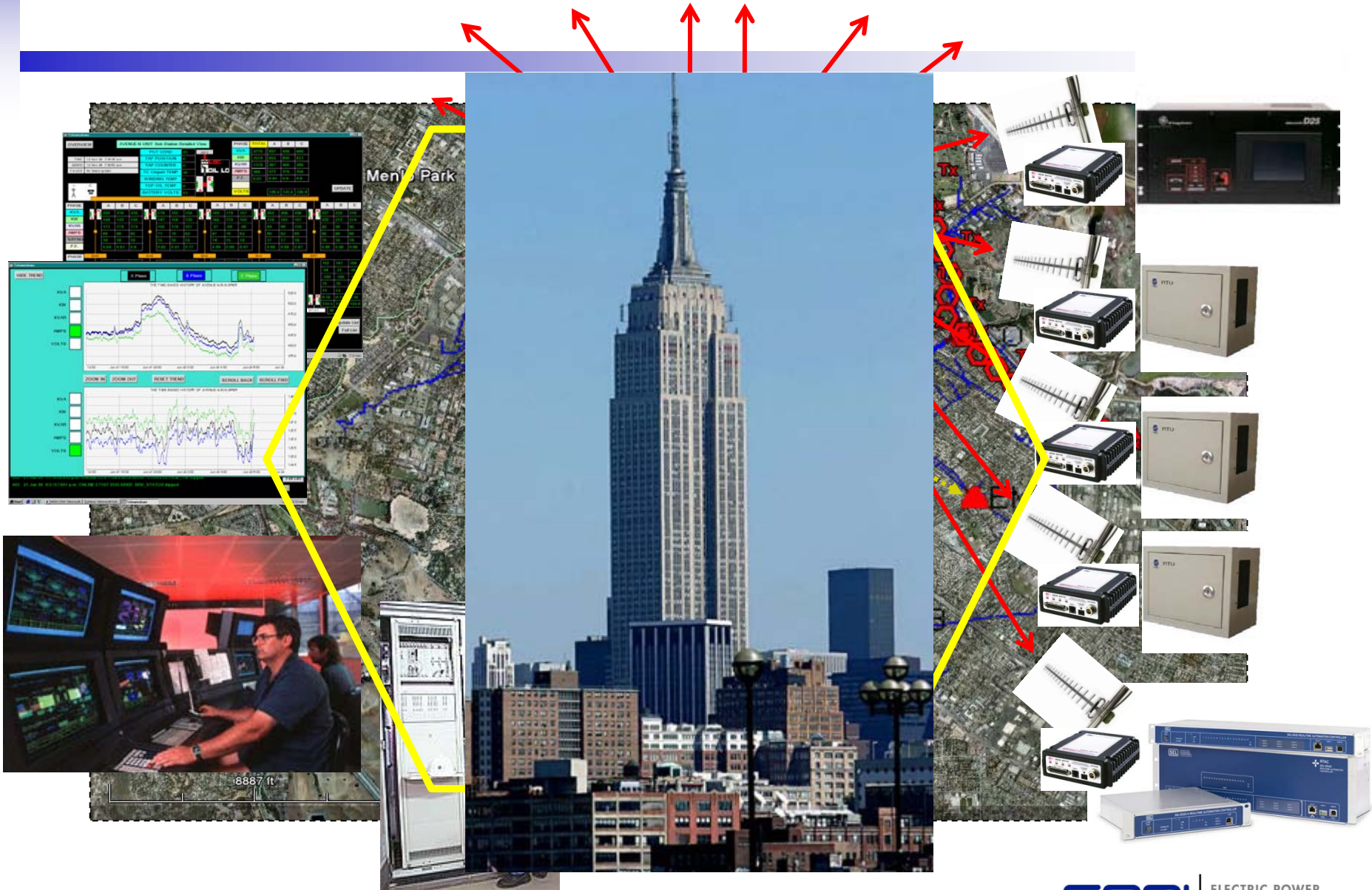
AMI and Demand Response (example)



2.4 GHz (IEEE 802.15.4 2006)
meter-to-device

915 MHz meter-to-infrastructure
[meter-to-meter (multi-hop)]
(proprietary, going to 802.15.4g/e)

Stars ...



... and Bars



Background: AMI



Centralized Star
(Attempt to scale D-SCADA)

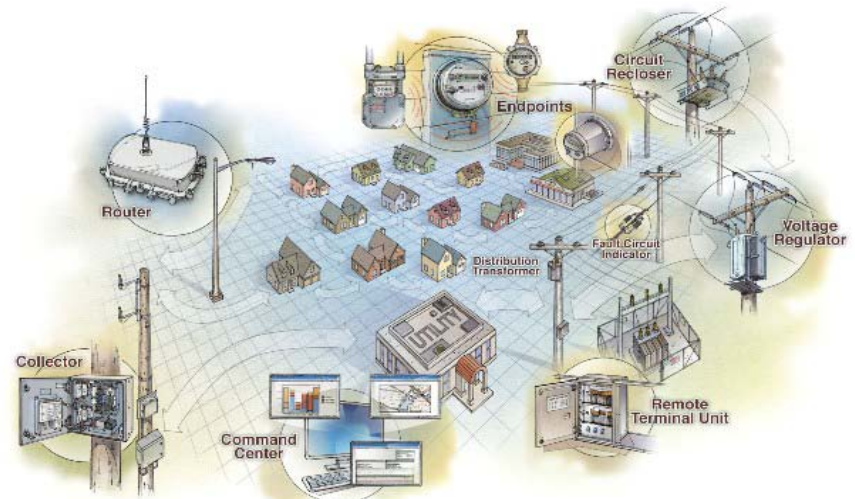
Trilliant

elster
Leading the World
in Metering Technology

SILVERSPRING
NETWORKS

Landis
Gyr+
manage energy better

Cellular
backhaul



Low-power mesh with backhaul

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AMI, DR, and the “first wave”

• Strengths

- Supports communication (direct or indirect) with the customer (energy consumption, messages, “soft” or “hard” Demand Response)
- Addressed what was thought (ca. 2007) to be the most pressing utility requirements: peak shaving through price signals, move-in/move-out, etc.
- Lowest barrier to entry (no license needed)

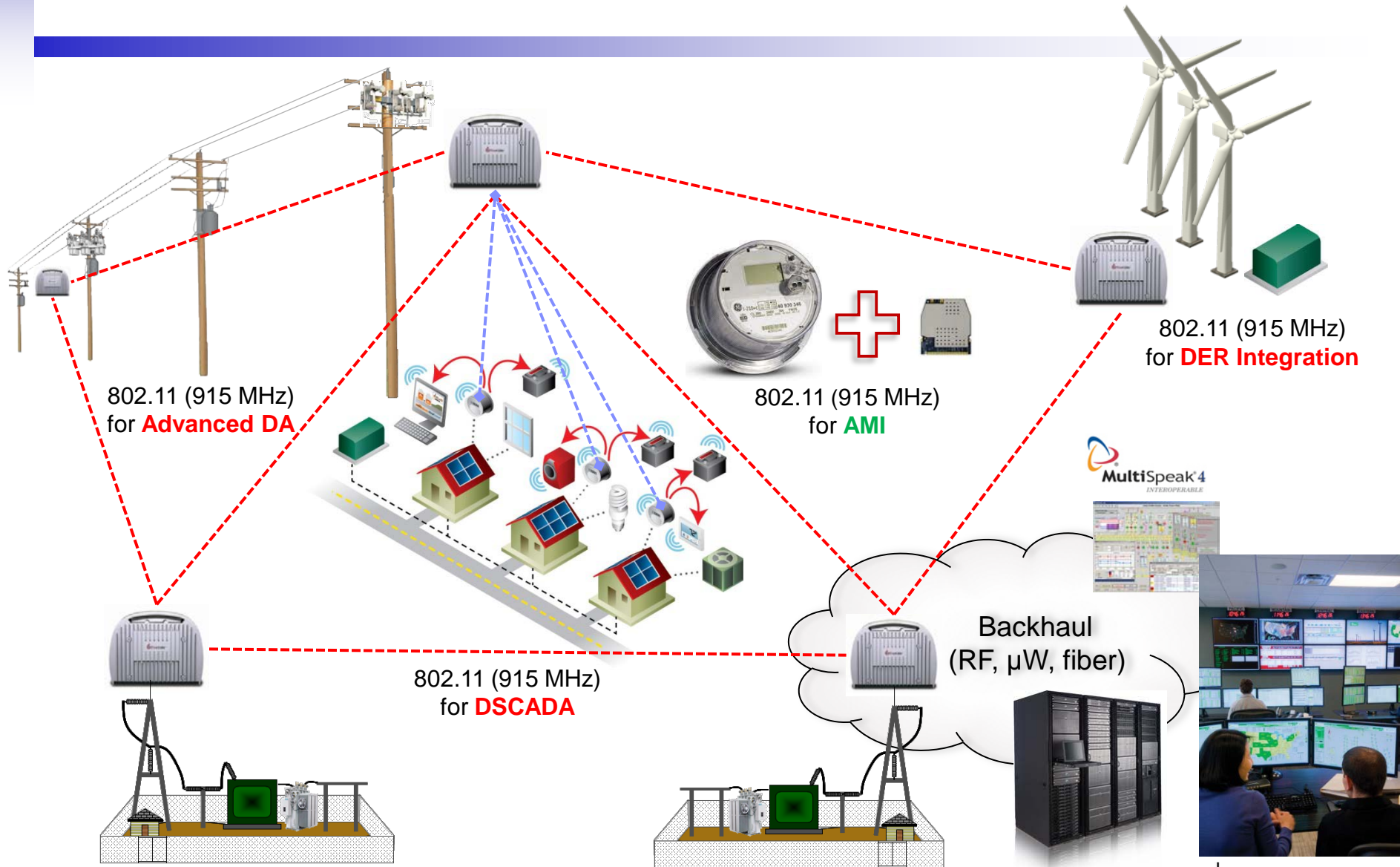
• Challenges

- Not as scalable as expected, desired (waiting for OFDM)
- Limited resources (bandwidth, throughput, compute power), a challenge for security, firmware upgrade, etc.
- Not obviously extensible to other applications (Distribution Automation, volume integration of DERs, etc.)
- Potentially challenged by other services deployed in the 915 MHz ISM band (modeling would help)

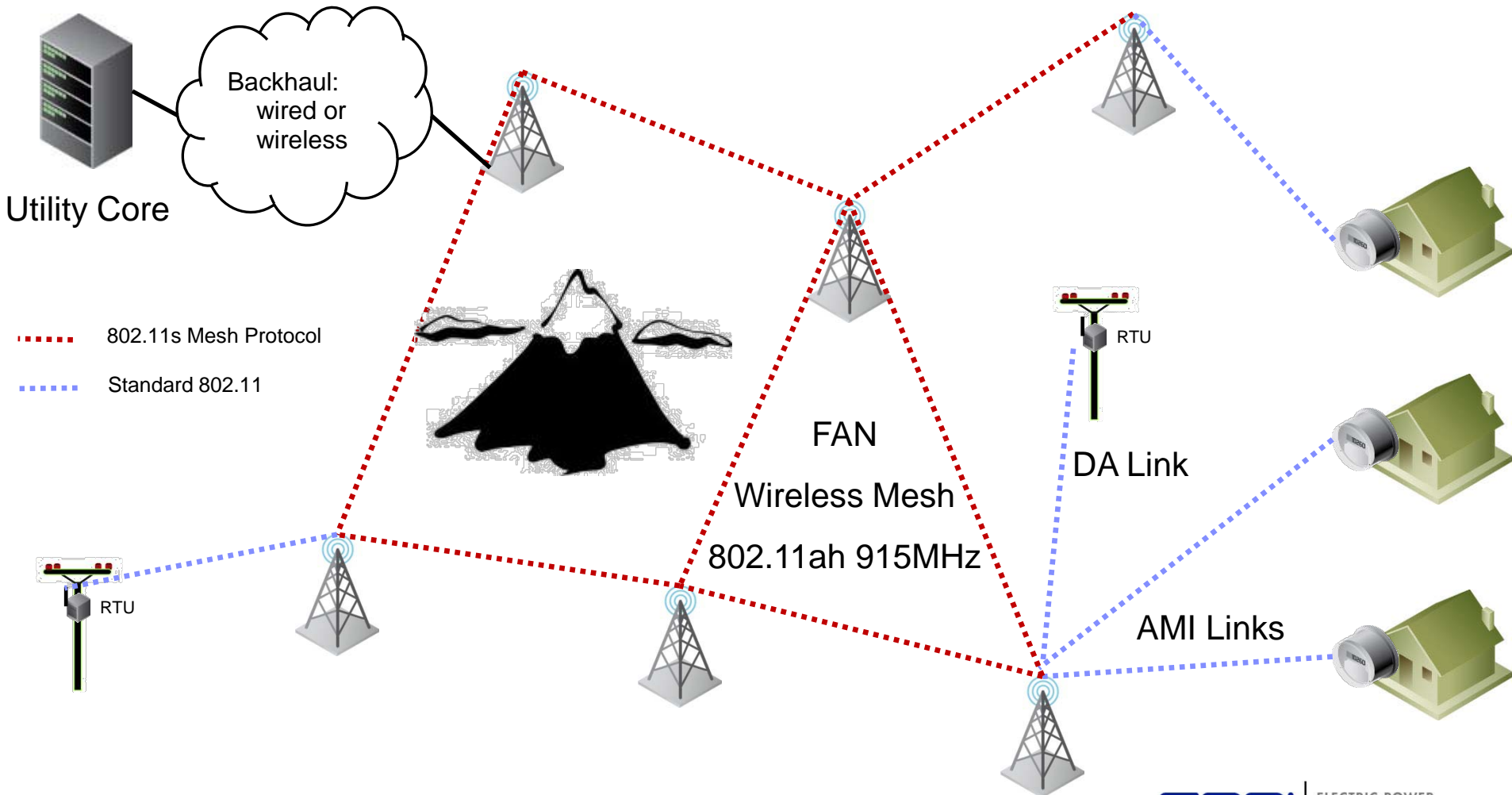
Towards robust unlicensed / lightly licensed systems

- Key concepts
 - Use multiple unlicensed bands to mitigate interference
 - 802.11n using 915 MHz, 2.450 GHz, 5.800 GHz (ISM)
 - Use frequency agility (3.65 GHz, TV Whitespace, ...)
 - Benefit from & drive innovations in wireless standards (IEEE 802, DySPAN) and technology (CR, SDR)
- Major challenges for utilities and vendors
 - Standards and technology timing, availability, commitment
 - Example, standards: 802.11y? 802.16h? 802.22? 802.11af?
 - Managing risk over space and time
 - Interference almost always increases almost everywhere!
 - Very large number of mesh nodes
 - Requires sophisticated network and element management

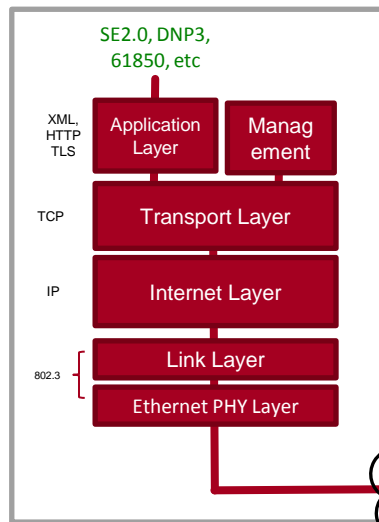
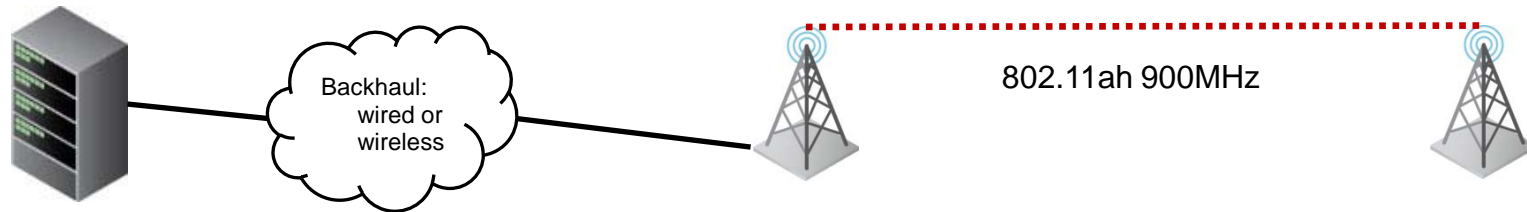
Concept: Industrial Wi-Fi (unlicensed) FAN



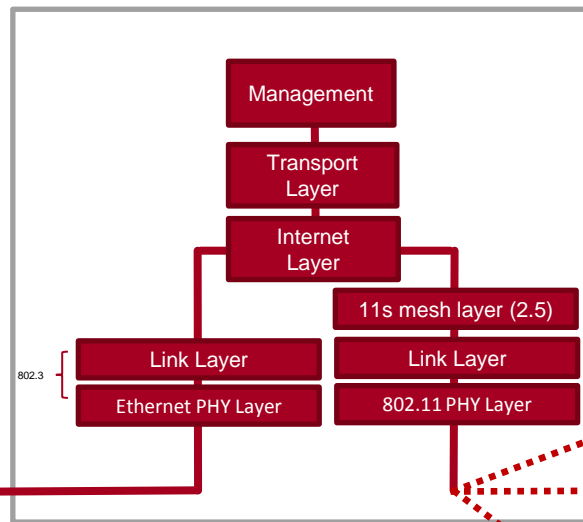
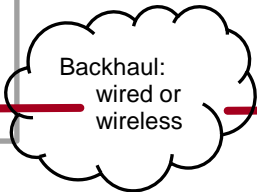
Industrial Wi-Fi: Overall Architecture



Industrial Wi-Fi: Back-end to FAN

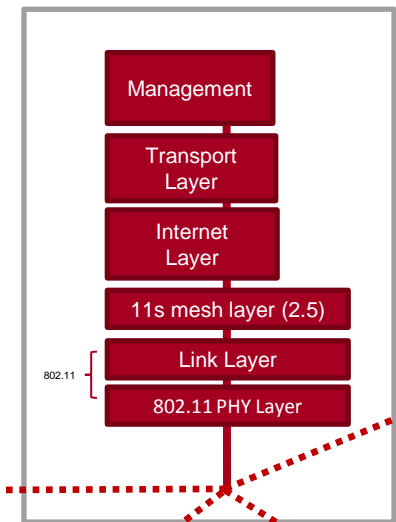


Utility Core



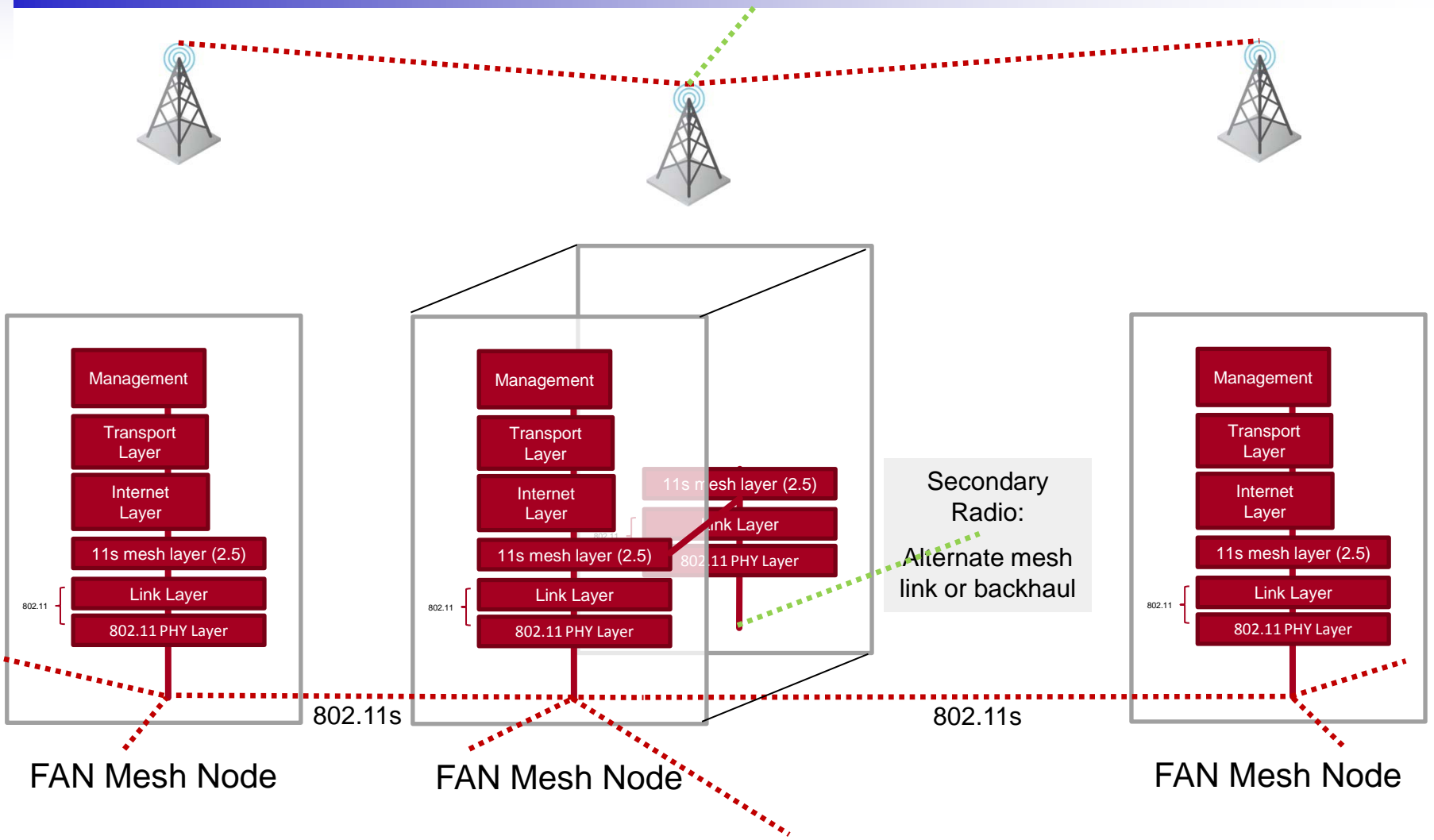
FAN Mesh Gateway Node

802.11s

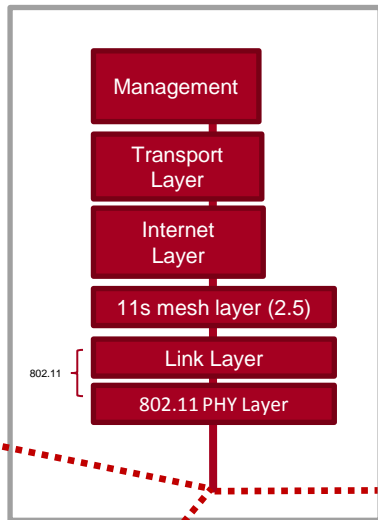
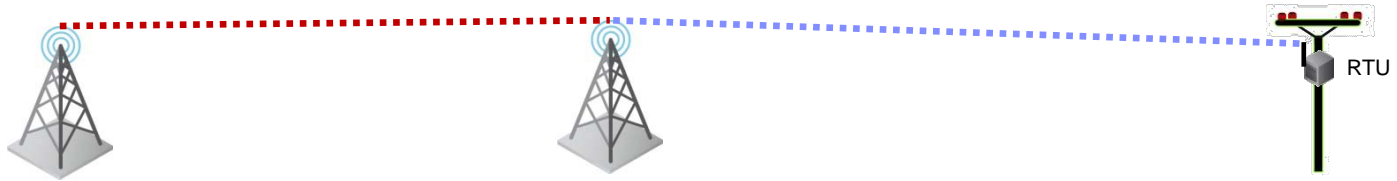


FAN Mesh Node

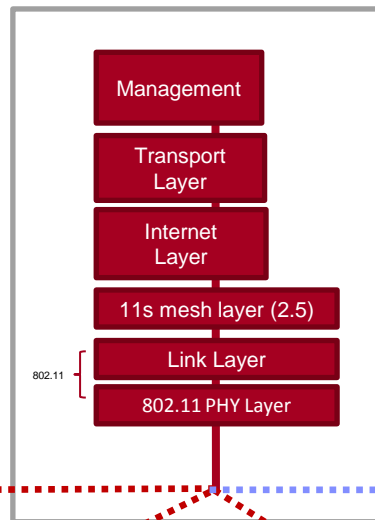
Industrial Wi-Fi: FAN to FAN (intra-mesh)



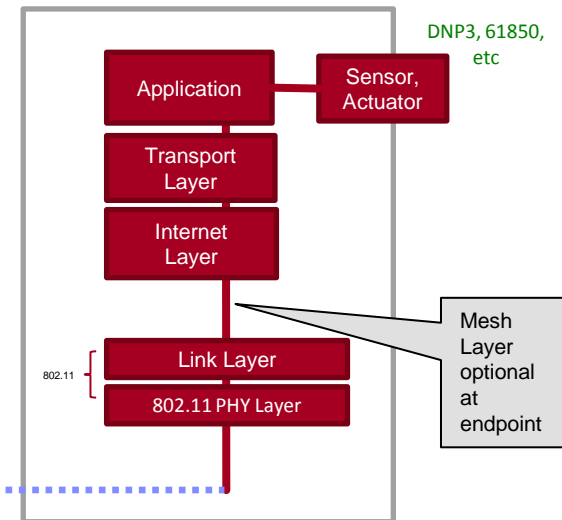
Industrial Wi-Fi: FAN to RTU



FAN Mesh Node



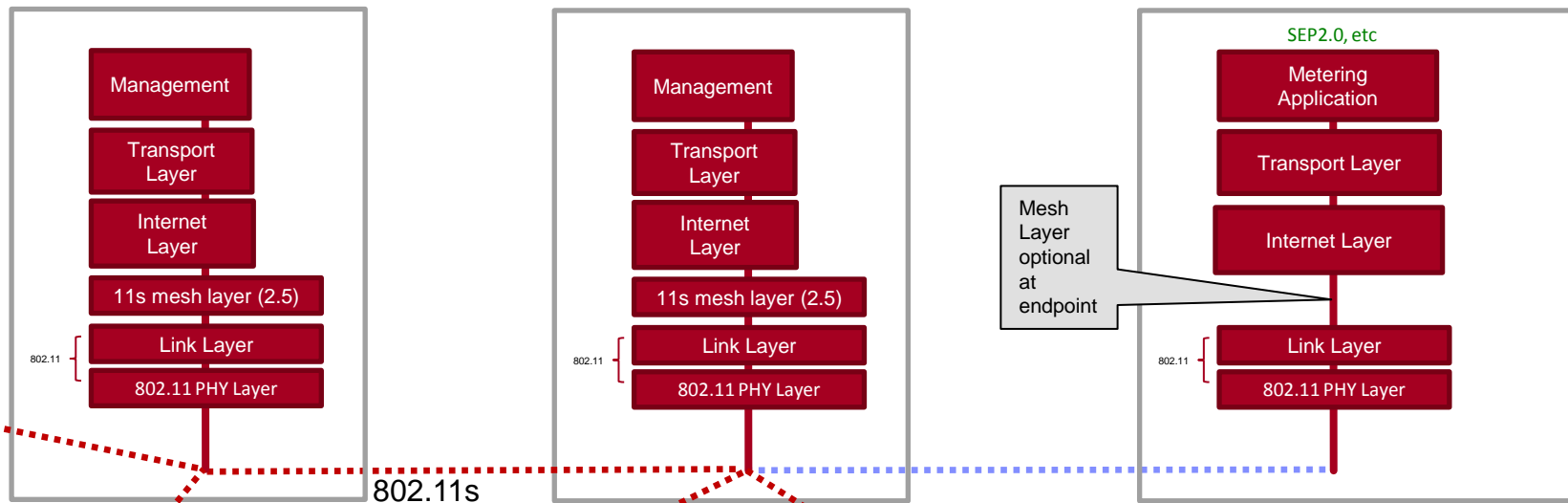
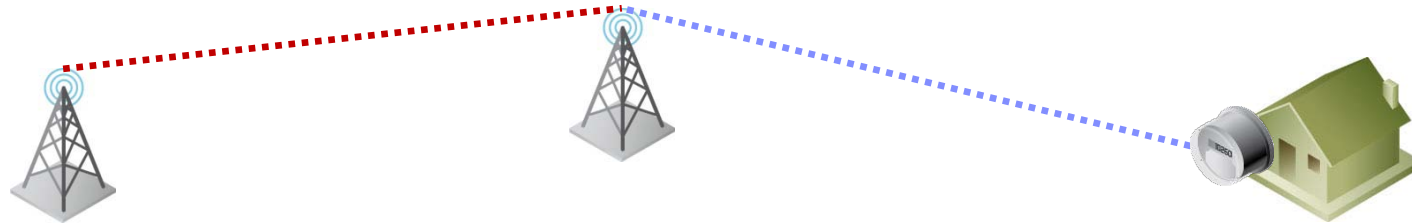
FAN Mesh Node



FAN End Node

802.11s

Industrial Wi-Fi: FAN to AMI



FAN Mesh Node

FAN Mesh Node

FAN End Node

Towards reliable, resilient 4G-based systems



• WiMAX

- Mature technology
- Rich ecosystem of vendors & services
- Fairly flexible, agile standards group
- Could merge with LTE

• LTE

- Powerful market force
- Mandated for Public Safety (700 MHz)
- Dominated by carriers
- Slower to develop M2M capabilities

FAN Reliability

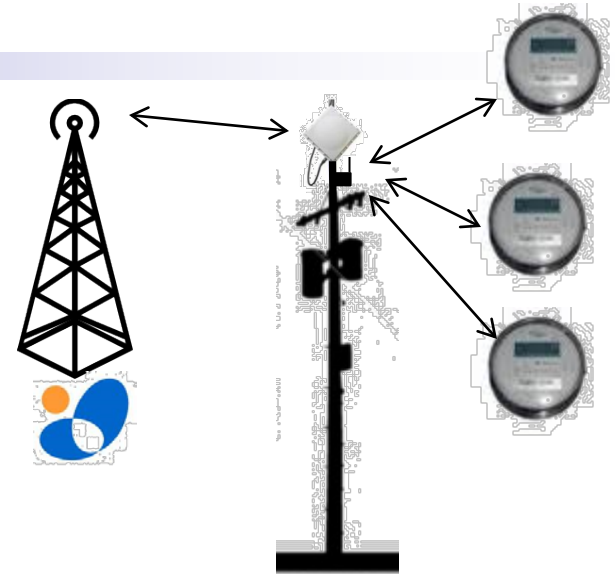
- Redundancy – today’s approach, seems sub-optimal
- Architecture – discrete elements vs. embedded reliability
- Cost Implications – CAPEX but also OPEX
- Public carrier vs. private utility infrastructure

- Approaches to Smart Grid network reliability
 - SG Network Node (DAP) (‘extrinsic’ reliability)
 - Resilient cellular infrastructure (‘intrinsic’ reliability)
 - New architecture for public or private networks

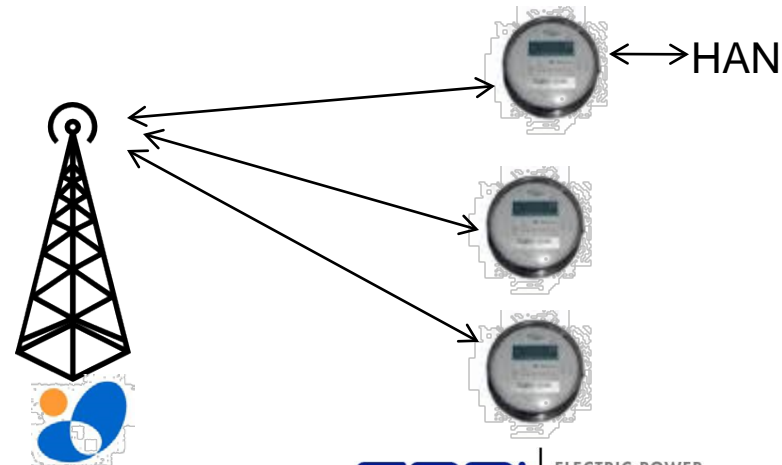
- EPRI Industry Technology Demonstration Project
 - Utility trials and evaluation of reliable FAN architectures

FAN applications for Smart Grid (AMI)

- AMI backhaul
 - AMI links to collector
 - Using 802.15.4g or other
 - Collector contains WiMAX device



- Direct AMI / HAN
 - Smart Meter contains WiMAX device
 - Possible Gateway to HAN



FAN applications for Smart Grid (Support)

- Field Operations Support
 - Mobile voice
 - LMR or cellular replacement
 - Longer term
 - Mobile data
 - Maps, manuals, reference documents
 - Consolidation of multiple networks on one infrastructure
- Transportable Base or Relay station
 - Create “hot spot” in high activity zones
 - Supplement coverage in difficult areas (vaults, etc)



Disclaimer...

“At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.”

IEEE-SA Standards Board Operation Manual (subclause 5.9.3)

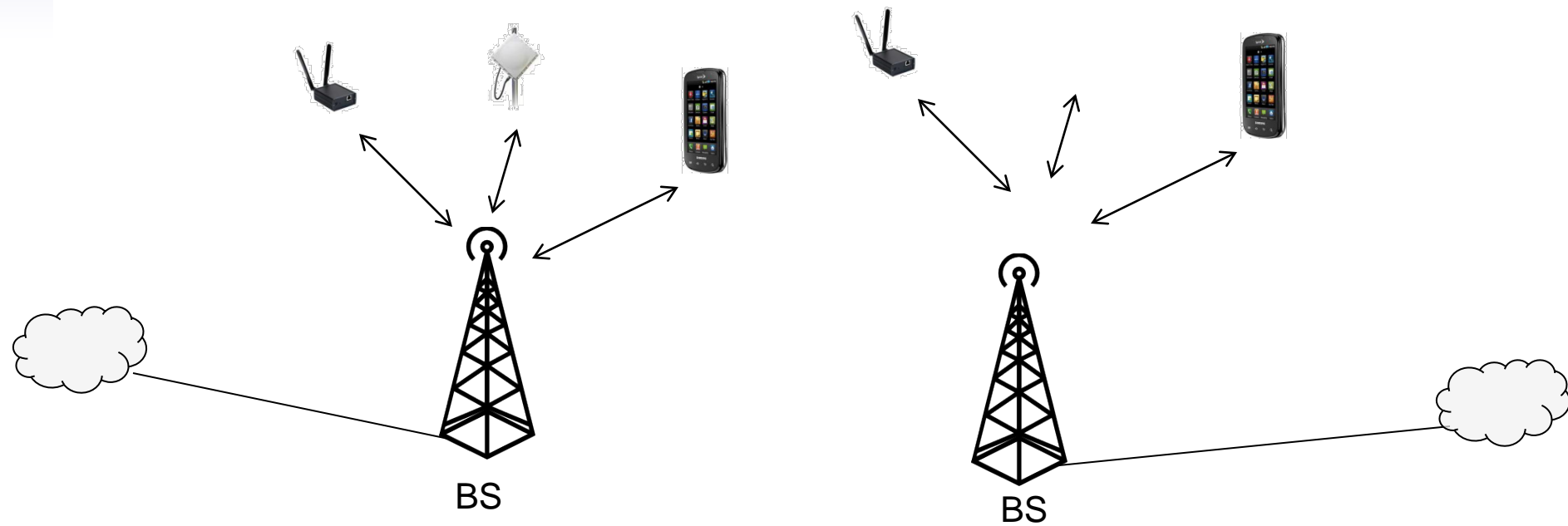
GRIDMAN Purpose and Scope

- GRIDMAN – “Greater Reliability in Disrupted Metropolitan Networks”
 - Improving metropolitan area and field area wireless network reliability and robustness by orders of magnitude
- Applications / Stakeholders
 - Utilities: Smart Grid, Distribution Automation
 - Public Safety
 - Disaster Relief
 - Government applications
 - Critical Infrastructure

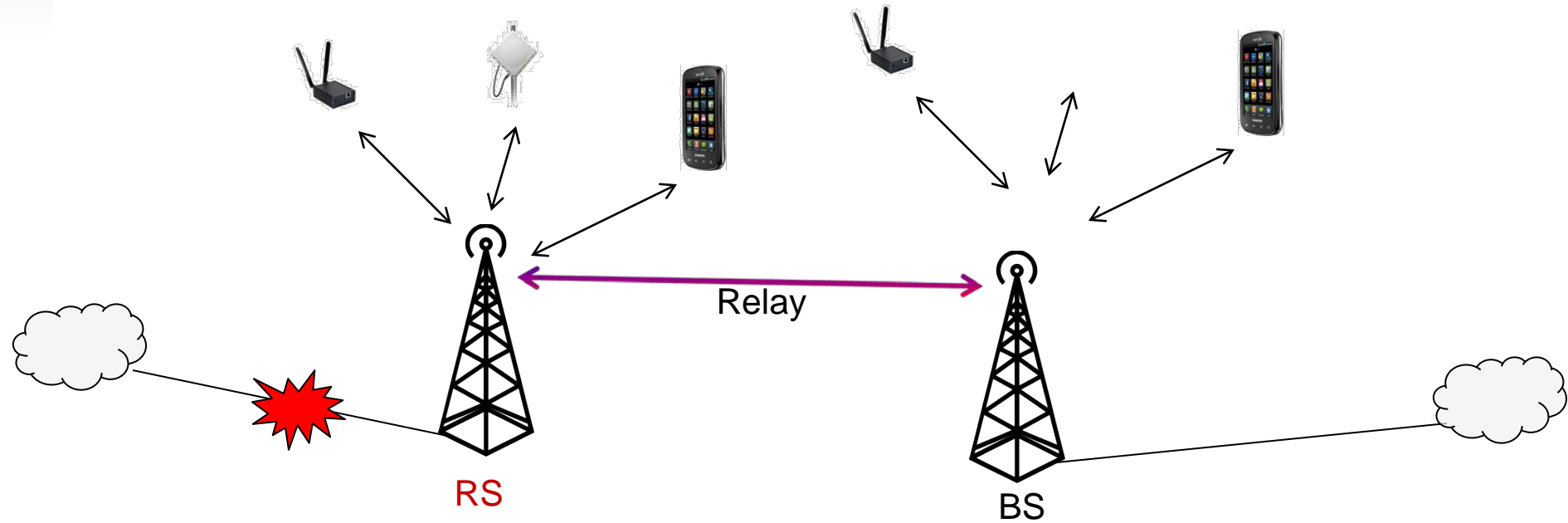
GRIDMAN Requirements Overview

- Enable deployment of networks with “Four 9’s” of reliability
- Immunity to single point of failure
 - Base stations can become relays if backhaul is down
 - Mobile stations can become relays to help other mobiles communicate with a base station
 - Mobile stations can form “ad-hoc” networks if all base stations are down
 - Mobile stations can function as base stations (with limited capabilities) in case of primary base station failure

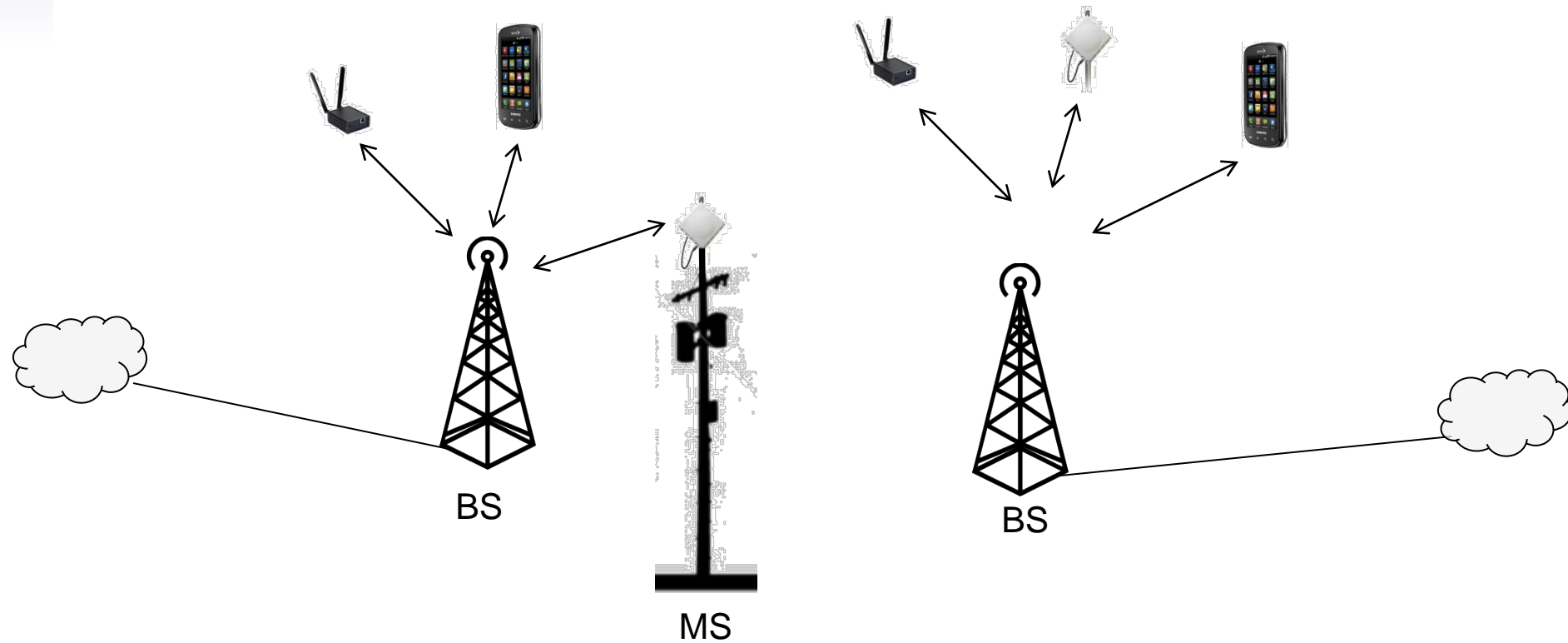
BS becomes RS



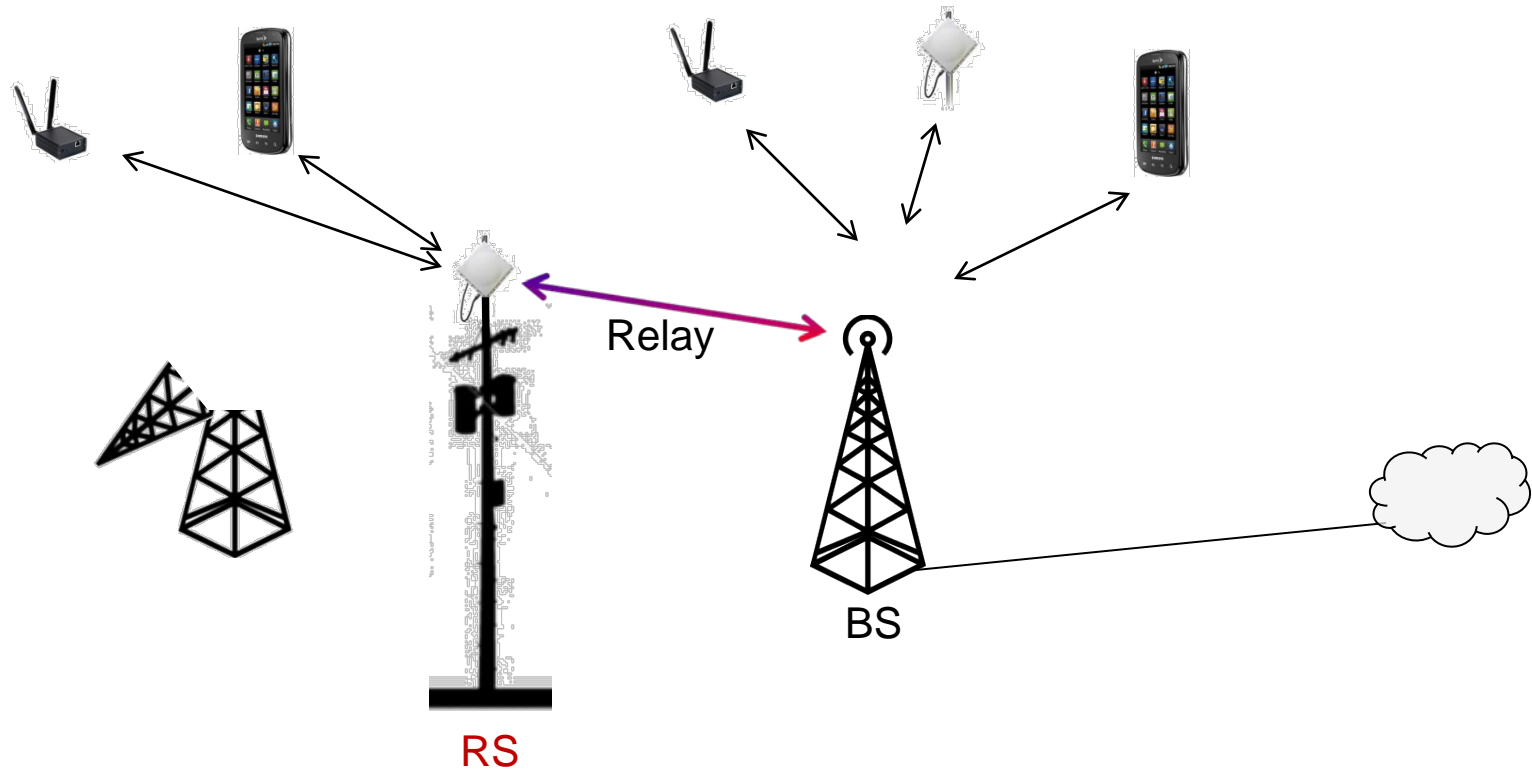
BS becomes RS



MS becomes RS



MS becomes RS



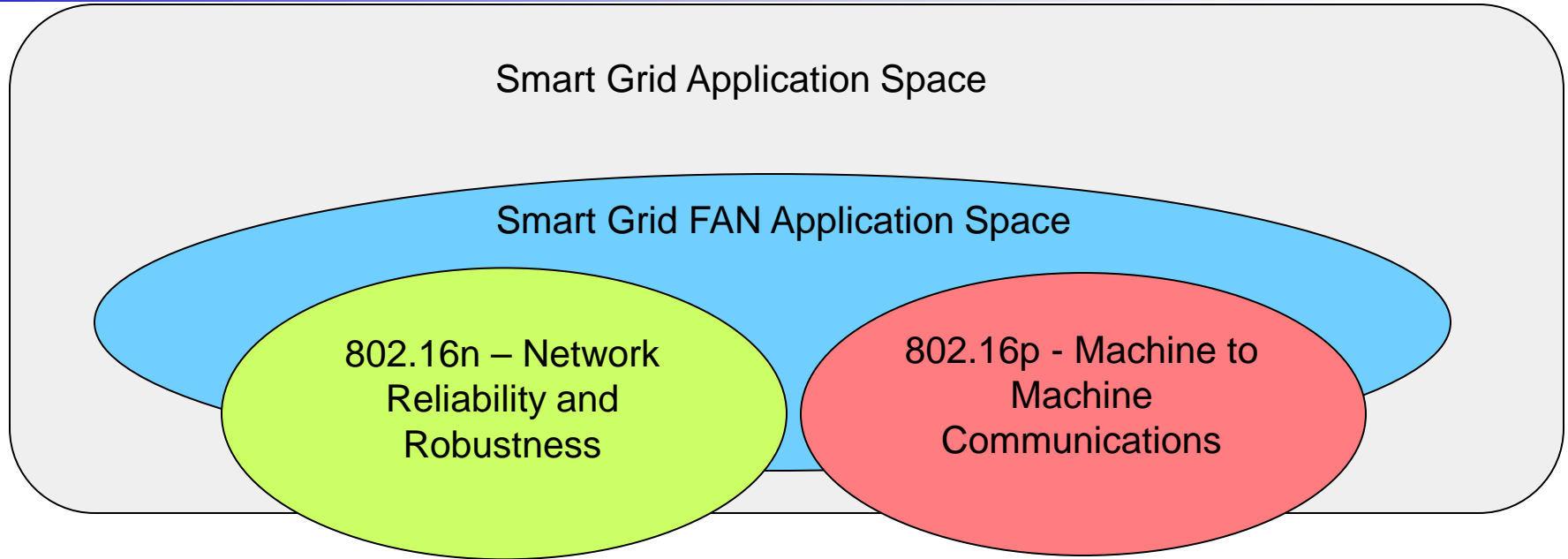
GRIDMAN Requirements Overview

- Dynamic Network Architecture
 - Devices can change roles as required to deal with failure and disruption
 - Multiple path routing and neighbor discovery
 - Combination roles
 - For example a station can serve as a relay to other stations while also sending and receiving its own data.
 - Base stations and relay stations can form “chains” if needed to reach infrastructure (multi-hop)
 - Base stations and relay stations may become mobile

GRIDMAN Requirements Overview

- Multicast Group Support
 - Large group multicast support
 - Emergency voice calling and enhanced VoIP services
- Flexible RF
 - Licensed, unlicensed, and “lightly” licensed bands
 - All radio frequencies where 802.16 operates
 - Bandwidths of the WirelessMAN-OFDMA or WirelessMAN-Advanced Air Interfaces.
 - Single or multiple RF carriers.
 - Support of TDD and FDD.

GRIDMAN and M2M Task Group



- 802.16n (GRIDMAN) – Reliability and robustness
- 802.16p (M2M) – Machine to Machine enhancements
- Each task group addresses unique Smart Grid requirements

- Both TGs plan for drafts in late 2011, and final approval in late 2012

Modeling cost and other practical aspects

Context and Motivation

- Utilities have limited access to licensed radio spectrum
 - No national coordination, niche markets for spectrum & equipment
 - Need is understood, some initiatives are being pursued, but the process may be long and arduous
- Reliance on unlicensed spectrum is potentially risky
 - Experience shows congestion is inevitable, can be overwhelming
 - Methods for interference tolerance are specific to a standard
 - Not generally the intent or reality in unlicensed bands (ISM: 915 MHz, 2.45 GHz)
 - Development of standards, products, certification/conformity, and the institution of cooperative behavior all takes time, effort

Context and Motivation

- EPRI's programmatic approach
 - TU #1022421 launches a series of planned Technical Updates
 - A systematic basis for Smart Grid Communications Planning
 - To enable & inform custom and collaborative SG Comms projects
 - One under way, one in approval process, others in development
 - Preparing an Industry-wide Technology Demonstration Project focused on High Reliability Field Area Networks (HR-FAN)
- Important distinction and notice!
 - *Within* EPRI mission and scope: research, analyze, and publish information on the technical and economic impacts of actual or potential spectrum allocations
 - *Not within* EPRI mission or scope: advocating or promoting any policy choices or recommendations regarding spectrum allocation

Definitions and Assumptions

- Field Area Network (FAN): “broadband wireless network providing essentially ubiquitous regional coverage”
 - Broadband: using 4G cellular (WiMAX, LTE) technology to provide coverage for current and future (+10 yrs) utility applications
 - Essentially ubiquitous: coverage in well-defined urban/suburban and rural environments and population densities (morphologies)
 - Security: robust application- and medium access layer (MAC)-level encryption and device authentication; “government grade” security
 - Reliability: 99.99% available (<2hrs/yr unplanned outage) including disruptions (e.g. storms) in outdoor urban/suburban areas; may be somewhat less indoors or in rural areas
 - Latency: end-to-end <1second worst case (can be up to 10x faster)

Definitions and Assumptions

- Morphologies used in the study
 - “Urban Model”
 - Based on a large, multi-county metropolitan area
 - Total population of roughly 4.8 million
 - Land area ~6500 km² including 442 km² dense urban (33,690 persons per km²)
 - “Rural Model”
 - Based on one largely rural state, excluding cities and towns of more than 5,000 population and counties with population densities below 0.2 persons per km²
 - Total population 1,428,000; avg density 6.64 persons per km²
 - Land area of roughly 215,000 km²

Definitions and Assumptions

- Data throughput based on OpenSG Network System Requirements, v4.0 (but with increased message size to allow for security)
- Models today's substation and feeder-based SCADA and AMI data, as well as growth in these traffic classes over 10 years
- All assumptions re: data flows, position of devices (meters), RF power levels, antenna configuration and gain, indoor and outdoor coverage, etc. are explicitly documented
- Summary

Timeframe	Condition	Throughput Including Smart Meter Communications		Throughput Without Smart Meter Communications	
		Downlink	Uplink	Downlink	Uplink
Present	Normal	0.49 Mbyte/hr	0.49 Mbyte/hr	0.42 Mbyte/hr	0.42 Mbyte/hr
	Disaster	1.27 Mbyte/hr	1.27 Mbyte/hr	1.26 Mbyte/hr	1.26 Mbyte/hr
10 Years	Normal	16.61 Mbyte/hr	16.61 Mbyte/hr	9.24 Mbyte/hr	9.24 Mbyte/hr
	Disaster	28.46 Mbyte/hr	28.46 Mbyte/hr	27.72 Mbyte/hr	27.72 Mbyte/hr

Methodology

- Model deployment of 4G technology on three bands
 - Unlicensed ISM bands (2.45 GHz, 915 MHz)
 - Licensed band, dedicated FAN (1800 MHz, 30 MHz ttl)
 - Licensed band, shared FAN (700 MHz, 22 MHz ttl)
- Use Extended HATA model for path loss and typical forward and reverse (UL/DL) power levels
- Make clear and explicit all aspects of 4G technology used in modeling (channel size; number of subchannels, assignable blocks, and subcarriers; path loss calculations; cell size and overlap; SNR; spectrum efficiency; etc.)
- Use data and models to estimate number of base stations and associated cost (CAPEX) of deploying a FAN

Findings

- General finding:
 - Wireless FANs will be coverage not capacity bound
 - Additional AMI traffic, growth over 10 years have minimal impact
- FAN on unlicensed spectrum seems impractical today
 - Limited power levels means thousands of base stations or APs
 - Operational complexity and cost seem prohibitive
- FAN on dedicated 1800 MHz spectrum
 - Requires 227 base stations, cost ~\$72M
 - Urban/sub: 136 BS, \$44M; Rural: 91 BS, \$28M
- FAN on shared 700 MHz spectrum
 - Requires 149 base stations, cost ~\$48M
 - Urban/sub: 73 BS, \$24M; Rural: 76 BS, \$24M

Conclusion

- Field Area Networks will provide critical infrastructure for the “second wave” of ICT-enabled utility systems
- There are multiple vectors of R&D being explored
 - More robust unlicensed and lightly licensed radio networks
 - 4G systems re-cast for reliable, scalable, critical utility infrastructure
 - Tiered architectures and more layered, distributed communications networks (reflecting and supporting new power system control design)
- Business models will have to be developed in parallel to standards and technologies

Q&A and discussion

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