ns-3 Web-Based User Interface - Power Grid Communications Planning and Modeling Tool

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Agenda

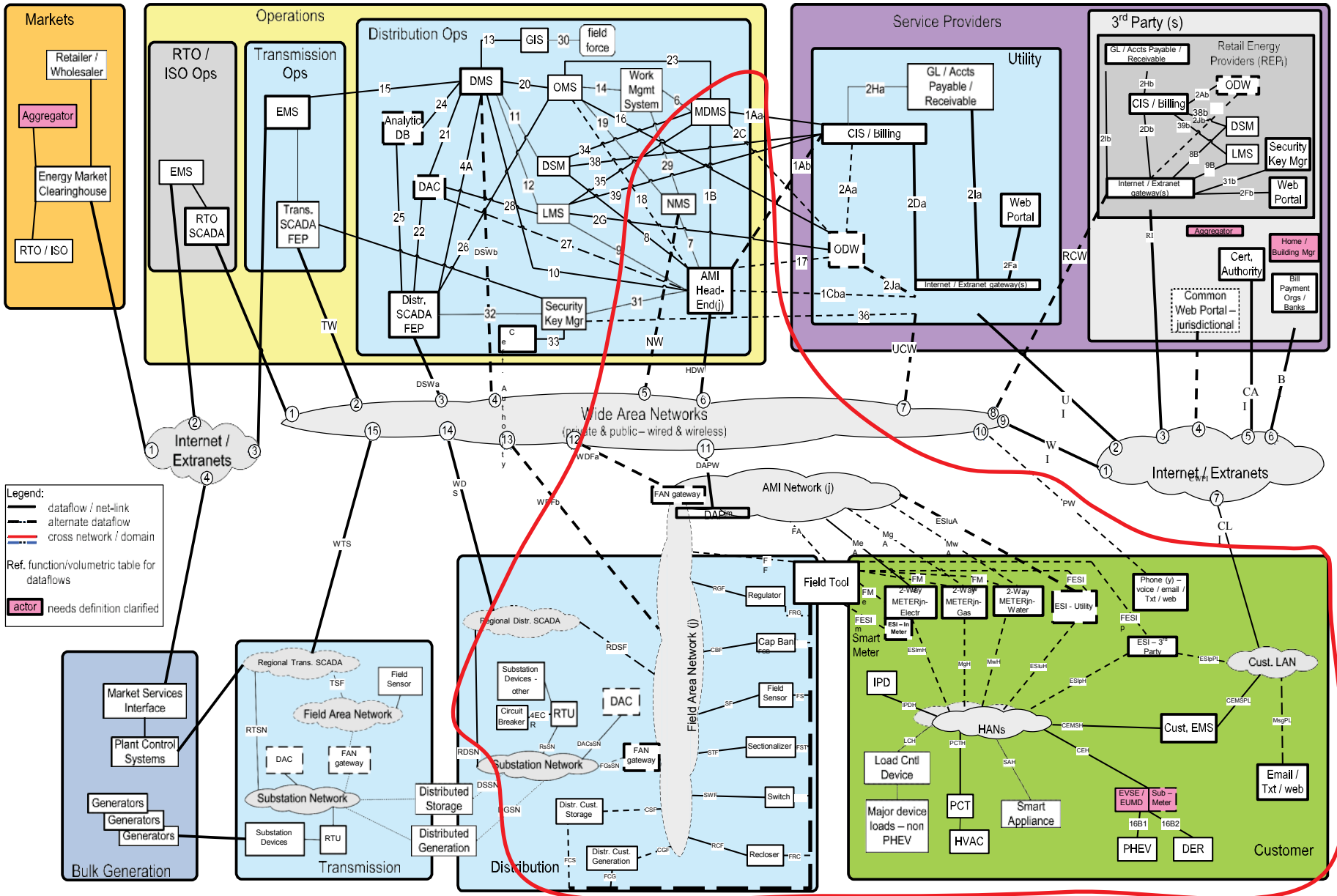
- Background
- Project Vision and PGCPMT High-Level Architecture
- AMI Meter Reading Communications Technologies
- Summary

What is the Smart Grid?

- Computer-based remote control and automation of the electricity grid[1]
- IEEE Vision for Smart Grid Controls: 2030 and Beyond
  - An end-to-end cyber-enabled electric power system, from fuel source to generation, transmission, distribution, and end use, that will:
    - 1) enable integration of intermittent renewable energy sources and help decarbonize power systems,
    - 2) allow reliable and secure two-way power and information flows,
    - 3) enable energy efficiency, effective demand management, and customer choice,
    - 4) provide self-healing from power disturbance events, and
    - 5) operate resiliently against physical and cyber attacks.
- Smart Grid best characterized by U.S. Energy Independence and Security Act of 2007

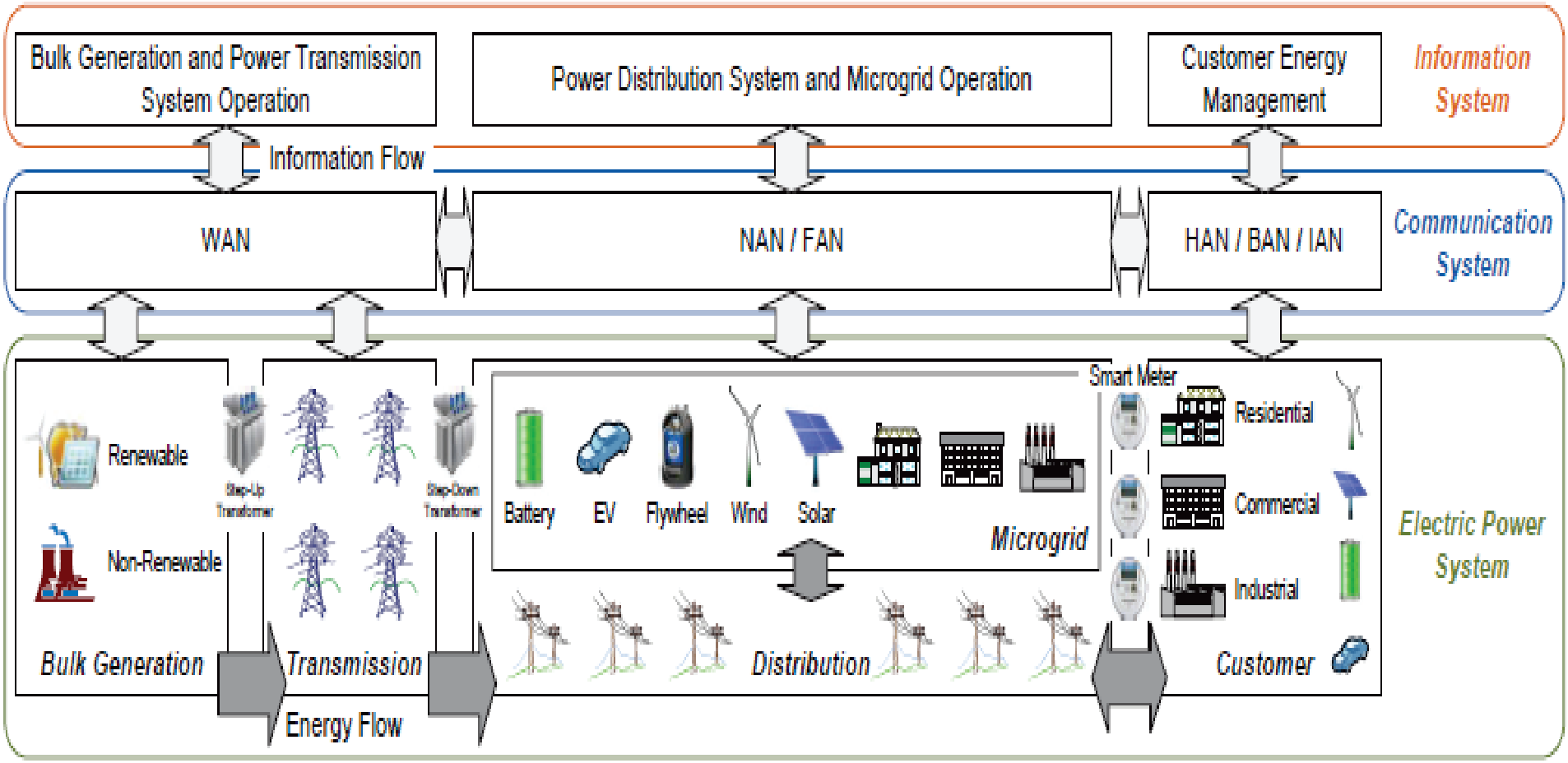
[1] http://energy.gov/oe/services/technology-development/smart-grid

Simulate Portions of the Smart Grid Infrastructure[1]



[1] OpenSG SG-Network 119 Task Force Core Development Team, Smart Grid Networks System Requirements Specification, Release Version 5

Illustration of Smart Grid System Architecture[1]



[1] IEEE Std 2030-2011, "Guide for smart grid interoperability of energy technology and information technology operation with the electric power system (EPS), and end-use applications and loads," 2011.

Our Approach to Building PGCPMT

- Agile methodology
- Start small and build what is needed today
  - Customer driven
  - Factor into manageable phases and build needed capabilities over time
- Prototype to evaluate and rebuild as necessary
  - Not trying to build a framework at this point in time

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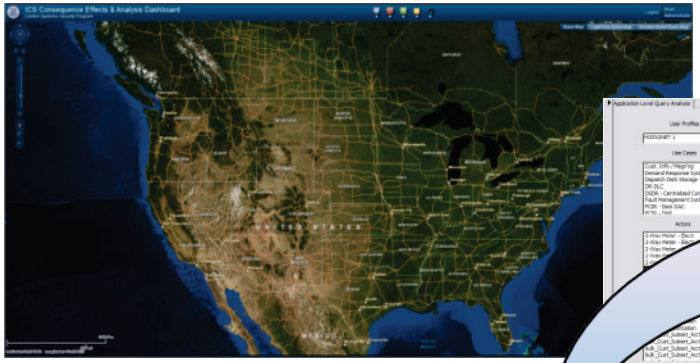
AMI Meter Reading Communications Technologies

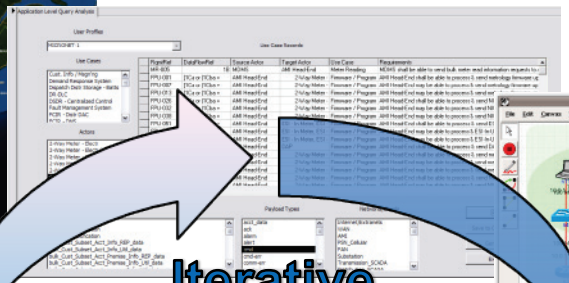
Summary

Conceptual Depiction of Software System
Integrated Tool Suite

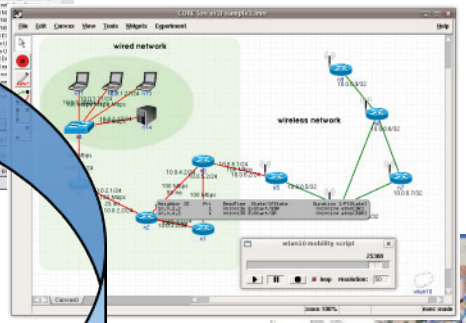


1 Geospatially Based Initial Interface

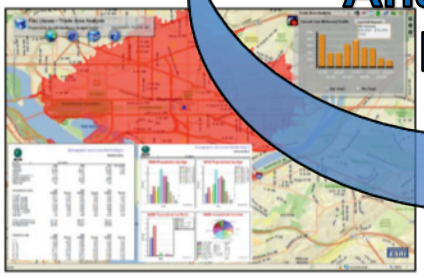
2 Access SG Component Database

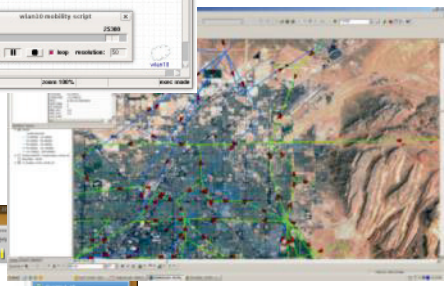


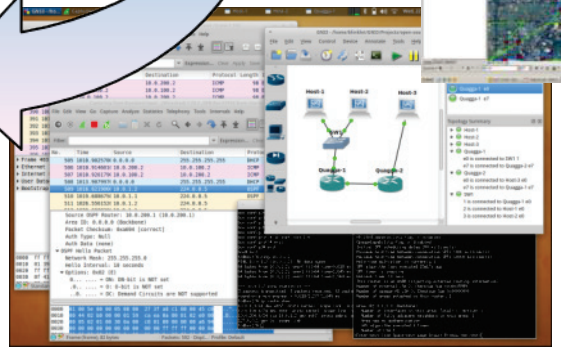
3 Interactively "Build-Up" SG Network



Iterative Planning, Analysis and Design







5 Provide analytical and visualization capabilities

- Required bandwidth and spectrum
- Multi-Scale areas of interest
- "Heat" Maps
- Report / design generation

4 High-fidelity modeling of networks

Examples of Questions That May Be Answered By Smart Grid Tool

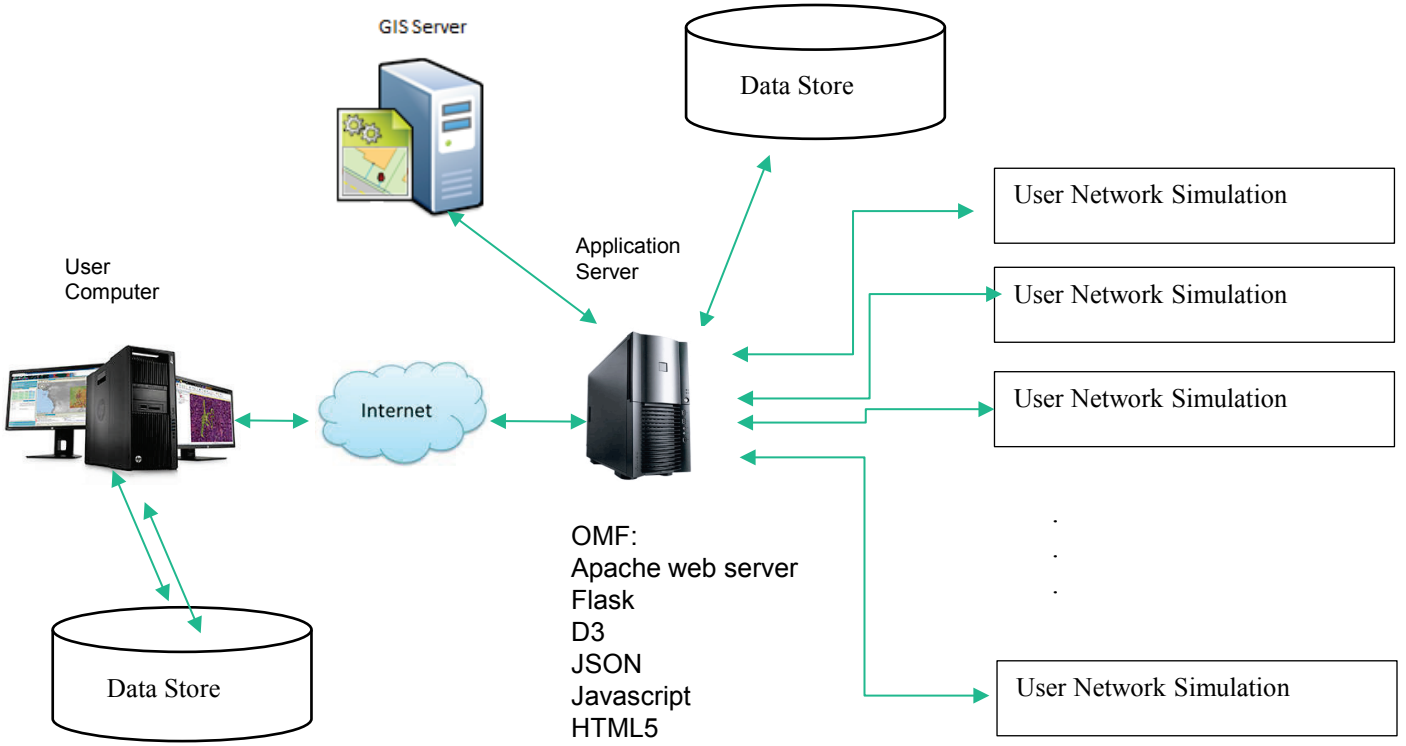
- What are the quality of service repercussions of upgrading our existing installation from 3G to LTE?
- How does scalability impact the performance of the system?
- What is the network performance? How to compute and improve the capacity, e.g., multi-radio/multi-channel techniques, routing methods, topology size, and architecture?
- How does aggregating meter data impact network performance?
- How long will it take to collect all smart meter data at the data and control center?
- How does the network performance compare when using WiMAX versus LTE technology?
- How far apart can wireless nodes be before they cannot communicate reliably?

Project Impetus and Requirements

- Provide a tool to help utilities plan and estimate cost and performance of smart grid communication deployments
  - ***Cost model*** and ***alternative topology modeling*** were two features highlighted by the utility community as most important
  - Web based, not a standalone application
- Extend the Open Modeling Framework (OMF), www.omf.coop, by the National Rural Electric Cooperative Association to include communications modeling
  - OMF[1] includes GridLAB-D[2], a power distribution system simulation and analysis tool
    - GridLAB-D is not integrated with the new communications modeling capability in OMF
- Tool should be applicable to a wide audience

[1] D. Pinney, Open Modeling Framework software, https://github.com/dpinney/omf.
[2] http://www.gridlabd.org/; Developed by the U.S. Department of Energy (DOE) at Pacific Northwest National Laboratory (PNNL) under funding for Office of Electricity in collaboration with industry and academia.

Architecture



ns-3 Code Generator

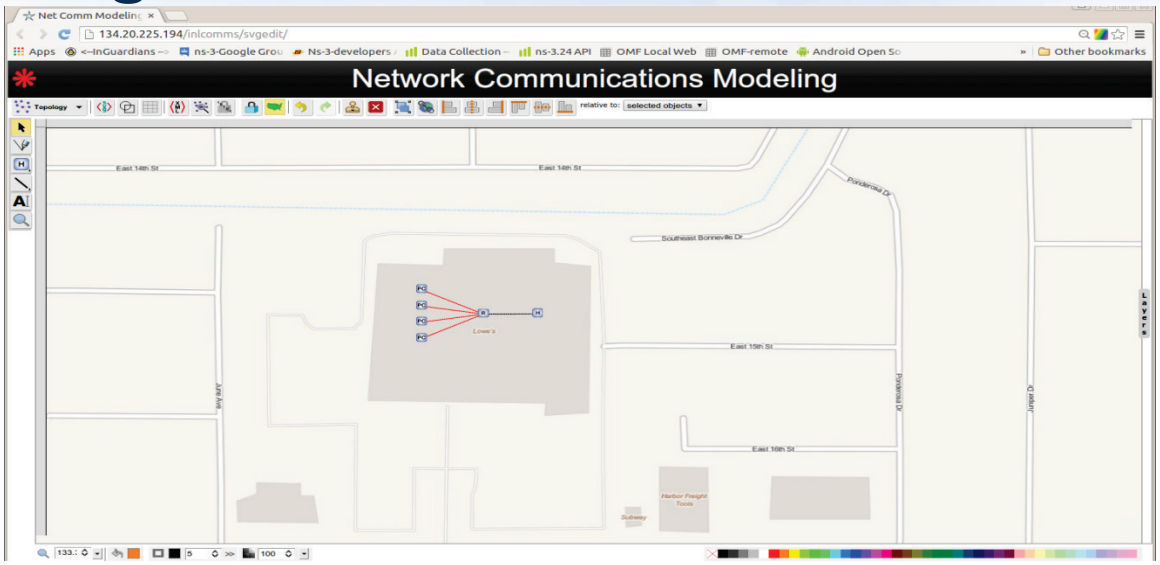
- Initial code generator work is application provided to the ns-3 community called the Topology Generator[1]
- Two new updated versions[2] created from that code base, both ns-3.24 compliant:
  - Topology Generator
    - Standalone, self-contained application with GUI that allows a user to design and build topologies and generate ns-3 output code
  - Code Generator
    - Command line application with no GUI
- Code Generator features
  - Generate FlowMonitor style metrics
  - Generate C++ style script syntax only
  - XSD validation of XML input file

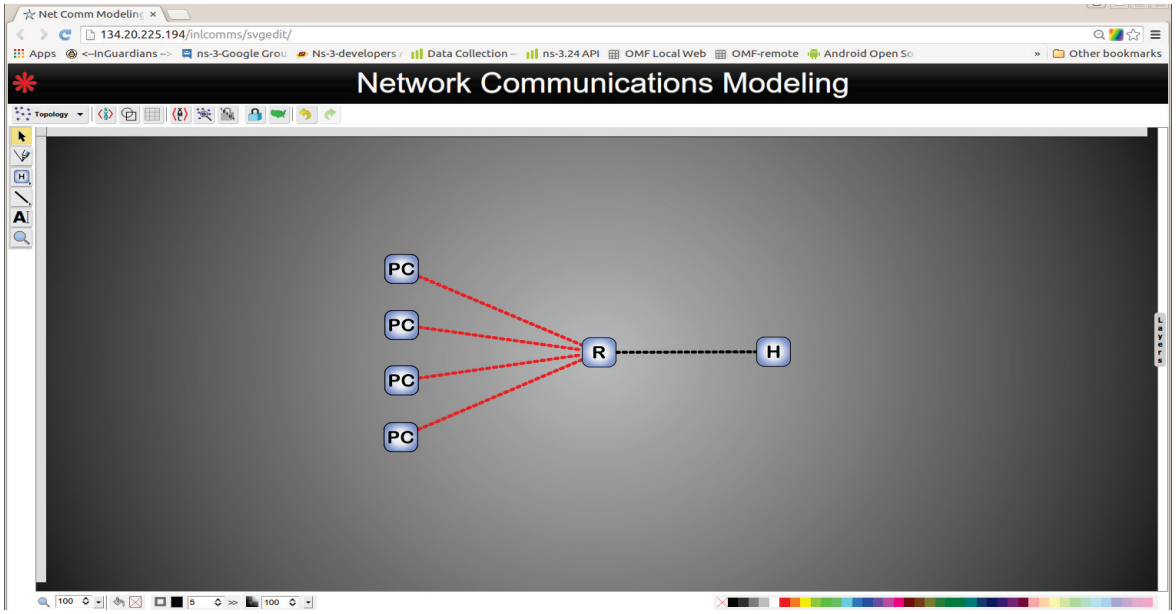
[1] Pierre Weiss & Sebastien Vincent, University of Strasbourg
[2] Jeff Young, Idaho National Laboratory

PGCPMT Components

- Graphical User Interface
  - Geospatial
  - Logical
- Network modeling and simulation
- Cyber security
- Component database and cost analysis

GIS and Logical Model User Interfaces



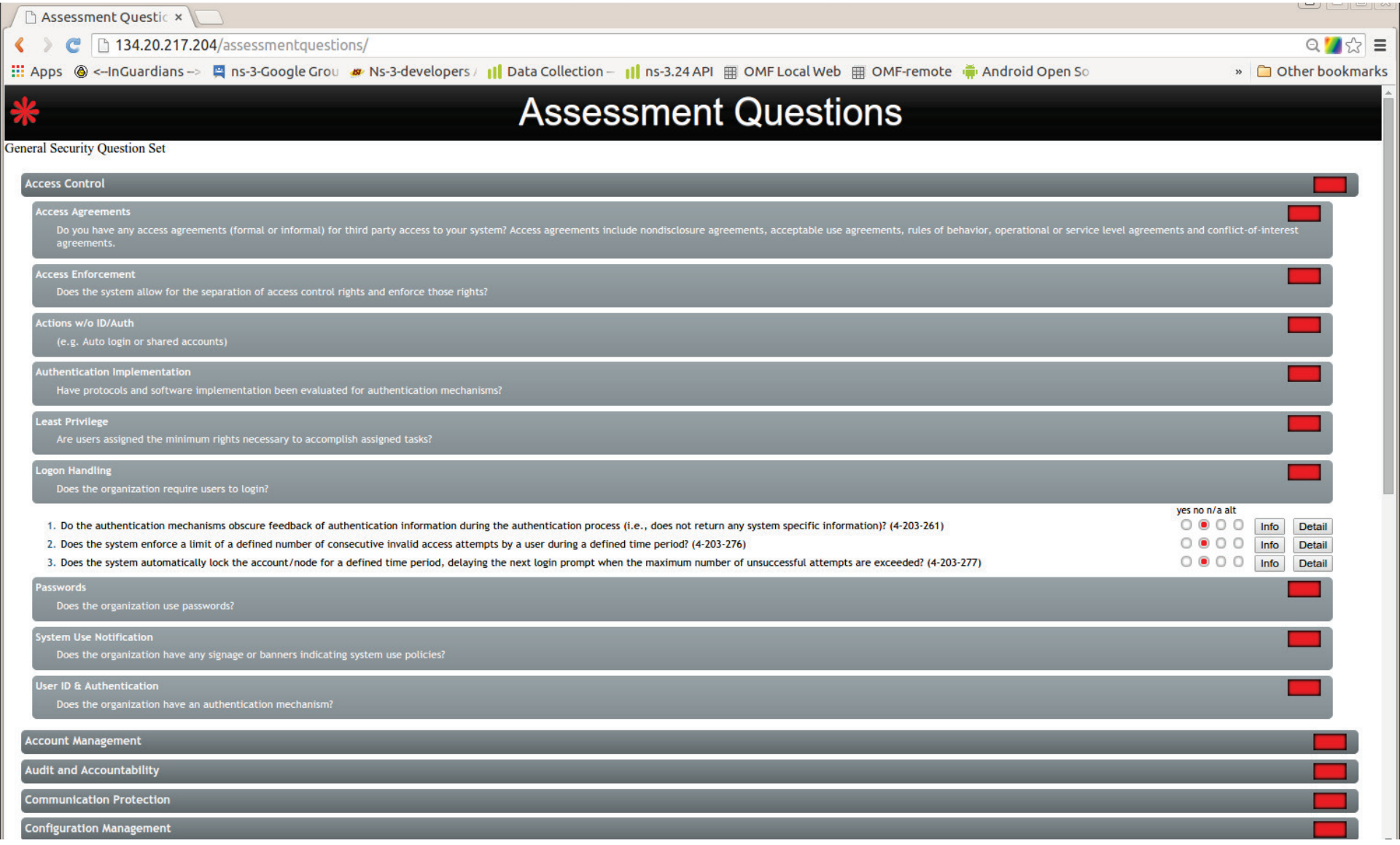


Cyber Security Module[1]

- Provides users with systematic approach and repeatable approach for assessing the cyber security posture of their grid network components
- Grid components are grouped into “security zones”
- Zone is a virtual representation (on the diagram) of a physical boundary separating different functional areas
- Each component is assigned levels for confidentiality, integrity, and availability, and these levels will be incorporated into the zone security level determination algorithms
- High level security analysis on the communication conduits between zones alerts users to potential vulnerabilities

[1] Based on Cyber Security Evaluation Tool, ICS-CERT, Industrial Control Systems Cyber Emergency Response Team, https://ics-cert.us-cert.gov/

Cyber Security Assessment Questions



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Background

Project Vision and PGCPMT High-Level Architecture

AMI Meter Reading Communications Technologies

Summary

Smart Grid Comprised of Multiple Applications

- Advanced Metering Infrastructure (AMI)
- Distribution Automation
- Distributed Generation
- Distributed Storage
- Electric Vehicles
- Home Area Networks
- Microgrids
- Demand Response

Technologies Supporting AMI Use Cases

- AMI → initial impetus of smart grid deployment technology
  - Utilize dlms-cosem-ns-3[1]
- WAN technologies:
  - Wireless mesh
  - Point-to-point
  - Long Term Evolution (LTE)
  - WiMAX
- NAN technologies:
  - Point-to-point
  - Wireless mesh
  - Power Line Communications (PLC)[2]
  - Wireless LAN

[1] R. Bustamante M. and J. M. Aranda L. K., University of Los Andes, School of Electric and Electronic Engineering, Bogota, Columbia, December 7, 2012; https://code.google.com/archive/p/dlms-cosem-ns-3/

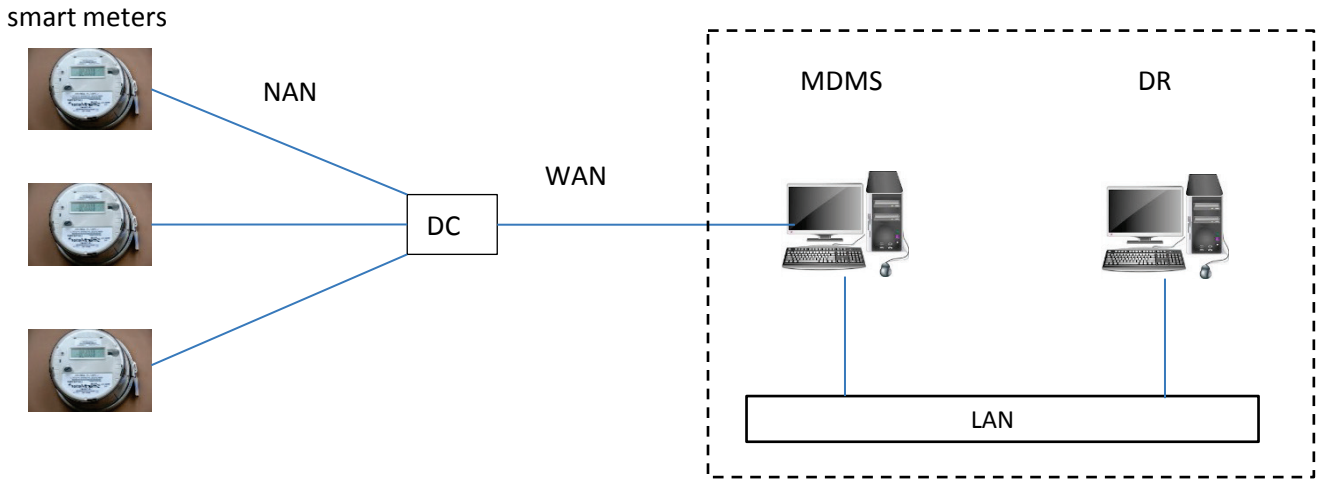
[2] F. Aalamifar, A. Schlogl, D. Harris, L. Lampe, "Modeling Power Line Communication Using Network Simulator-3", Globecom 2013; http://wee.ece.ubc.ca/~lampe/PLC/

DLMS/COSEM

- DLMS → Device Language Message Specification
  - Generalized concept for abstract modeling of communication entities
- COSEM → Companion Specification for Energy Metering
  - Sets the rules, based on existing standards, for data exchange with energy meters
- dlms-cosem-ns-3
  - Based on International Electrotechnical Commission (IEC) 62056-47/53
- ANSI C12.22 used in North America

WAN-NAN Technology Example 1

Use Case: MDMS periodically requesting meter data from DC

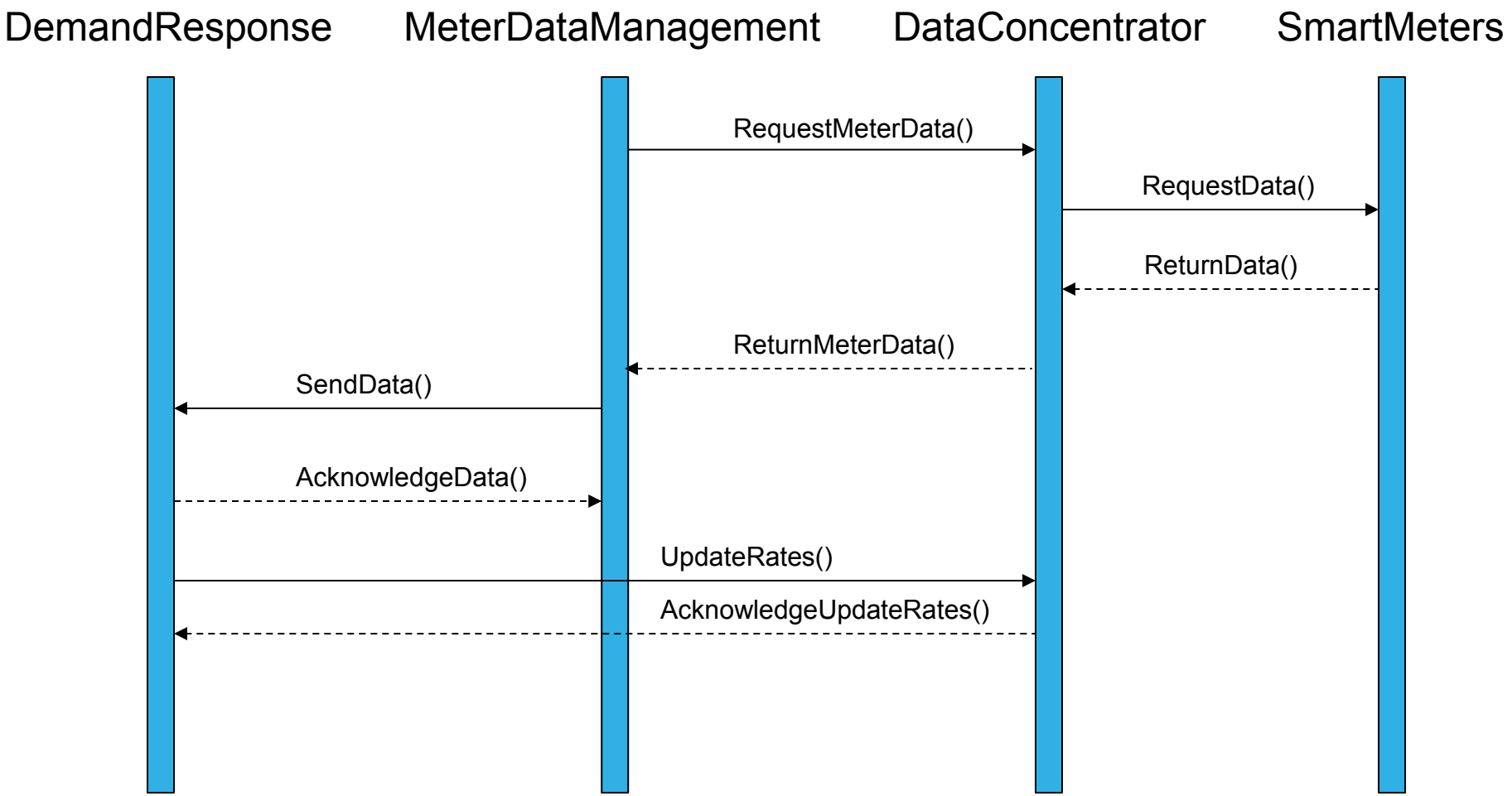


DC = Data Concentrator
WAN = Wide Area Network (point-to-point link)
NAN = Neighborhood Area Network (Wireless LAN; alternatives)

MDMS = Meter Data Management System
DR = Demand Response
LAN = Local Area Network
WLAN = Wireless LAN

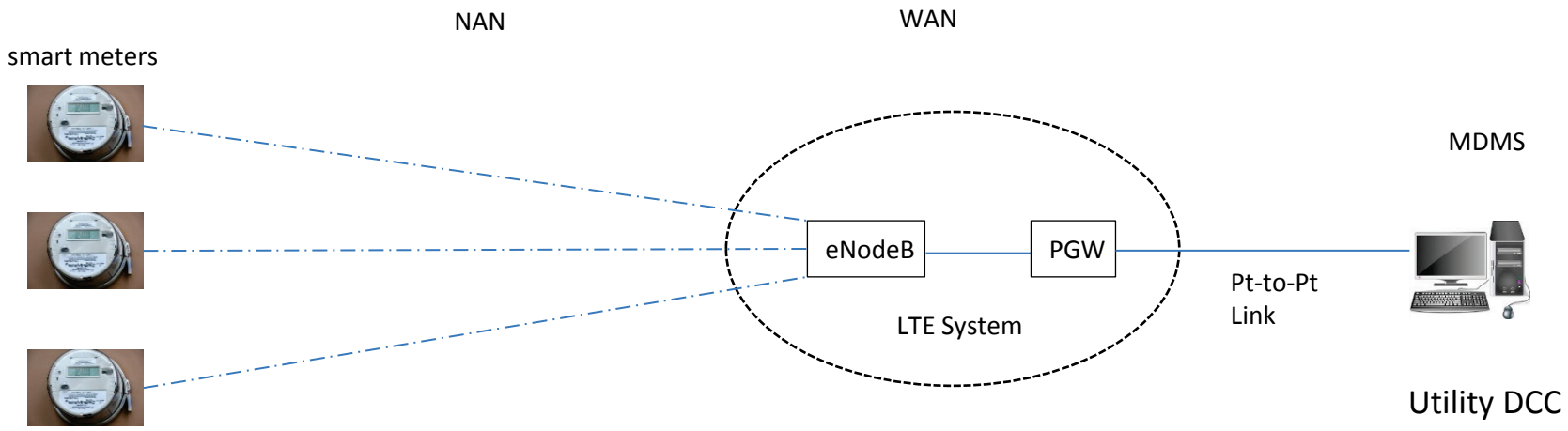
Node	Application(s)	NetworkDevice
Smart Meter	UdpCosemServerHelper	WifiNetDevice
DC	UdpCosemClientHelper, DataConcentratorApplicationHelper	PointToPointNetDevice, WifiNetDevice
MDMS	MeterDataManagementApplicationHelper	CsmaNetDevice, PointToPointNetDevice
DR	DemandResponseApplicationHelper	CsmaNetDevice

DLMS/COSEM Sequence Diagram



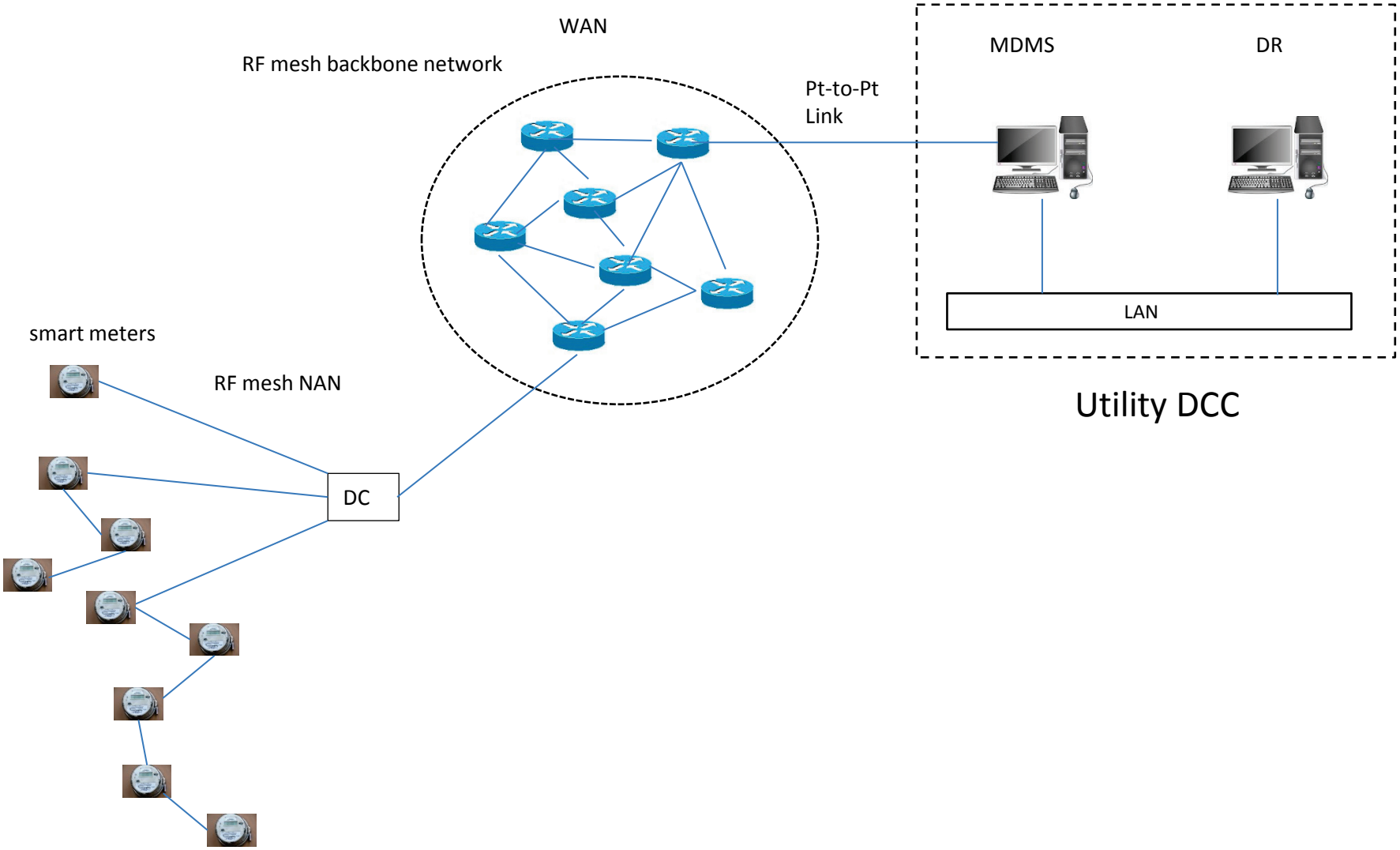
WAN-NAN Technology Example 2

Use Case: Meters periodically sending data to MDMS



Node	Application(s)	NetworkHardware (NetworkDevice)
Smart Meter (UE)	OnOffHelper	LteUeNetDevice
PGW	LteHelper, PointToPointEpcHelper	PointToPointNetDevice
eNodeB	LteHelper, PointToPointEpcHelper	PointToPointNetDevice, LteEnbNetDevice
MDMS	PacketSinkHelper	PointToPointNetDevice

WAN-NAN Technology Example 3



Example of Output Results from Multiple Simulation Runs

- FlowMonitor only at this point
  - FlowMonitor output data stored in sqlite database
- Integrating a query capability in the GUI to extract performance data

Run Number	Error Rate	Number of Smart Meters	Tx Packets	Rx Packets	Delay	Lost Packets	Packet Delivery Ratio	Packet Lost Ratio
1	0	10	355	350	0.00191	5	0.98591	0.14084
2	0	100	3425	3420	0.00211	5	0.99854	0.00145
3	0.01	10	255	249	0.00947	6	0.97647	0.02352
4	0.01	20	529	525	0.00894	4	0.99243	0.00756
5	0.001	25	865	860	0.00202	5	0.99422	0.00578
6	0.01	25	860	855	0.00202	5	0.99418	0.00581
7	0.1	25	854	850	0.00203	4	0.99531	0.00468

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Path Forward

- Working with utility companies:
  - Validate models
  - Enhance tool functionality based on utility needs
- Open source version of tool

Lessons Learned

- Learning curve for smart grid and ns-3
- Work scope is ambitious
- Long software development cycle for web-based apps
  - OMF constraints
- Important to solicit feedback and build relationships with academia, industry researchers, and utilities

Related Work

- CORE Documentation, Release 4.8, core-dev, June 5, 2015.
- A. Quereilhac, NEP Network Experimental Programming Interface, INRIA Sophia Antipolis, France.
- R. Bustamente and J. Aranda, Modeling and Simulation of AMI Network Implemented under LTE and Wifi Technologies, Universidad de los Andes, Electric and Electronic Engineering Department, December 7, 2012.
- OpenSG SG-Network 119 Task Force Core Development Team, Smart Grid Networks System Requirements Specification, Release Version 5.