Smart Grid Interconnections, Communications and Implementation

New Energy Forum (NEF)

2013

New Energy Forum

1. Solar Energy
2. Wind Energy
3. **Energy Storage and Smart Grid Technologies**
    1. Energy Storage Market and Technologies
    2. Smart Grid Regulation, Policy and Investment
    3. Grid Integration and Energy Storage for Renewable Energies
    4. **Smart Grid Interconnections, Communications and Implementation** *(8:30 to 8:35)*

       September 28, 2013 (Saturday)
       Chair: Leonhard Korowajczuk- CelPlan International, Inc. , USA
       Co-Chair: Patrick Avery- G&W Electric Company., USA

       4.1. Smart Grid Wireless Design Considerations *(8:35 to 9:00)*
       Leonhard Korowajczuk- CelPlan International, Inc., USA

       4.2. Smart City Development in Sino-Singapore Guangzhou Knowledge City (9:00 to 9:25)
       Nee Pai Chee,- Sino-Singapore Guangzhou Knowledge City, China

       4.3. Renewable Energy Automation (9:25 to 9:50)
       Patrick Avery- G&W Electric Co., USA

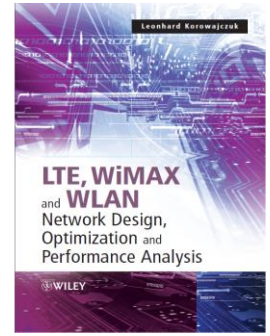
       4.4. Smart Grid and Security Analysis in the context of AMI (Advanced Metering Infrastructure) (9:50 to 10:15)
       Akbar Hussein- Aalborg University, Denmark
4. Offshore wind energy and marine renewable energy
5. Advances in other New Energy technology
6. Hydrogen Energy
7. Renewable Bio-Energy
8. Nuclear Energy
9. Geothermal Energy

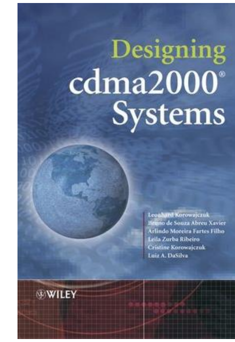
SMART GRID

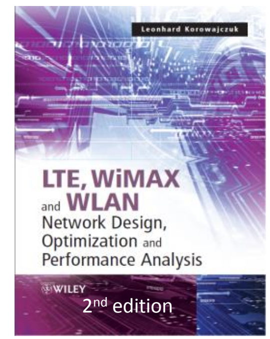
- During the last century energy generating plants were interconnected into a GRID
  - Users are energy consumers connected to the GRID
- During this century the increasing power demand will require significant changes to the GRID
  - Users will become power consumers and generators
  - Energy will have to be stored during low demand and used during high demand periods
  - Energy use will have to be more rational and efficient
  - The next-generation power grid has to improve upon the GRID weaknesses, which are:
    - Centralized power generation, with huge losses in transmission lines
    - Lack of coordination between energy production and consumption
    - The GRID has to become a SMART GRID
- This next-generation power network is referred as SMART GRID
- The SMART GRID concept requires an overlaid communications network that:
  - Must be able to reach every point of the interconnected power network
  - Provide wideband communications for real-time usage, performance and automation
  - Provide adequate reliability and availability
  - Be cost effective

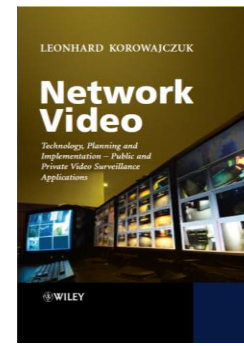
Presenter

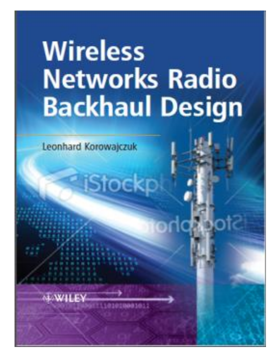
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and services areas)
  - Holds13 patents
  - Published books
    - “Designing cdma2000 Systems”
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book and Kindle
    - “LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis ”
      - published by Wiley in June 2011- 750 pages, available in hard cover, e-book and Kindle
  - Books in Preparation:
    - LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis
      - second edition (2012) LTE-A and WiMAX 2.2
    - Network Video: Private and Public Safety Applications (2013)
    - Backhaul Network Design (2014)
    - Multi-Technology Networks: from GSM to LTE (2014)
    - Smart Grid Network Design (2014)

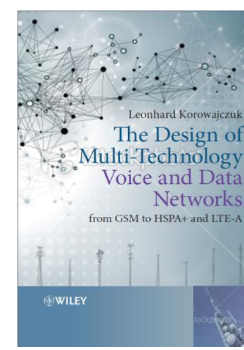










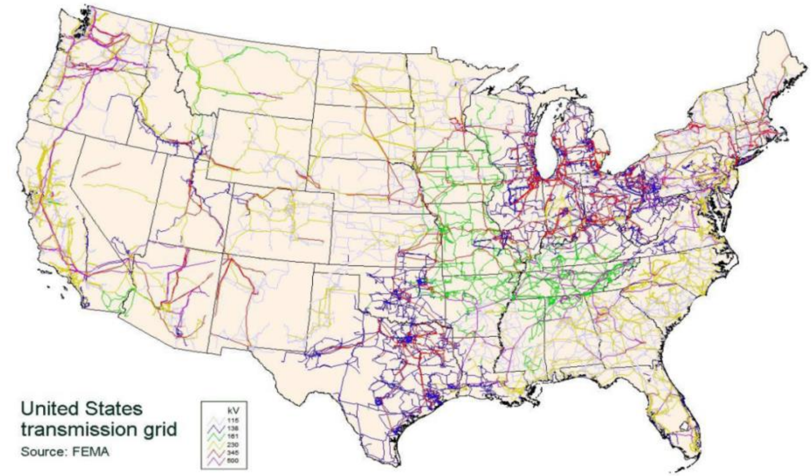


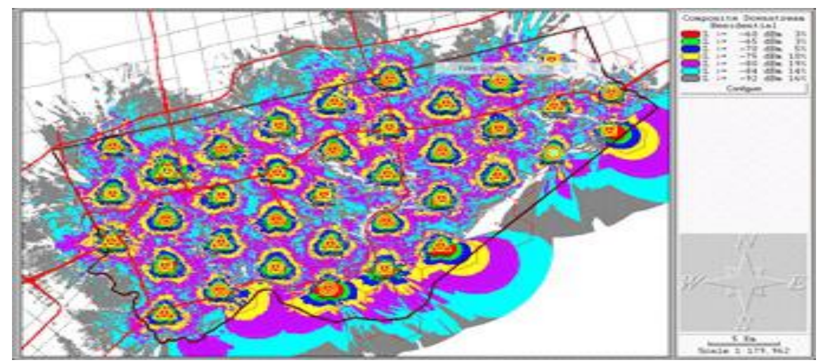
CelPlan International

- *CelPlan has rapidly established itself as an innovative leader in providing the most advanced engineering solutions for the wireless industry.*
- *CelPlan brings a powerful and sophisticated portfolio of software and engineering capabilities to bear on the design and development of next generation wireless*

Solutions & Services for Utilities

- **Smart Grid require Wireless Network Planning Solutions and Engineering Services for**
  - Advanced Metering Infrastructure (AMI)
  - Advanced Distribution Automation (ADA)
  - M2M Communications
  - Smart Grid
  - Intelligent Grids
- **Wireless Network Design for Critical Infrastructure**
  - Designs should be done for wireless networks with specific latency and reliability goals to enable the deployment of power grid automation and other sensitive operations in Critical Infrastructure environments
  - Typical network specifications used during the design & planning exercises are:
    - Reliability: > 99.99%
    - Availability: > 99.999%
    - Latency: < 20 ms





Signal Level (dBm)

Dynamic Traffic Placement Simulation

Smart Grid Wireless Design Considerations

Designing for

Reliability - Availability - Latency

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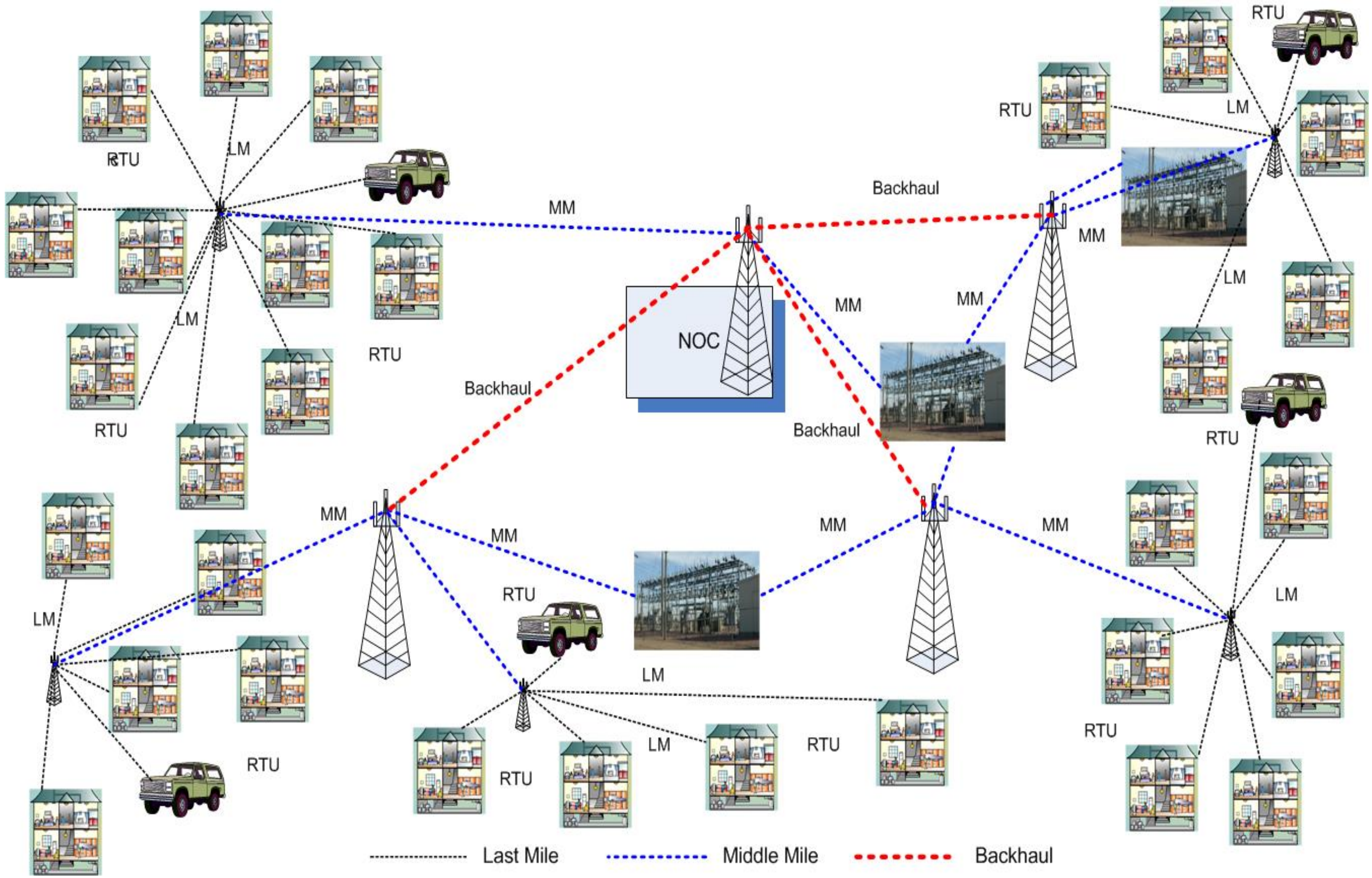
Smart Grid Wireless Architecture

Smart Grid Wireless Architecture



Smart Grid Architecture

- Remote Units
- Interconnection Network
  - Communications Network
  - Communication Network Technology

Architecture- Remote Units

- Remote Terminal Unit (RTU)
  - Distribution Automation (DA): up to 10,000 RTU
    - Polling and autonomous messaging (RTU: 1kbps)
    - Mission Critical (Latency: < 20 ms, Availability: 99.999%)
    - DH (Design Hour) total traffic: 10 Mbit/s
  - Advanced Metering Infrastructure (AMI)- up to 10,000,000 RTU
    - Polling (RTU: 10 bps)
    - Non mission critical (Latency: non critical, Availability: 99.0%)
    - DH total traffic: 100 Mbit/s
  - Mobile Force (MF): 5,000 RTU
    - Low throughput conversational and text (RTU: 1 kbps)
    - Non mission critical (Latency: conversational , Availability: 99.9%)
    - DH total traffic: 5 Mbit/s
  - Video Network (VN): 1,000 RTU
    - High throughput uplink (2 Mpixel, 1 fps, H.264): (RTU: 1 Mbps)
    - Non mission critical (Latency: video, Availability: 99.9%)
    - DH total traffic: 1 Gbit/s

Architecture- Interconnection Network

- Last Mile (LM) Concentration Points (CP)
  - Point to Multipoint (PtM) non LOS (non Line of Sight)
  - Latency: non critical (100 ms)
  - Availability: 99.99%
- Middle Mile (MM) Concentration Points (CP)
  - Point to multipoint mainly LOS (Line of Sight)
  - Latency: 20 ms
  - Availability: 99.999%
- High capacity Backhaul
  - Point to Point (PtP) LOS
  - Latency: 10 ms
  - Availability: 99.9999%

Communications Network

- Commercial
  - Not recommended for last mile (LM) or middle mile (ML)
  - Throughput can not be guaranteed
  - May be considered as a temporary solution
- Proprietary
  - Requires spectrum availability
  - May be expensive
  - Full control
- Shared
  - Provisioned by third party
  - Some implementations allow for bandwidth segregation
  - Growth and expansion may be tricky

Communication Network Technologies

- Cable / ADSL
- All-Dielectric Self Supporting (ADSS) fiber
- Optical Ground Wire (OPGW)
  - Fiber to the Home (FTTH)
  - Fiber to the Node (FTTN)
- Wireless over Power Line
- Licensed Point to Multipoint Wireless / Point to Point Wireless
  - Cellular
  - Satellite
  - WiMAX/LTE
  - Proprietary

Wireless Communication Technology Alternatives

- VHF and UHF Narrow Band (SCADA)
  - 12.5 to 50 kHz bandwidth
  - 100 kbps marketing throughput
- Commercial Cellular
  - Cdma2000, EVDO
  - GSM, EDGE, HSPA
  - Wi-Fi
    - Contention based protocol
    - Throughput drops exponentially with number of users, mainly in mesh configurations
- Satellite
  - Limited throughput
  - Emergency situations
- OFDM Based (4G)
  - WiMAX
    - 200 kHz to 20 MHz
    - Up to 8 MBps (10 MHz TDD)
    - Based on commercial IP infrastructure
    - WiGRID specification
  - LTE
    - 200 kHz to 20 MHz
    - Up to 8 MBps (10 + 10 MHz FDD)
    - Based on operator specific infrastructure

Wireless Communication Technology Alternatives

- The overall solution should be a mix of the listed alternatives
- WiMAX is the most adequate technology
  - Higher spectral efficiency
  - Available for licensed and unlicensed bands
  - TDD oriented
  - Powerful interference avoidance and control
  - Possible frequency reuse of 1, through segmentation and zoning
  - Compatible with regular IT infrastructure
  - Best cost to capacity ratio
  - WiGRID specification specially developed for Smart Grids

Typical System Characteristics

- Reliability
  - Hardware dependable (redundancy)
- Availability
  - Link dependable (redundancy, repetition)
- Latency
  - Delay (confirmation, repetition)

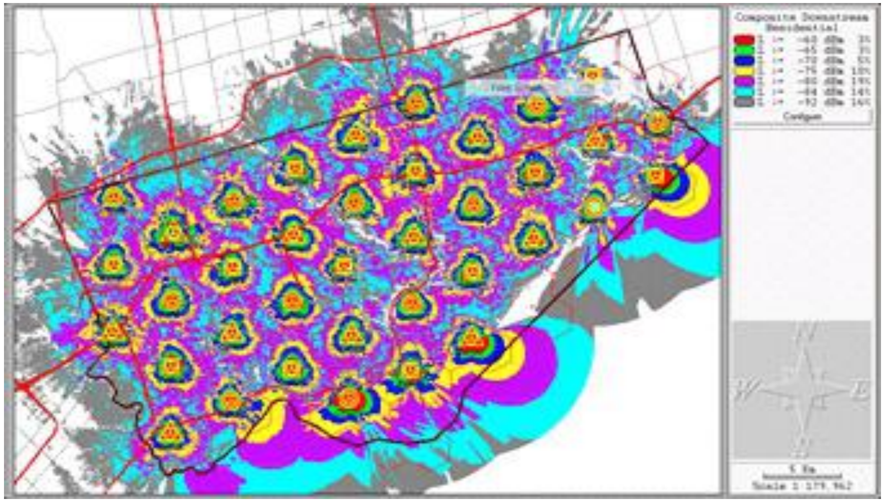
Typical Values							
	Application				Communication		
	AMI	SCADA/MF	DA	Video	LM	MM	Backhaul
Reliability (%)	99.00	99.9	99.999	99.00	99.99	99.999	99.9999
Availability (%)	99.00	99.9	99.999	99.00	99.99	99.999	99.9999
Data Throughput (kbps)	0.01	1	1	1,000	1,000	20,000	100,000
Type	TCP	TCP	TCP	UDP	IP	IP	IP
Latency (ms)	10,000	1,000	25	-	100	20	10
Technology					WiMAX	WiMAX	PM/WiMAX
Band (MHz)					220, 700, 900	2,500, 3,500	6,000, 12,000, 18,000

Network Design

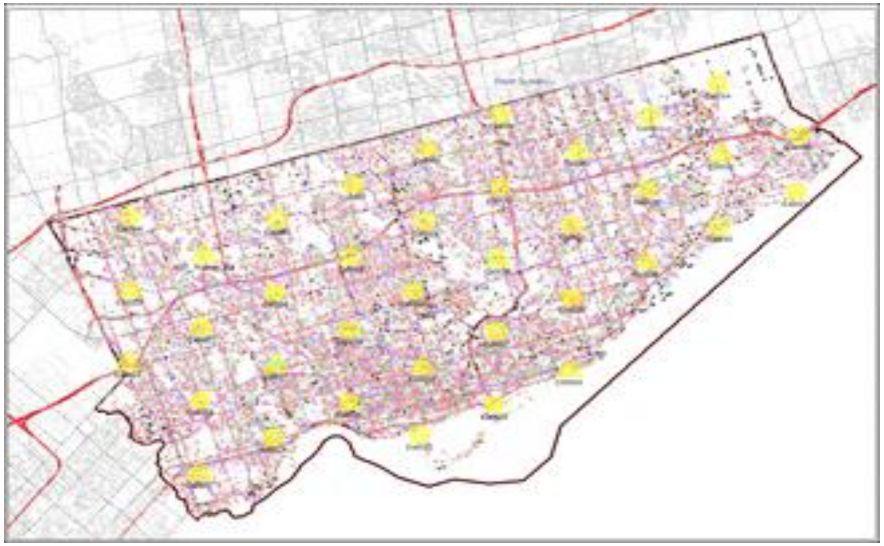
- A mixed network (Wireline and Wireless) is the best solution
- Broadband Wireless network should be utility owned
  - WiMAX is the best technology
- Robust protocol must be used for Network Automation
- A comprehensive design covering the whole network should be done since the beginning
- A professional design must be done covering all applications

Network Design

- RF propagation model is used to calculate the average signal level
- M2M traffic is simulated as a load to the technology of choice
- Service area and capacity are determined
- Availability and latency are calculated
- A proper design saves significant amounts (CAPEX and OPEX) along the life of the network



Signal Level (dBm)



Dynamic Traffic Placement Simulation

Practical Design Examples

Availability Centric Design

Reliability Centric Design

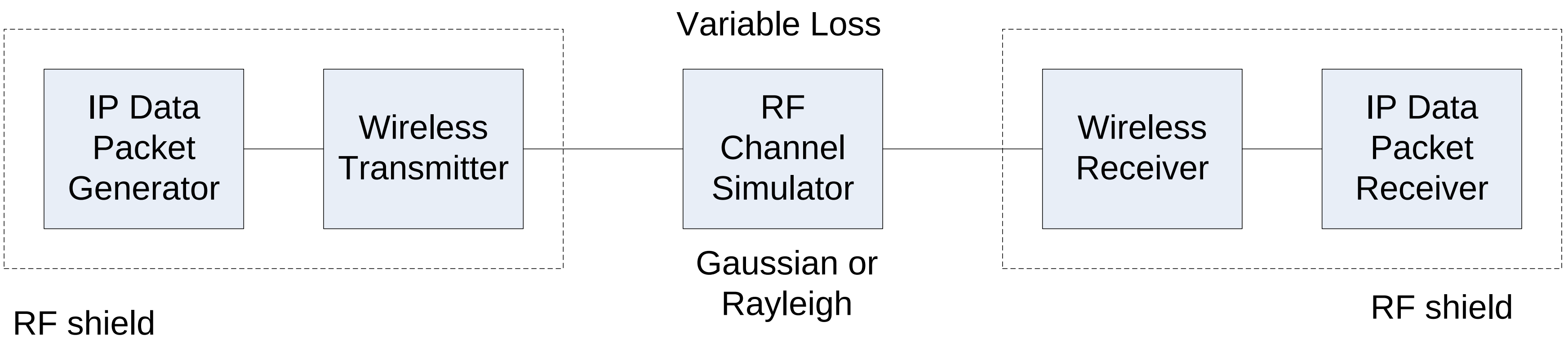
Availability Centric Design

Design done for an Utility Company in Canada

Focus on Automation

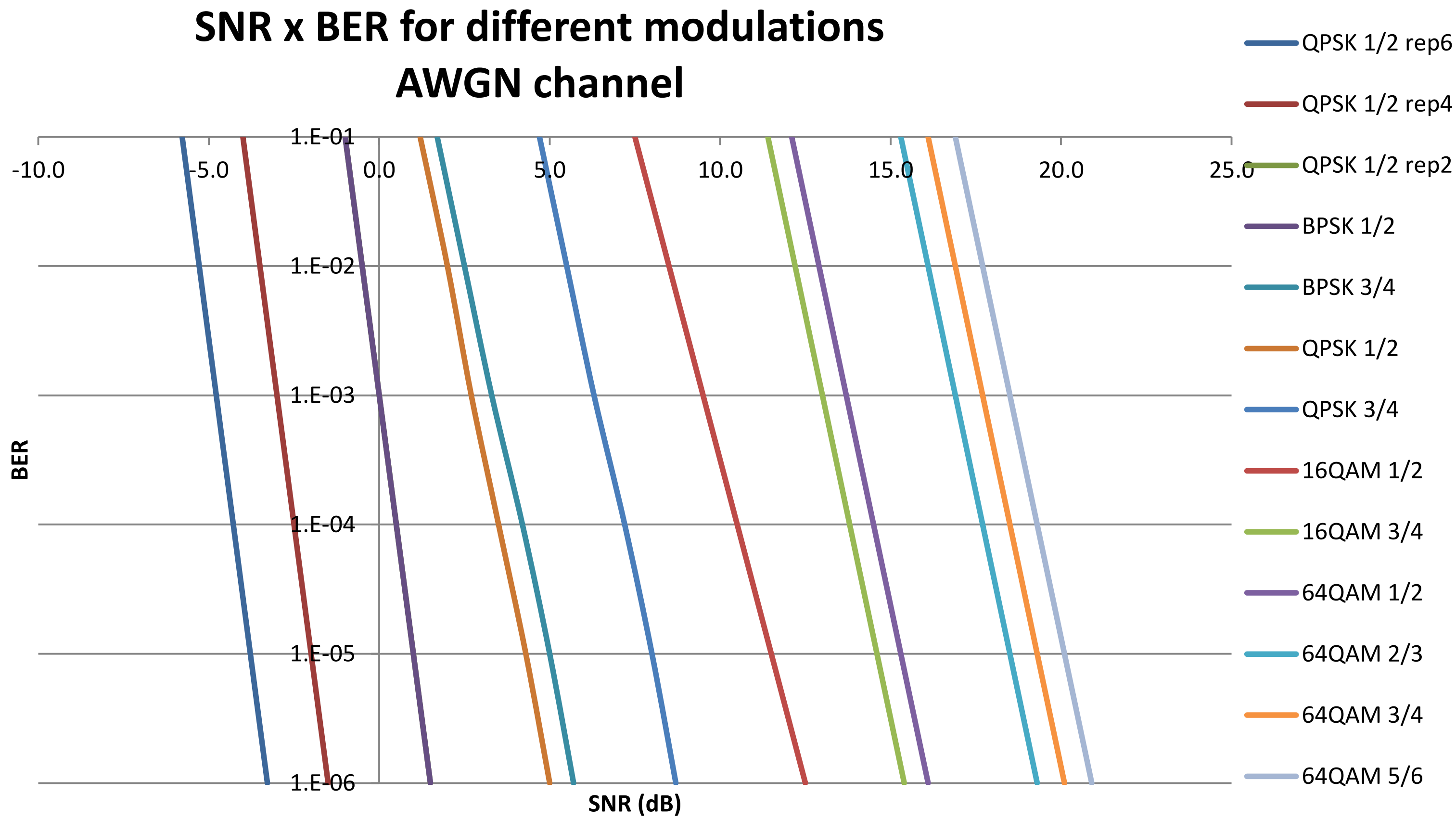
Wireless Channel

- Data transmission based on IP
- Wireless Channel Signal to Noise Ratio (SNR)
  - LOS (Line of Sight)
  - NLOS (Non Line of Sight)
  - Fading
- Data Protocol Overhead
- Error correction (Forward and Backward)
- Technology Used



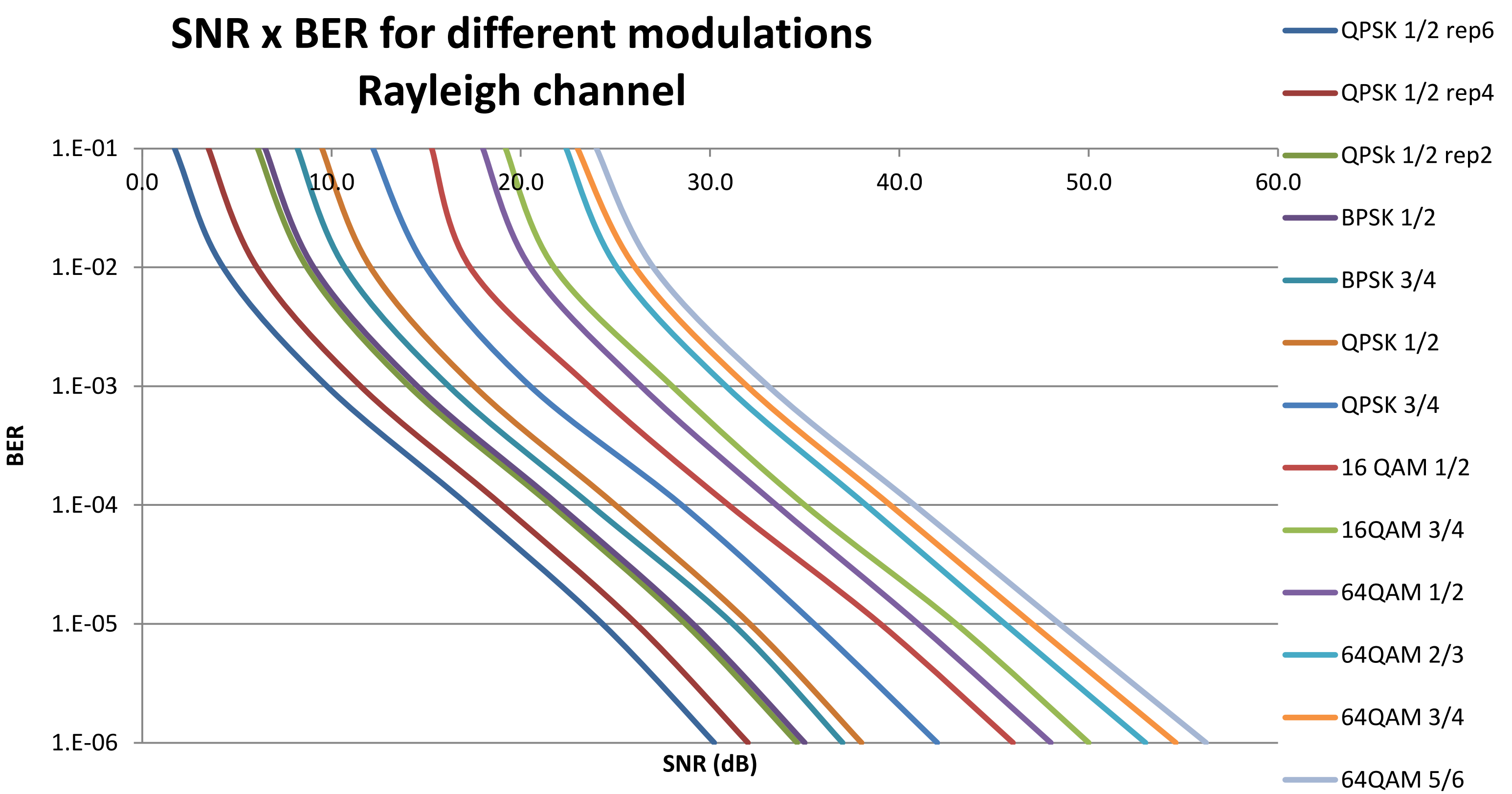
SNR in a Gaussian Channel

- Line of Sight signal is prevalent in this channel



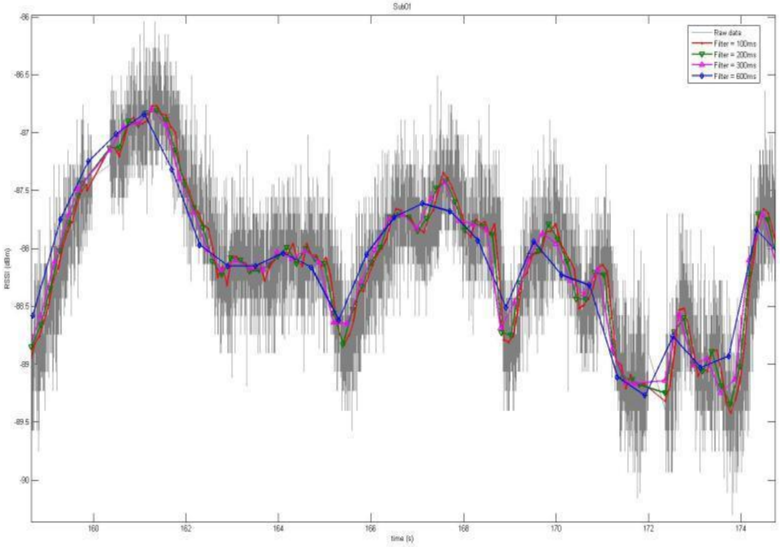
SNR in a Rayleigh Channel

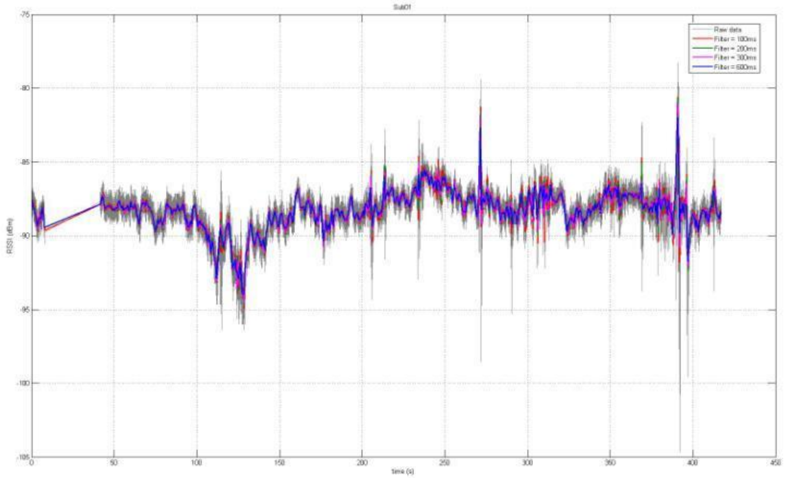
- No prevalent signal is available, in those none Line of Sight conditions



Propagation Characterization

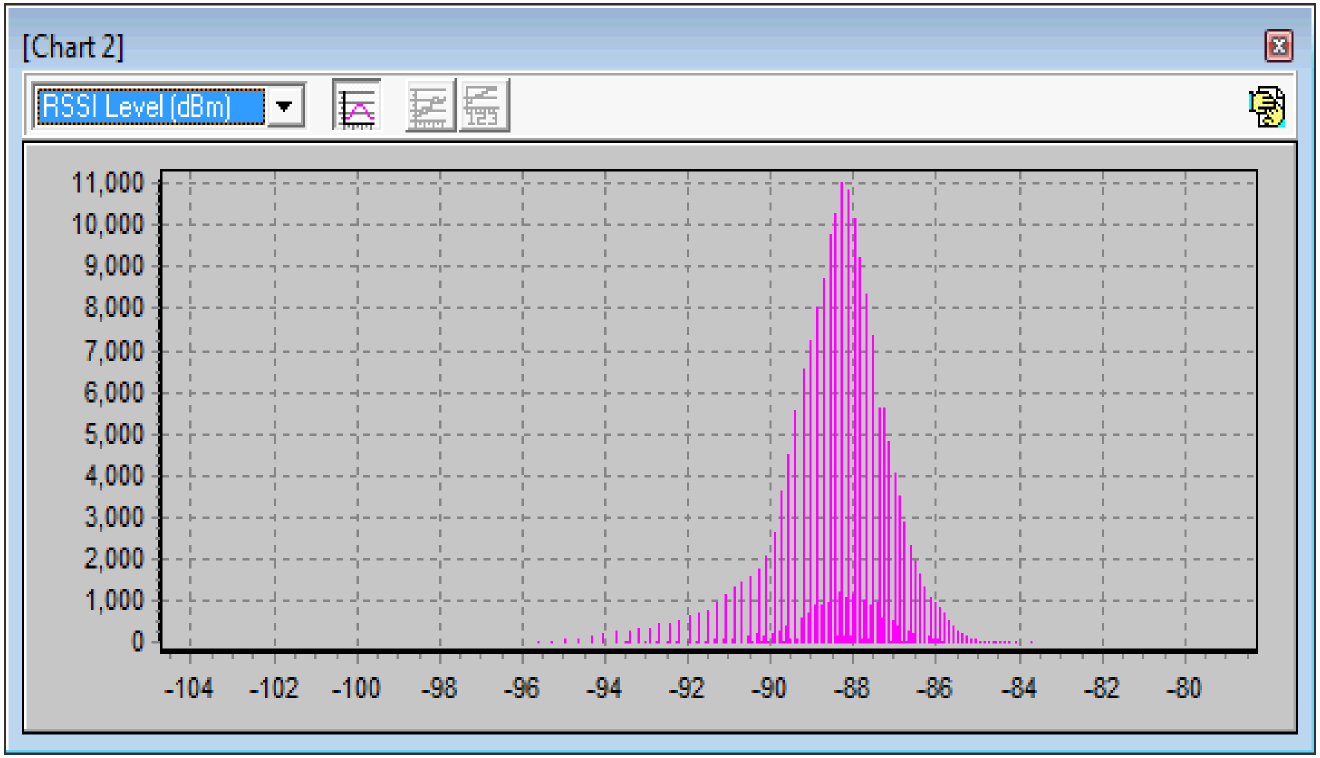
- CelSignal test equipment
  - Data collection
  - Moving and static





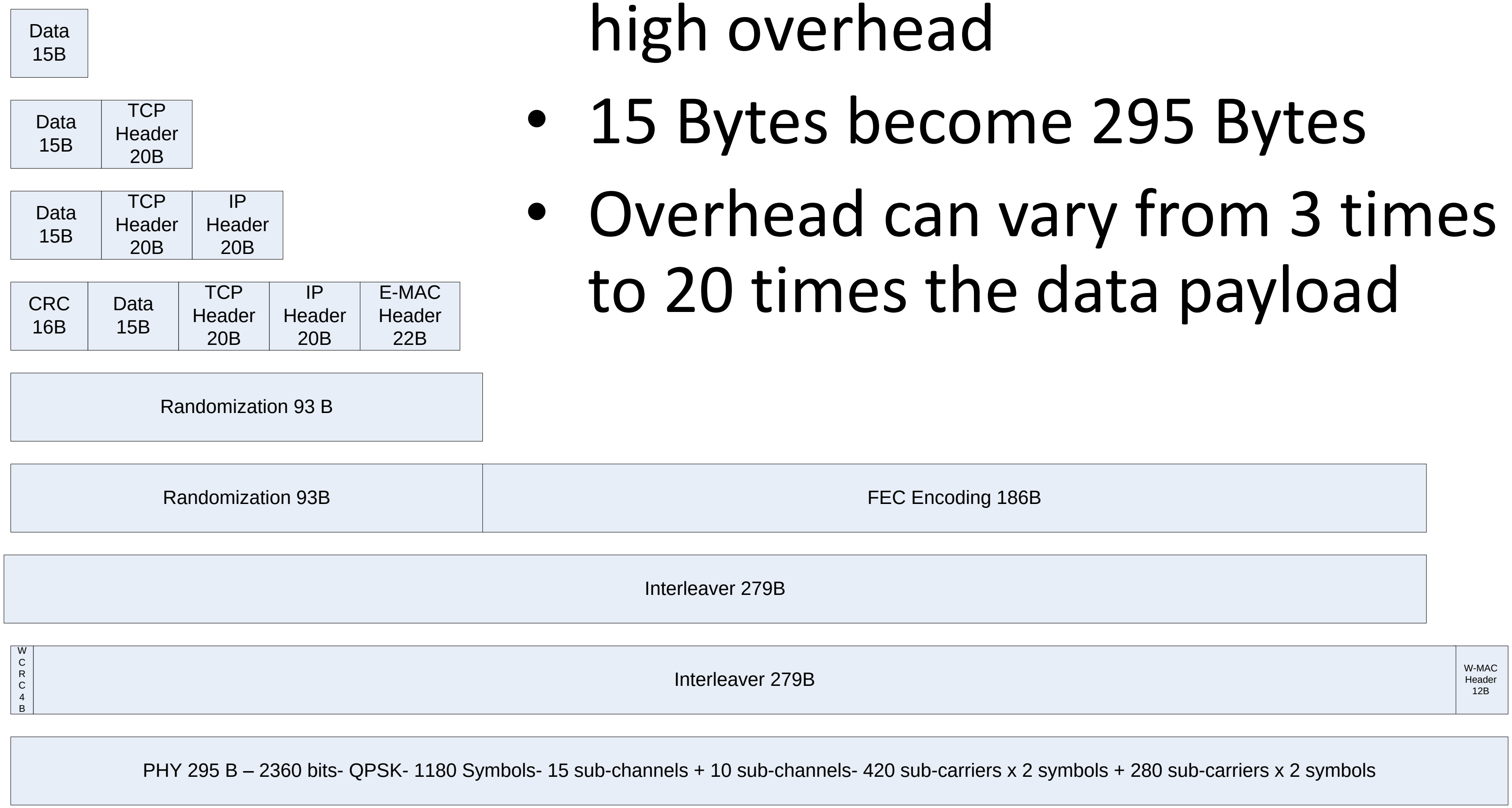
Fading distribution

- Typical signal level distribution during measurement at a location

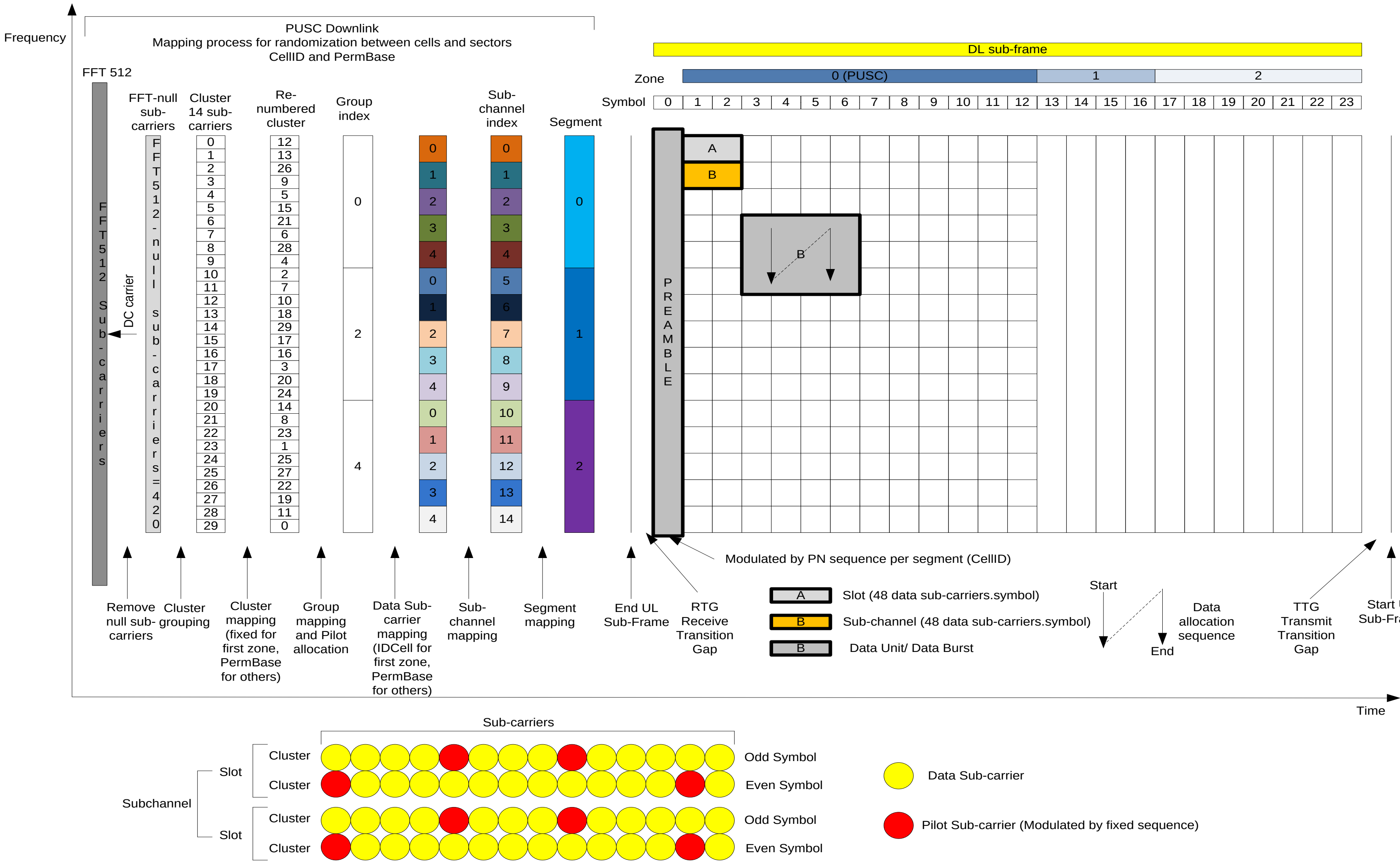


Data Overhead

- Small packets have a relatively high overhead
- 15 Bytes become 295 Bytes
- Overhead can vary from 3 times to 20 times the data payload



WiMAX OFDMA data allocation (PUSC)

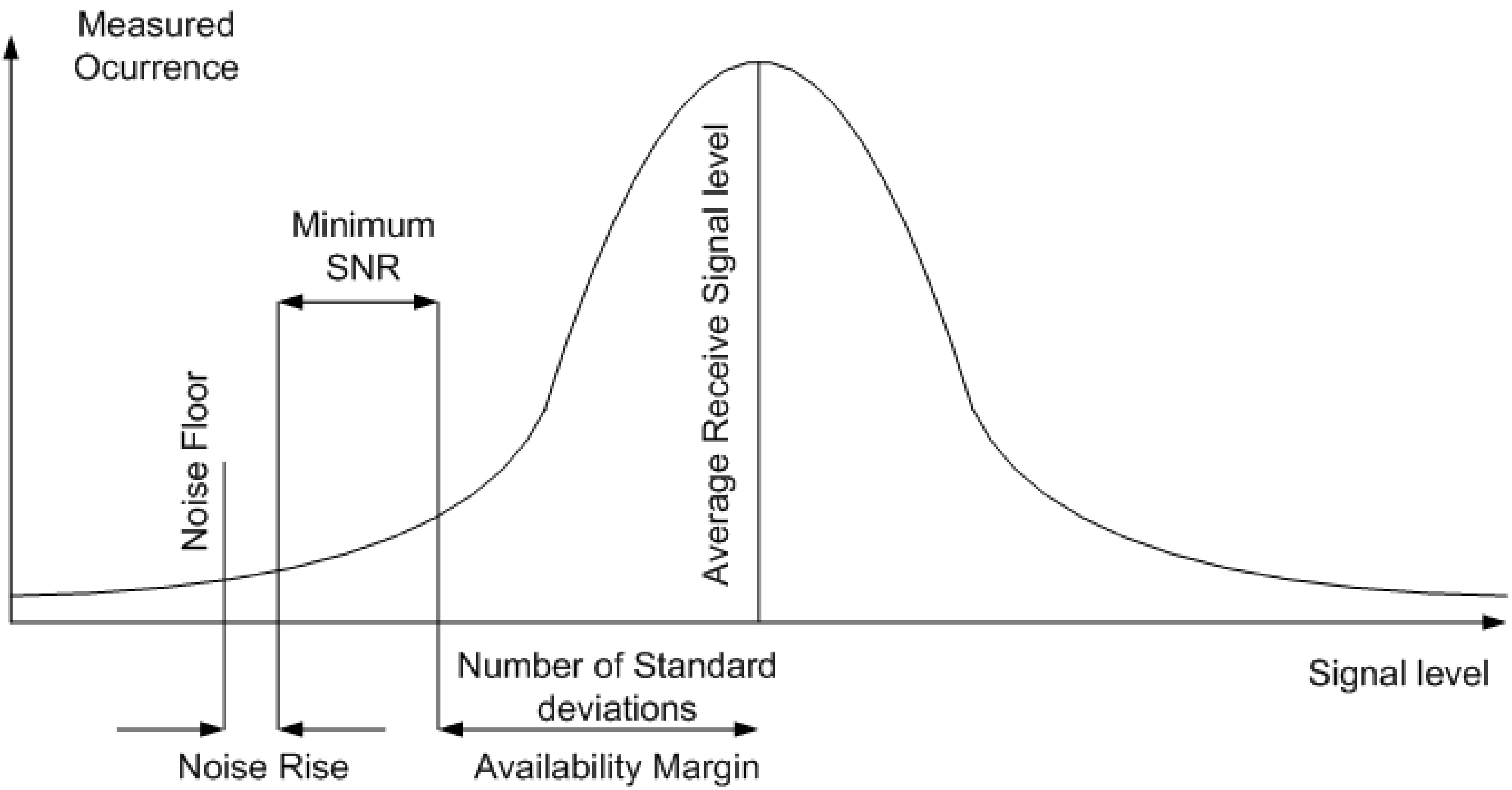


Wireless Communications

- Wireless Communications are designed for a certain error rate
- Error correction instances
  - Forward error correction codes (Turbo codes)
  - Backward error correction codes (Check sum)
    - HARQ (Hybrid Automatic Repeat Request)
    - ARQ (Automatic Repeat request)
  - Message repetition
    - IP- Internet Protocol (no error correction)
    - TCP- Transmission Control Protocol (error correction)
    - UDP- User Datagram Protocol (no error correction)

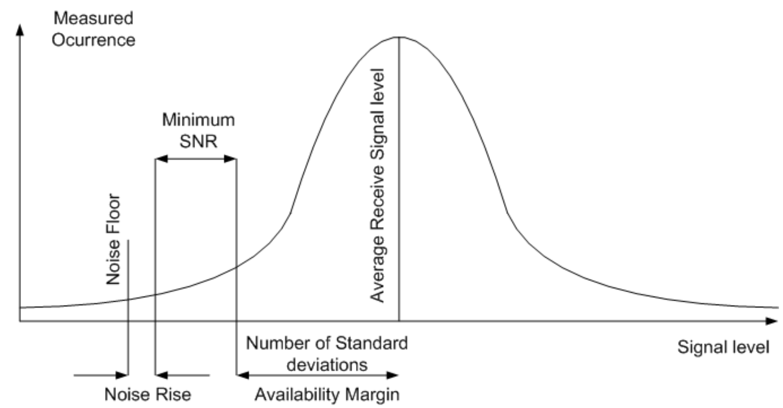
Availability Margins

- Wireless Signal Availability



Availability

- Signal Level Thresholds
  - Noise Floor
  - Noise Rise (due to interference)
  - SNR Margin required by modulation scheme for environment type
  - Average received Signal Level and its statistical distribution
- Margin for availability
  - Defines number of 9s



Signal Level x Availability

- Signal Level Thresholds for 3, 4 and 5 nines availability, considering 1 HARQ cycle

				1 HARQ cycle			
Availability (%)	Error Rate	SNR for QPSK1/2 rep 2 (dB)	Fading std (dB)	number of std	Margin (dB)	Noise Floor +Noise Rise (dBm)	Average Signal Threshold (dBm)
99	10^{-2}	5	1.44	2.33	8.35	-99	-90.65
99.9	10^{-3}	12	1.44	3.09	16.45	-99	-82.55
99.999	10^{-5}	25	1.44	4.27	31.14	-99	-67.86

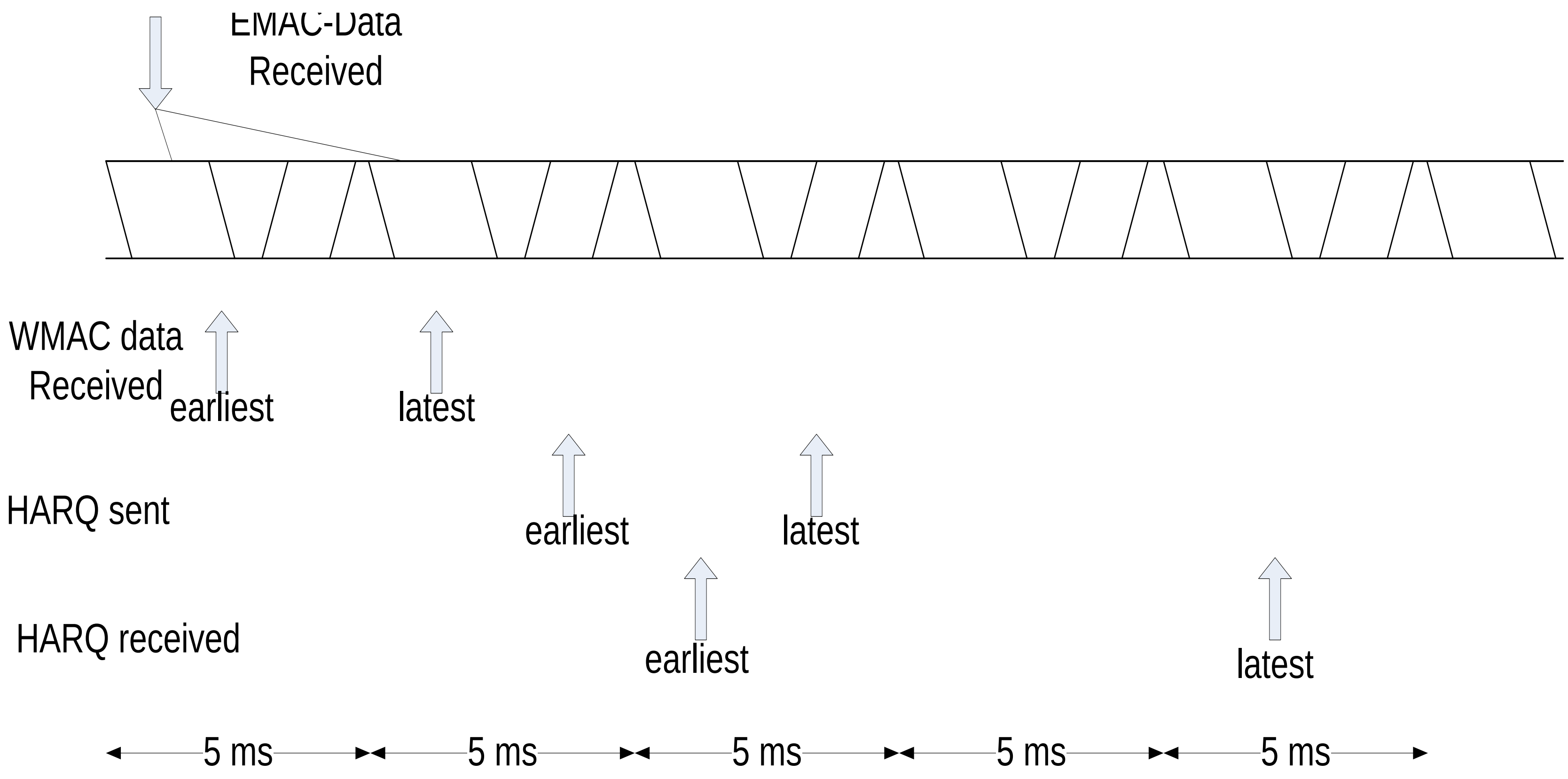
Signal Level x Availability x Latency

- Signal Level Thresholds for 3, 4 and 5 nines availability, considering 2 HARQ cycle

				2 HARQ cycle			
Availability (%)	Error Rate	SNR for QPSK1/2 rep 2 (dB)	Fading std (dB)	number of std	Margin	Noise Floor +Noise Rise (dBm)	Average Signal Threshold (dBm)
99	10^{-2}	5	1.44	1.28	6.85	-99	-92.15
99.9	10^{-3}	12	1.44	1.86	14.67	-99	-84.33
99.999	10^{-5}	25	1.44	2.73	28.93	-99	-70.07

Latency x HARQ

- Latency for WiMAX TDD
  - Function of frame size



Latency

- Requirement: 30 ms
- One HARQ cycle: 15 ms
- Two HARQ cycles: 25 ms
- One ARQ cycle: 50 ms

	Earliest (frames)	Latest (frames)
First HARQ cycle	2	3
Extra HARQ cycle	1	2
ARQ cycle	4	6

Reliability Centric Design

Design done for a Mineral Extraction Company in Brazil

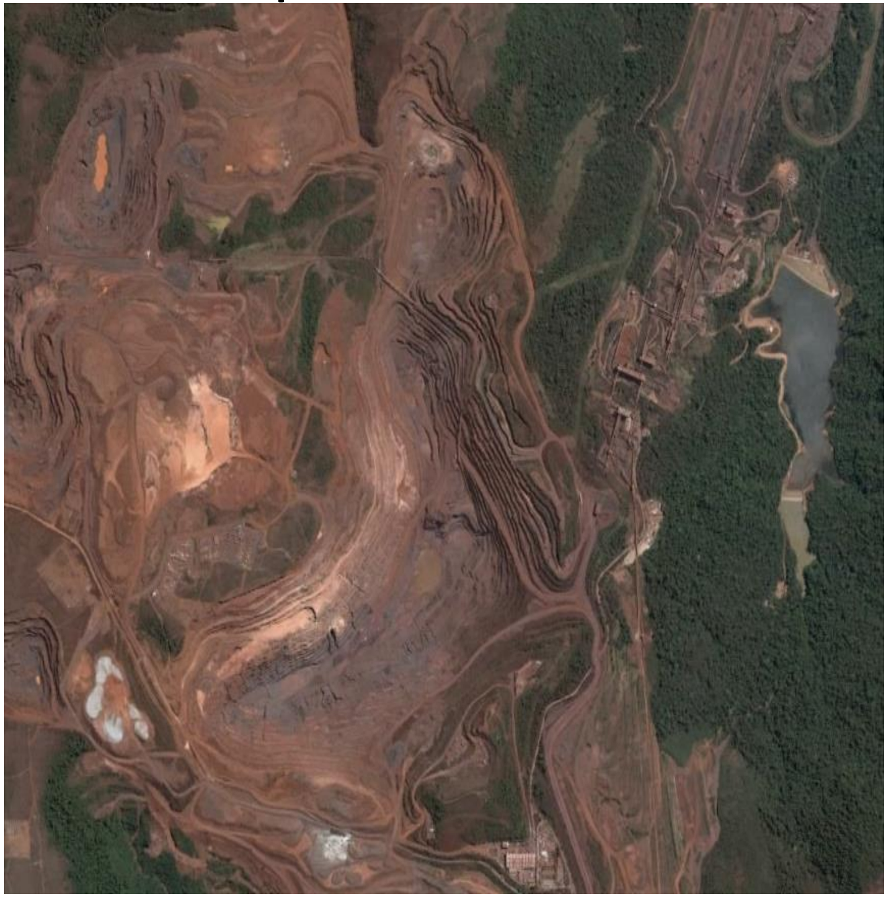
Focus on Reliability

Reliability

- Ore extraction project in North East of Brazil required a reliable high throughput communication system
- WiMAX technology was chosen due to its features, like TDD, fading resilience, flexible data size, segmentation and non proprietary fully IP based infrastructure.
- CelPlan did the design and frequency plan complying with all network requirements
  - Network continues to operate even with two simultaneous failures

Iron Ore Extraction

- Ore is extracted, loaded on trains and transported to the port area



Iron Ore Storage

- Ore is stored until ships are available for transportation

Iron Ore Loading

- Ore is loaded on conveyor belts and transported to ships

Iron Ore Loading

- Monstrous machines on rails process and load the ore
- Operator has limited vision inside the machine and relies on several high definition video cameras to operate
- Environment inside the machines is noisy, vibrating and highly susceptible to equipment damage

Remote Machine Command

- The command of each machine was transferred to an operation Center
- The cost of a non operational machine is very high
- A high Reliability network was required
- Four WiMAX Base Stations were assembled in the periphery of the ore deposit field
- Redundant Video Cameras are able to connect to any of the WiMAX systems
- The system was designed to recover from double failure in each machine and triple failure at the WiMAX nodes

Conclusions

- Smart Grid implementation require a detail characterization of the services to be offered
- The wireless network has to be designed to provide the require QoS (Quality of Service) for each service
- The wireless design will define
  - Technology
  - Site locations
  - Protocol
  - Frequencies, codes and network parameters
- Specialized tools and expertise are required to perform this determinations

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Questions?