  

Power System Engineering, Inc.

UTC Regional Event

Bandwidth Planning for Deployment of Smart Grid Applications

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UTC UTILITIES TELECOM COUNCIL

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About the Presenter:

Rick leads the System Design and Communications Department, providing automation and communications consulting and engineering services, including Technology Work Plans, strategic communications plans, and automation planning and deployment including: SCADA, distribution automation, substation automation and design, AMI, demand response, GIS, MWM, AVL, OMS, IVR, and a variety of automation/ communications areas, including land mobile radio, fiber and microwave backbones, mobile data, etc. Rick has over 25 years of professional relevant experience with an emphasis on the business side of technology. He has an MBA from Cardinal Stritch University in Milwaukee, WI.

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About the Presenter:

Kevin is Manager, System Design and Communications at PSE. He has over 20 years of communications, engineering and business management experience including utility wireless systems, wireless technology migration and road mapping, strategic planning, and operations management. Kevin has a BS in Chemical Engineering and an MBA from the University of Wisconsin – Madison.

Primary Overview Of This Presentation

Power System Engineering, Inc. (PSE) is an engineering consulting firm with clients throughout the United States. Our staff is currently working on several smart grid communication and automation projects. **We plan to walk through our evolving methodology for Bandwidth Sizing for AMI and DA backhaul.**

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PSE Methodology: Smart Grid Bandwidth Sizing

1) Create Architecture Design & Automation Program Roadmap
2) Develop Operational Assumptions for the Applications
3) Create Communication Related Specifications for Each Application
4) Model Assumptions via Excel Spreadsheet
5) Conduct Bid Process to Select Products
6) Test Products – Lab and Small Scale Field
7) Create Design
8) Build – Then Re-test Each Phase
9) Monitor Results and Make Modifications

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Agenda

- **Overview: Smart Grid Applications**
- Communications Media for Smart Grid Applications
- Bandwidth Estimates
- DA Bandwidth Estimate Case Study
- Throughput Measurement
- Challenges with Bandwidth-Limited Networks

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Overview: Smart Grid Applications

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Common Smart Grid Applications

1. Distribution Automation (DA)

- Smart Feeder Switching
- Conservation Voltage Reduction (CVR)
- Advanced Volt/VAr

2. Advanced Metering Infrastructure (AMI)

- Demand Response: In-Home Displays, Load Control, Critical Peak Pricing, Time of Use (TOU) Pricing, etc.
- Meter Data Management (MDM)

3. SCADA

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Communications Media for Smart Grid Applications

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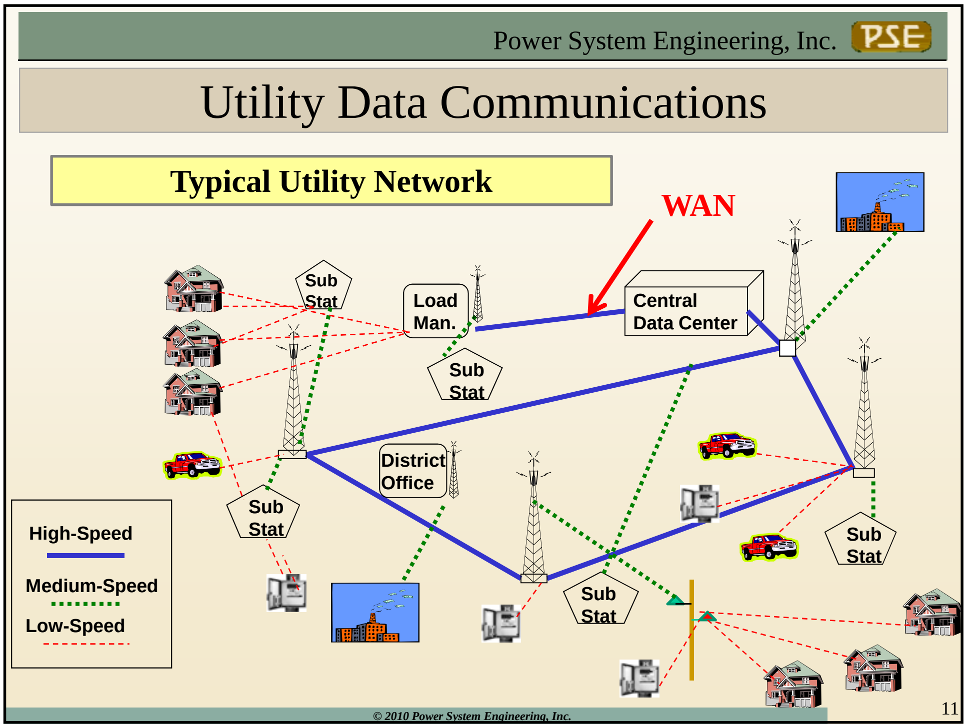
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Utility Data Communications
Typical Utility Network
WAN
Sub Stat
Load Man.
Central Data Center
Sub Stat
District Office
Sub Stat
Sub Stat
Sub Stat
High-Speed
Medium-Speed
Low-Speed
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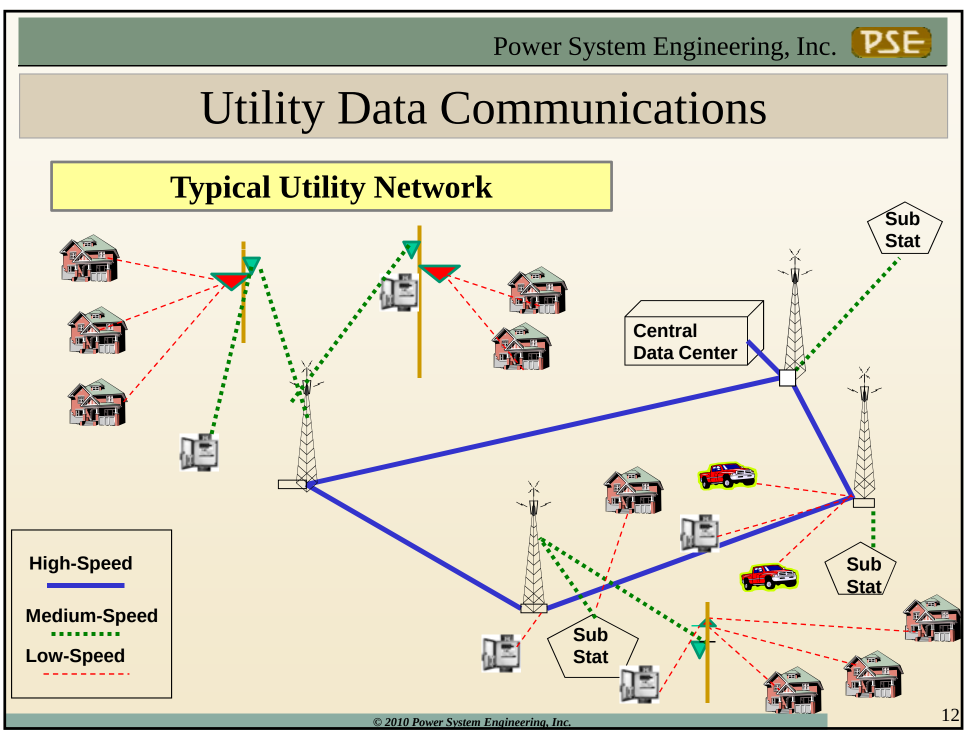
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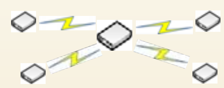
Types of Backhaul Media

Fixed Data Technologies

Point-to-Point (PTP)

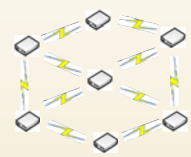
(Backbone)

Point-to-MultiPoint (PMP)



(Distribution Automation)

Mesh



(AMI, DA)

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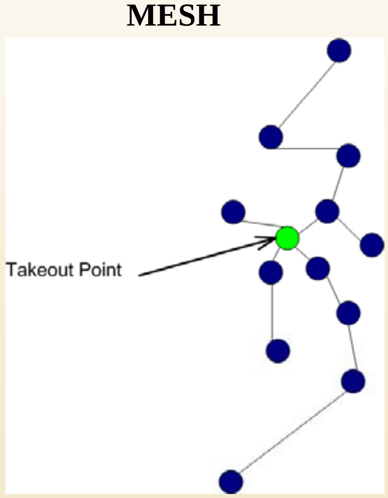
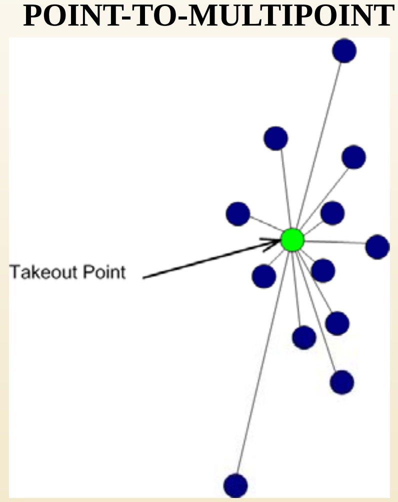
Wireless Network Topologies

MESH



MESH

POINT-TO-MULTIPOINT



POINT-TO-MULTIPOINT

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Extending Coverage of an AMI Mesh Network

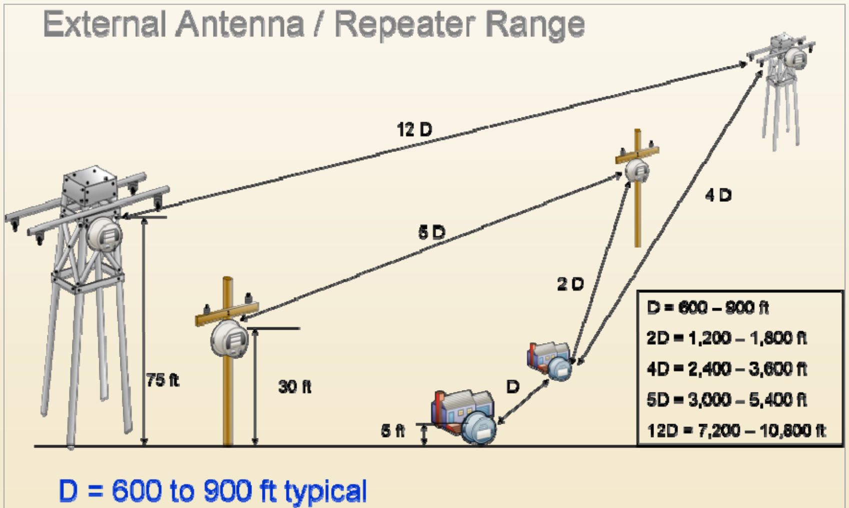

Diagram courtesy of Elster Metering.

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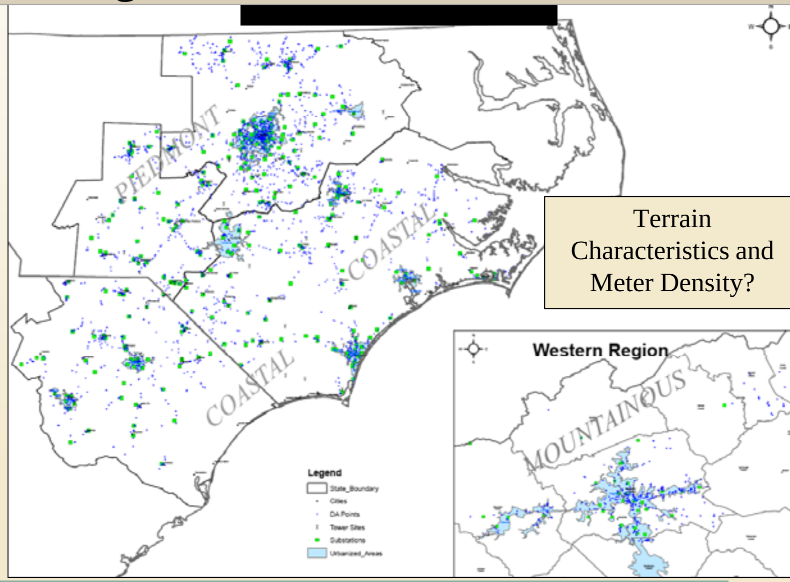
Coverage: Where Do You Need to Reach?

[redacted]



Terrain Characteristics and Meter Density?

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Smart Grid Communications

- AMI provides communication transport for **low data rate applications.** That is, communication to meters and in-home devices (e.g. in-home displays and load control switches and for low voltage sensors for DA).
- AMI requires **medium data rate communications backhaul transport** from metering data collection points.
  - Many wireless AMI technologies have takeout points that are often located in the field, attached to poles, etc.
  - PLC AMI collection points in the substations.
- DA may consist of both **low and medium data rate communications** infrastructure communicating directly to devices located in substations and/or the field attached to poles, etc.
- SCADA requires **medium** rate communications.

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PSE Methodology: Smart Grid Bandwidth Sizing

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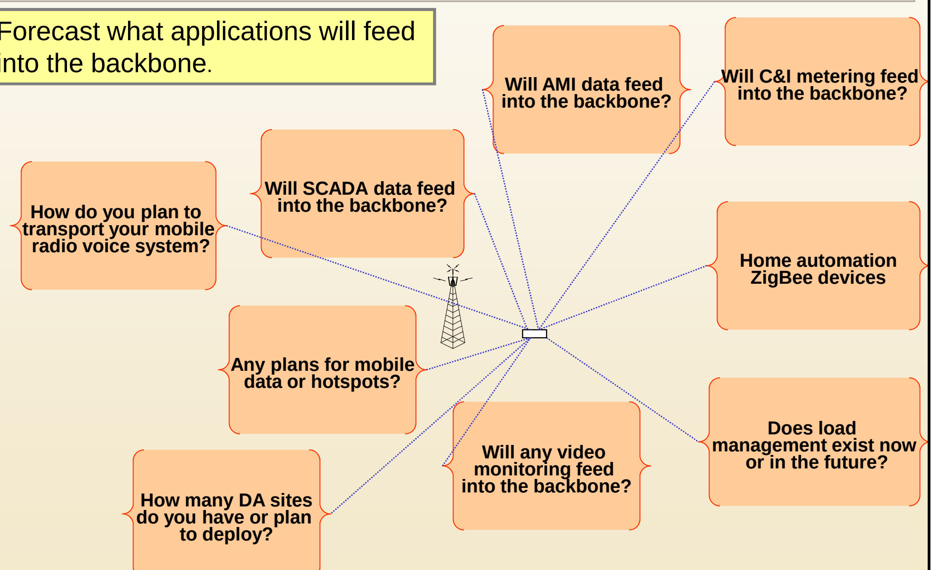
Common Utility Communication Requirements

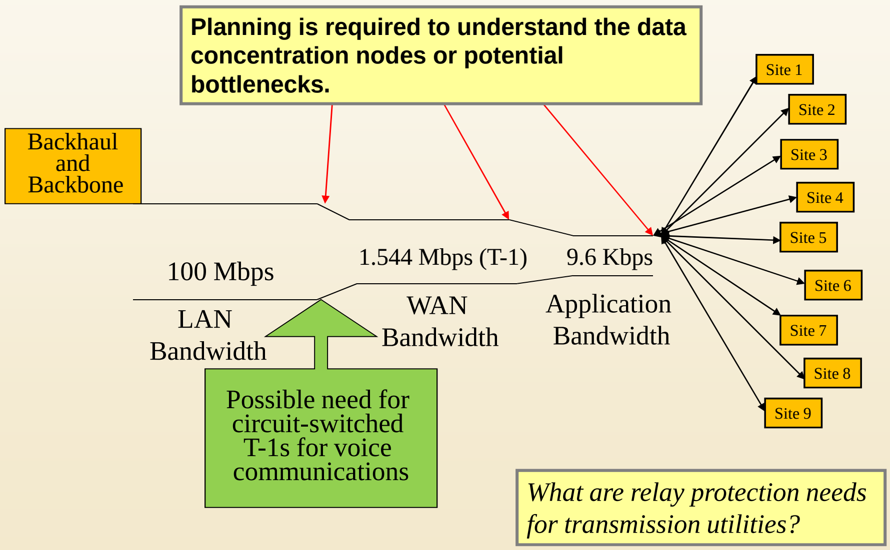
Attribute	DA	SCADA	Fixed Wireless AMI	Backbone or Major Node
Data Throughput	>4.8 Kbps	>100 Kbps	>768 Kbps	50 Mbps
Latency/Site - Seconds	<1 to 5 seconds	1 to 2 seconds	<10 seconds	sub-second capable
Reliability % Target	99.9%	99.99%	99.99%	99.999%
Security Level	High	Very High	High	Very High
Coverage	95%	100%	100%	100% with backup

Bandwidth Planning & Forecasting

Forecast what applications will feed into the backbone.



Bandwidth Planning



Smart Grid Application Bandwidth Estimates

Terminology: Throughput, Capacity, and Bandwidth

- *Throughput* is the net bit rate of successful data transfer through a communication link. Usually expressed as a data rate in bits or bytes per second.
- *Capacity* and *Bandwidth* are synonymous terms. Capacity and bandwidth are equal to the communication link's *maximum throughput.*
  - Theoretical. Not to be expected in a real network. Best case throughput.
  - No competing network traffic, no contention, no collisions, no protocol overhead, and no processing time.
  - Can be closely estimated by using the right tools, right protocols, careful analysis of test data, and by accounting for processing delays.

Throughput Multiple Representations

Throughput values can be represented in different ways.

- Maximum throughput (capacity/bandwidth).
- IP protocol throughput can have substantially lower value on the same link. On IP Networks: Ping, UDP, or TCP protocols will all show different maximum throughputs and even vary based on link quality of service.
- Different modes such as half duplex or full duplex.
- Allocated or designed bandwidth or throughput. In a point-to-multipoint system this is approximately equal to the maximum throughput divided by the number of remotes.

Smart Grid Application Bandwidth Estimates

What type of bandwidth estimate is needed?

1. **High Level** – based on generalized assumptions.
   - Suitable for conceptual planning.
   - Business cases.
2. **Design or specification** – best obtained through lab or field measurements.

Requirements for Utility Automation

- Substations
- AMI Take-Out Points
- Home Area Networks (Smart Metering)
- Distribution Automation (DA)
- Mobile Data
- Backbone

Communication requirements at tower sites will vary based on number of field locations and applications that will feed into the tower site.

Communication Requirements for Substations

Distribution substations have become regional nodes for a variety of utility automation applications including:

- SCADA
- AMI via PLC or nodes for fixed wireless take-out points
- Direct connect via Ethernet into substation IEDs
- Video monitoring
- Communication hubs or concentration points for down-line DA
- Hot spots for mobile data

Substation Bandwidth Forecasting

- Determine the applications that require **continuous** communications.
- Determine the frequency – **how often** will an application be used – e.g., every 15 minutes, once per hour, ten times per day, etc.?
- Determine the **bytes used** per application.
- Determine the acceptable level of **latency** by application.

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(sample) AMI Communications

#	Future Need or Capability	Tower Collection Point	Substation Collection Point	Feeder Collection Point
1	More than one communications technology can be used	Yes	Yes	Yes
2	Targeted communications uptime performance (outside of normal maintenance)	99.999%	99.99%	99.9%
3	Interface to backhaul third-party communications network	Ethernet	Ethernet	Ethernet
4	Typical antenna height	Tower site specific	Substation specific ~ 70 feet	Target 25 feet
5	Backhaul communications Ethernet, protocol is TCP/IP	Yes	Yes	Yes
6	From collector, the targeted latency in sending a 50,000 byte file	<10 seconds for AMI	<10 seconds for AMI	<10 seconds for AMI

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Sample Bandwidth Calculation for AMI

Assumptions: AMI Take-Out Point

1. Number of endpoints estimated per AMI collector (at substation): assume 3,000.
2. Data read interval: polled every 15 minutes.
3. Record size: 100 bytes * 8 * 3,000 meters = ~ 2.4 Mbits.

Result

If we assume the substation has a communications media in place with a guaranteed data rate of 120 kbps over the IP communications network, it would take slightly over 20 seconds to transport the AMI data between that substation and utility office. Less latency would require more than 120 Kbps of bandwidth.

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Smart Grid SCADA & DA Bandwidth

Factors that go into bandwidth estimates include but are not limited to:

- Polled or unsolicited reporting.
- If unsolicited polling rate, then analog deadband settings on the device.
- If polled, then the polling method ("round robin" or "shotgun"), polling rate, and response time wait.
- Amount of data being brought back.
- Reliability of link (unreliable links will have **more** traffic caused by protocol retransmits).

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Distribution Automation (DA) Communications

#	Future Need or Capability	Remote to Master via SCADA Operator	Peer-To-Peer Automated
1	More than one communications technology can be used for DA	Yes	Yes
2	Number of bytes per frame	Up to 292	Up to 292
3	Number of bytes possible if not polled frequently	~9,000	Not applicable
4	Need for unsolicited report by exception	Yes	Yes
5	Targeted communications uptime performance (outside of normal maintenance)	99.9%	99.99%

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Distribution Automation (DA) Communications

#	Future Need or Capability	Remote to Master via SCADA Operator	Peer-To-Peer Automated
6	The communications system provides the flexibility to successfully transport one DNP3 frame of data between 2 to 8 seconds.	Yes	N/A
7	The communications system provides the capability to successfully transport one DNP3 frame of data to less than 4 ms.	N/A	Yes
8	If wireless media is used, coverage should be able to be established with short antenna heights including: 3' for pad mounted, 20' for pole mounted.	Yes	Yes

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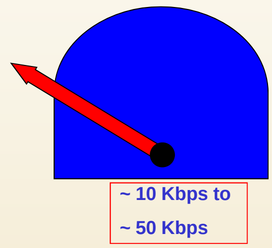
Low Rate Communications Media

- Dedicated low data rate communications needed mostly for DA, often not robust enough for AMI.
- The bandwidth challenge is at the master radio point versus the remote radio locations.
- Some options include:
  - Some use of core AMI infrastructure for the backhaul of DA
  - Satellite (LEO)
  - Unlicensed Radio – ISM Spread Spectrum
  - Licensed Radio – VHF, UHF, and 900 MHz - 12 KHz, 25 KHz and 50 KHz channels



Most wireless products are Point-to-Multi Point (PMP)

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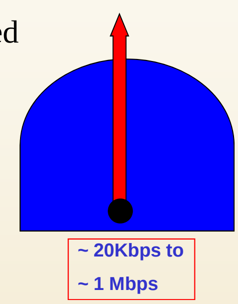
Medium Rate Communications Media

- Dedicated medium data rate communications needed for AMI & DA Smart Grid applications.
- Some options include:
  - Telephone company provided frame relay and Multiple Protocol Labeling Service (MPLS)
  - Broadband VSAT Satellite (GEO)
  - Unlicensed radio – ISM Spread Spectrum
  - Mesh-based, mostly unlicensed
  - 3.65 GHz WiMax
  - 2.5/3G cellular & new 4G GSM-GPRS and CDMA



**3G & 4G: New commercial cellular data*
(G = generation of technology)

Most Wireless Products are Point-to-MultiPoint (PMP)

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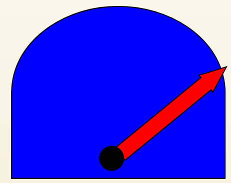
High Rate Communications Media

- Used for backhaul of substation data and backbone tower to tower or node to node.
- Not commonly used for remote fixed wireless AMI or DA points.
- Some options include:
  - Telephone company provided frame relay and Multiple Protocol Labeling Service (MPLS)
  - Unlicensed radio point-to-multipoint: some 900 MHz Spread Spectrum, but mostly 2.4 GHz or 5.8 GHz
  - Point-to-point microwave, unlicensed microwave 2.4/5.8 GHz
  - Point-to-point licensed microwave - 6, 12, 18 GHz
  - 3.65 GHZ WiMax (usually distance limitation)
  - Fiber (where affordable)



> ~ 1 Mbps

DA Bandwidth Estimate Case Study

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Computing Bandwidth for DA

- Determine the nature of the data that will be sent to and from devices (poll sizes in raw bytes by poll type and frequency from devices such as capacitor banks, voltage regulators, sensors, etc.).
- Make assumptions for the expected Round Trip Time (RTT) for each poll type, add overheads, and compute bandwidth requirement for each DA device type.
- Estimate the quantity of DA points by type of point and technology that will be backhauled through each WAN collection point in the system (tower or substation, etc.).
- Multiply quantity of sites from above estimate by the bandwidth requirement to determine the site bandwidth requirement.

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DA Bandwidth Estimate Case Study

	Class 0 (Read All Points)			Class 1 (Status Change Events)			Class 2 (Analog Change Events)		
Device	Bytes	Bits + TCP	kbps	Bytes	Bits + TCP	kbps	Bytes	Bits + TCP	kbps
VRC	270	3672	7.3	70	952	3.2	120	1632	5.4
CBC	620	8432	16.9	70	952	3.2	70	952	3.2
MV Sensor	270	3672	7.3	0	0	0.0	70	952	3.2
LV Sensor	270	3672	7.3	0	0	0.0	70	952	3.2
Recloser	270	3672	7.3	70	952	3.2	70	952	3.2

Type of Poll	Expected RTT in Seconds
Class 0 RTT	0.5
Class 1 RTT	0.3
Class 2 RTT	0.3
Analog Set RTT	2.0
Digital Command RTT	1.0
Class 1,2,3 RTT	0.5

	Analog Setpoint			Digital Command			Class 1,2,3 (Max events)			MAX
Device	Bytes	Bits + TCP	kbps	Bytes	Bits + TCP	kbps	Bytes	Bits + TCP	kbps	kbps
VRC	620	8432	4.2	620	8432	8.4	0	0	0.0	**8.4**
CBC	620	8432	4.2	120	1632	1.6	1020	13872	27.7	**27.7**
MV Sensor	0	0	0.0	0	0	0.0	0	0	0.0	**7.3**
LV Sensor	0	0	0.0	0	0	0.0	0	0	0.0	**7.3**
Recloser	0	0	0.0	0	0	0.0	0	0	0.0	**7.3**

Assumption 1: *SCADA master will not send more than one poll function to any single device at a time.*

Assumption 2: *TCP overhead is 70%.*

Assumption 3: *Poll of any type is 20 bytes in raw size.*

Assumption 4: *Expected RTT per poll type according to blue table .*

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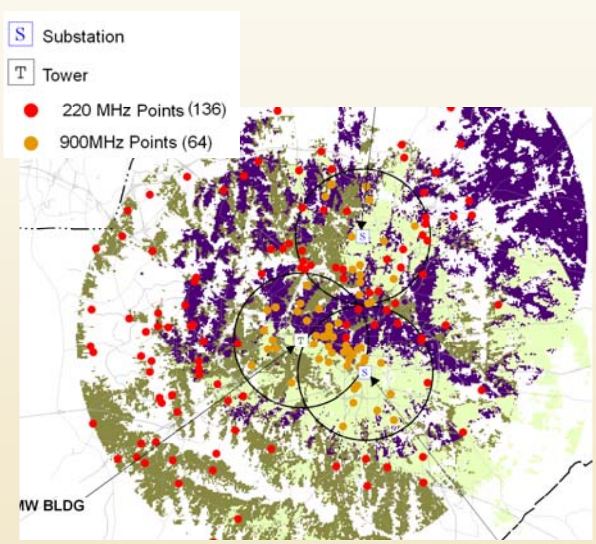
DA Bandwidth Requirements by Site Example



Use GIS viewshed and spatial analysis to assign points by technology to WAN collection point.

Example: two wireless technologies considered (900MHz and 220MHz).

900MHz considered feasible if viewshed and within 3 mile buffer of the WAN collection point. Remaining points assumed feasible with 220MHz.

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DA Bandwidth Requirement by Site Results

		900MHz (< 3 Miles) and terrain LOS				
Type	Substation / Tower	CBC	VRC	Total		Total Capacity Requirement (kbps)
Substation	East St Sub	0	0	0		-
Substation	Chestnut Hills	15	1	16		425
Tower	West tower	0	0	0		-
Tower	Pilot tower	1	2	3		45
				19		

CBC	VRC
27.74 kbps	8.432 kbps

		220MHz (=> 3 Miles) or NLOS				
Type	Substation / Tower	CBC	VRC	Total		Total Capacity Requirement (kbps)
Substation	East St Sub	0	0	0		-
Substation	Chestnut Hills	44	2	46		1,238
Tower	West tower	0	0	0		-
Tower	Pilot tower	9	14	23		368
				69		

Throughput Measurement

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Measuring Throughput

- Use one PC to perform tests and another PC to capture data on wire for future analysis.
  - **Raw and DNP wire capture** and protocol analyzers.
- Decide what type of throughput is measured:
  - **Application throughput requirement** of application – used to create specification or design.
  - **Maximum throughput (bandwidth capacity)** of an existing link – used to determine how much application traffic the link can handle without failure. For example, how many remote devices (AMI collectors, DA points, or IEDs) can be downstream of the device?
  - **Allocated bandwidth or worst-case bandwidth.** This is throughput that is available to each remote device when each device is simultaneously demanding network resources.

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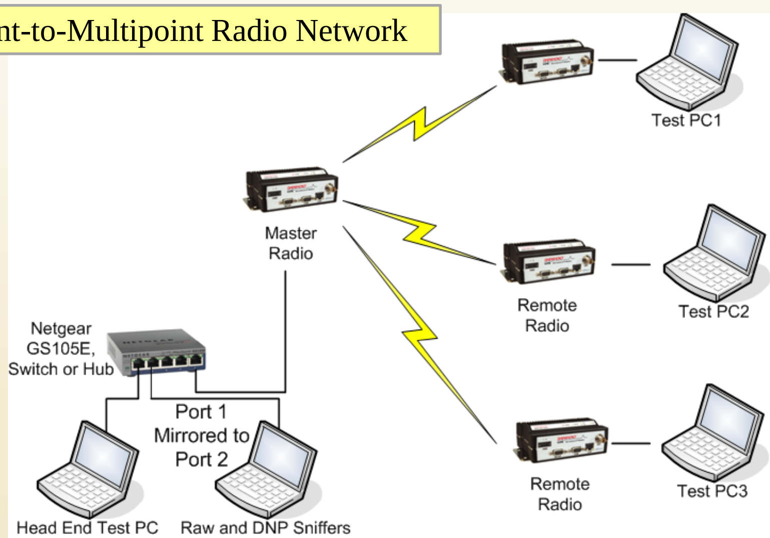
Throughput Measurement Test Setup

Point-to-Multipoint Radio Network



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Measuring Capacity

- **Measured by a point-to-point throughput test between two points in a system.**
  - ➢ It is often useful to know bandwidth capacity of bandwidth limited (bottleneck) link. This is most often the last mile network links.
- Capacity is maximum throughput = no other traffic on network.
- Requires computer with special software loaded on each end. Selection of software depends on type of maximum throughput measured.
  - ➢ Q-Check (TCP and UDP throughput and latency)
  - ➢ Iperf (TCP and UDP throughput and latency)
  - ➢ Ping (ICMP latency, reliability)
  - ➢ Echo servers (TCP and UDP full duplex throughput and latency)

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Measuring Allocated Bandwidth

- **Measured by a point-to-multipoint simultaneous throughput test between one central point and all remotes.**
- Allocated or designed bandwidth or throughput. In an ideal system, this is equal to the maximum throughput divided by the number of remotes.
- This is a measurement of what throughput can be expected in worst-case network conditions, i.e., most contention between remotes.
- As a general rule of thumb, TCP/IP based applications require around 25 kbps to function at worst case throughput. A well designed network will allocate 25 kbps of bandwidth to each network device.

Measuring Application Throughput

- Measuring application throughput in a lab or small scale setup is **highly recommended** prior to design of any system so all communications links can be appropriately sized.
  - Sizing impacts not only design of last mile network but also sizing of backbone links and even backbone media selection.
  - Impacts sectorization schemes in point-to-multipoint radio.
- Failing to correctly size links may result quality of service issues.
  - Low throughput, high latency, dropped packets, increased retransmissions, failed, or unreliable communications.

Application throughput testing procedures will be covered in the next section.

Estimating Capacity with Ping Tool

- It is possible to *estimate* throughput using the **ping utility**: a basic network diagnosis tool built into many IP native devices.
- Using ICMP protocol ping calculates round trip time (latency) and success rate.
- Latency and bandwidth are related.
- Ping payload size adjusted.
- Ping tests can be performed without having a computer on each end of the link in question, saving time and labor in troubleshooting and diagnostics.

Estimating Capacity with Ping

Disclaimers to this approach are:

- The defined method does not model UDP or TCP throughput as overheads are not accounted for.
- Loss asymmetry and true packet loss is unknown without initiating pings from both ends.
- If ICMP packets are sent too quickly, they will queue up and could skew results.
- Congestion and contention on network will impact round trip delay measured by ping. It is unclear if this traffic will accurately or consistently measure worst-case bandwidth capacity (or allocated bandwidth).

Challenges with Bandwidth-Limited Networks

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Bandwidth Limitations

- All communication systems have some bandwidth limitation that may cause a bottleneck in a network.
- Wireless systems that provide the most coverage are often the most bandwidth-limited.
- On the other hand, wireless systems that have the most bandwidth often have poor coverage.
- Depending on application, electrical utilities generally deploy systems that provide superior coverage over bandwidth.
- Understanding these limitations is important to ensuring reliable communications.
- Coverage vs. bandwidth tradeoff in wireless systems.

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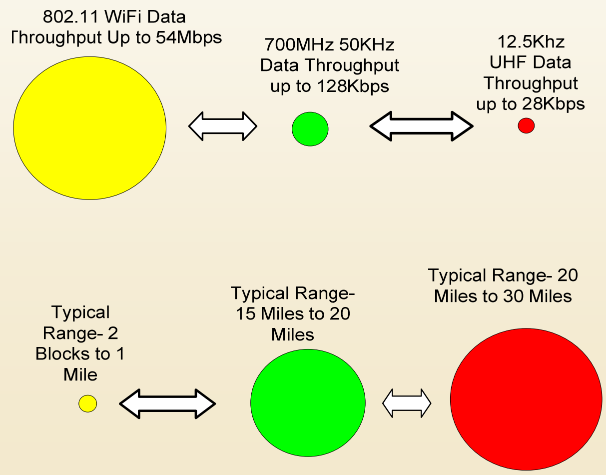
Coverage versus Throughput (For Any Wireless Data Application)

For illustrative purposes only



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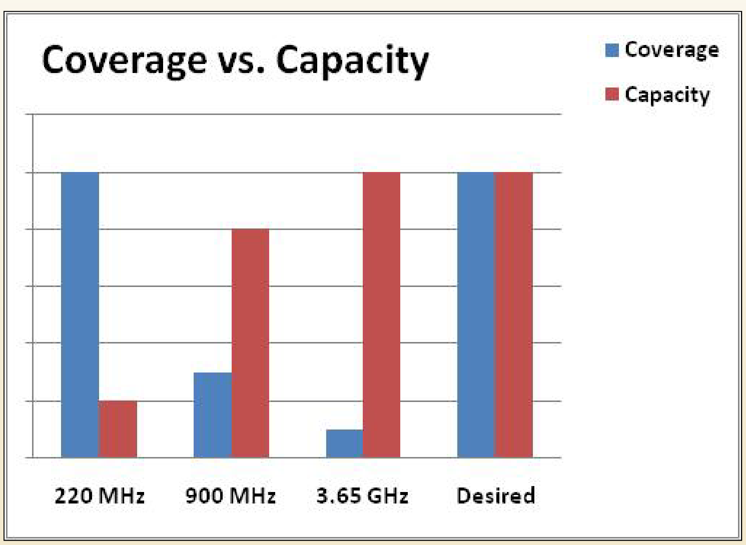
Trade-Offs of Coverage versus Capacity



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Bandwidth Requirement Testing

- How much bandwidth/capacity is required to make the utility's application work?
- The answer is: complete application throughput testing.
- This type of testing is best accomplished in an ideal (unrestricted, e.g. fiber) network. That is one without any relative capacity limitation compared to what is being considered.

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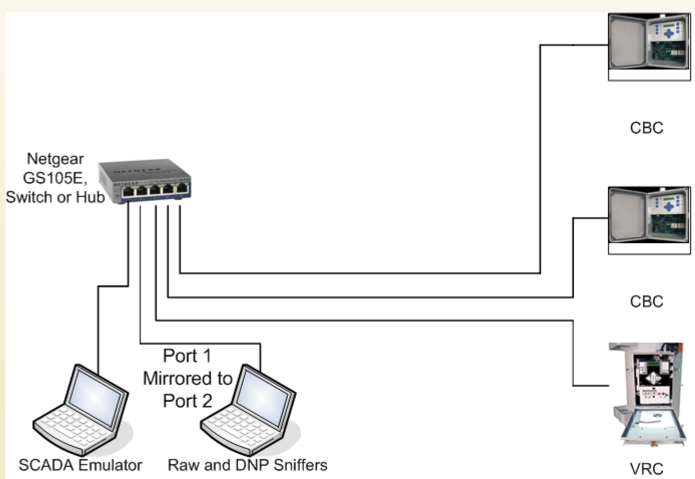
Typical Setup Application Throughput Testing



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Testing Requirement over Unrestricted Link

- Front end master should poll with the same settings as in full system: poll rate, poll mode, and wait on response times.
- Device should be configured as in real deployment. Analog dead band settings, DNP maps, wait on response time, polling mode, unsolicited events, etc. Device should also be connected to voltage/current simulator (or live in field) such that real event data will be generated.
- The monitoring laptop will "see" all communication between devices and master. This data will be captured by raw packet capture tool, such as Wireshark, for future analysis.

Bandwidth-Limited and Simplex Challenged Products Mitigation Strategies

If bandwidth constraints or simplex challenges cause problems with communications, there are mitigation strategies:

- **Front End Processor (FEP).** FEP consists of an embedded computer, RTU, or data concentrator at the WAN gateway location. This device will interrogate downstream devices in a slower, more controlled round robin and will wait for response before polling again. The SCADA master would interrogate the FEP at any pace desired, and receive values stored within the FEP database.
- **Hierarchical design strategies.** Utilize higher bandwidth technologies (fiber, microwave links, line of sight point to multipoint radio products, etc.) to strategic points in the network where the bandwidth limited product is deployed to fewer locally distributed endpoints.
- **Leverage other technologies** for backhaul, where possible, to reduce number of devices that would utilize the last mile network.
- **Prioritization** schemes such as VLAN tagging.

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Prioritization for Better QoS

- Prioritization of packets, such as using VLAN tagging, is one method of ensuring priority traffic gets through first.
- Make sure the communication device supports true over-the-air prioritization according to IEEE 801.1q.
- Some vendors claim to support VLAN tagging but will only pass VLAN tagged packets, not inspect and prioritize VLAN tagged traffic.

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PSE would like to thank you for your time and the opportunity to speak at this event.

Thank You.

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About PSE

- Power System Engineering, Inc. (PSE) is a full service consulting firm for electric utilities.
- The professionals at PSE include engineers, IT and communication experts, utility strategy experts, economists, and financial analysts.
- Established in 1974 to serve the engineering and technology needs of electric utilities, now has served more than 250 clients including distribution cooperatives, G&Ts, municipal utilities, and IOUs.
- 100 % employee owned and managed.
- Offices in Wisconsin, Ohio, Minnesota, South Dakota, Colorado, and Indiana.
- PSE is independent:
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  - Our entire business model is based on being an agent, advocate, resource, and technical advisor to our clients.

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PSE Services

PSE provides a full range of engineering, economic, and planning services to utilities nationwide. Some of our services include:

- Communications (Fixed and Mobile)
- Technology Work Plans, Strategic Plans & Project Management
- Transmission & Distribution Studies and Planning
- Transmission & Distribution Line Design
- Daily Operations & Engineering Support
- Rates and Cost of Service Studies
- Time of Use and Dynamic Pricing
- DG Rates and Contracts
- Energy Efficiency & Demand Response Evaluation
- Load Forecasting with & without Demand Side Management
- Carbon Footprint Studies
- Consulting on AMI, SCADA, IVR, OMS, GIS, CIS, etc.

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