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# Methodology for Evaluation and Selection of Wireless Communication Systems for Smart Grid Applications

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## SUMMARY

Smart Grid applications have widely varying communication needs, depending on many factors. Some of these are: primary grid application (SCADA, distribution automation, substation automation), performance attributes of the grid application (latency, throughput, and range), security requirements, and QoS needs. Application layer messages are exchanged between smart grid devices over the underlying communication system. Therefore, for the successful deployment of grid applications, it is extremely important to choose the correct underlying communication infrastructure. The communication system that works well for SCADA may not be a good fit for distribution automation. The challenge confronting every application engineering team is: How should we go about the process of selecting the optimal (performance vs. cost) communication system to serve our grid application(s)?

This paper attempts to provide a clear and well-defined methodology to first evaluate the various available communication technologies and second pick the communication technology that best fits specific application needs. Our focus is on wireless technologies since they are ubiquitous, flexible, and more scalable than wireline technologies.

The first step in the evaluation process is to understand grid applications and their performance characteristics. Then, we have to review the many different communication technologies available, and their constraints and limitations. Communication technologies have different performance characteristics and no single communications technology will fit all needs. In many cases, the optimal solution is to deploy a hybrid set of communication technologies.

## KEYWORDS

Smart Grid, Distribution Automation (DA), Wireless, Communication technologies, Advanced Metering Infrastructure (AMI), Quality of Service (QoS), Throughput, Latency.

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# I. INTRODUCTION

The main objective behind smart grid initiatives and distribution automation in particular is to make the electrical power grid "smarter" by having an "intelligent" distribution system that is fully controllable and flexible. Such a system can help operate the electrical power grid more efficiently. It is also self-healing during power outages, which is a significant benefit for both the utility as well as the end consumer [1].

Communications can make or break a distribution automation project. Even though communications typically account for less than 10% of the cost for an automation system, they make the difference between success and failure.

# II. GRID APPLICATIONS AND THEIR PERFORMANCE CHARACTERISTICS

Smart grid applications impose specific and unique requirements on the communication systems that serve them. In fact, a robust communication infrastructure is an essential requirement for smart grid implementation.

Figure 1 shows how advancing grid applications (on the x-axis) impose higher demands on the communication network (on the y-axis). The higher network demand is a mixture of downlink and uplink throughput, message rate, network device density, and latency, among other things.

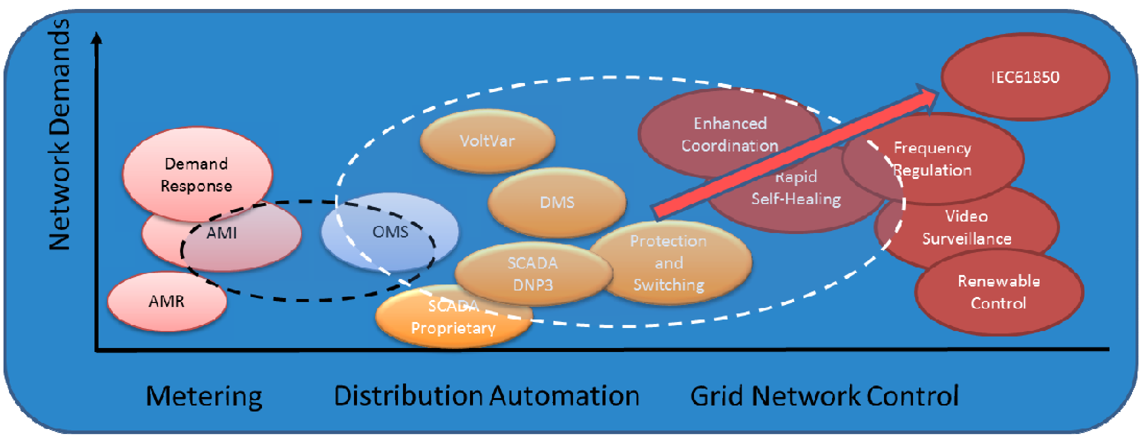


**Figure 1. Grid applications advancement and future trajectory**

At the far left of the x-axis, we have metering applications. AMR (Automated Meter Reading) allows the utility access to consumption records, alarms, and status from customers' premises remotely. However, it does not solve demand-side management and utilities cannot respond to the information received from meters [1]. AMI (Advanced Metering infrastructure) improves upon AMR by being bi-directional in nature. It allows the utility to modify customers' service-level parameters and impose caps on consumption, in addition to collection of frequent usage data on smart meters installed in homes and offices [1] [3].

Moving along the x-axis, we have distribution automation which includes many individual applications with their own specific communications needs – SCADA, DNP3, Volt/Var optimization. Automation and communications are now being applied to a large range of devices including switches, reclosers and sectionalizers. Fault detection, isolation and recovery systems facilitate reconfiguration of the grid in real-time in order to respond to outages [2].

At the far right of the x-axis, grid network control, which includes advanced applications like rapid self-healing, restoration, and communication enhanced coordination, is moving away from centralized, operated included control to regionally distributed control. Outage times must be reduced by opening a switch closest to the fault and potentially contracting power from an alternate source.

An evolution is happening in distribution automation. Higher network demands for services like video surveillance will continue to raise the performance bar for communication systems. They will need to support higher capacity, more device density, less latency, and support for more utility protocols like IEC 61850 (for intra-substation automation).

## III. GRID COMMUNICATION EVALUATION CRITERIA

The critical communications system requirements, from a DA perspective are: performance (latency and bandwidth), reliability, quality of service (QoS) and security.

Figure 2 describes the various communication system requirements in detail, and parameters used to evaluate and compare different technologies.

| Requirement | Parameter |
|---|---|
| **Bandwidth** | **Packet rate** (pps) |
| | Packet size |
| **Quality of Service** | **Latency** |
| | Jitter |
| | Packet Loss |
| | Transaction delay |
| | Traffic Priority |
| **Network Management** | Alarms logging |
| | Statistics logging |
| | Accounting |
| | Privacy |
| | Time Sync |

| Requirement | Parameter |
|---|---|
| **Scalability** | No. of devices |
| | Packet size |
| | Multicast |
| **Availability** | Uptime |
| | Redundancy |
| | Fault tolerance |
| **Security** | Authentication |
| | Authorization |
| | Confidentiality |
| | Privacy |
| | Integrity |
| | Segmentation |
| | Threat detection & mitigation |

**Figure 2. Distribution automation communication system requirements**

The two most important parameters used to measure network performance are latency (maximum time in which a message will reach its intended destination) and bandwidth (data rate or communications link speed). In turn, latency is directly impacted by the data rates supported by communication system as well as the network architecture and topology (the number of hops that the message has to traverse from source to destination) [2] [3]. The system bandwidth comes into play when a large number of devices are communicating simultaneously over a large geographical area. Additionally, applications like video surveillance are inherently bandwidth intensive requiring multiple megabytes per second of capacity.

The purpose of QoS is to assign priority levels to traffic, so that the network can recognize and prioritize routing of data packets belonging to a latency-sensitive application. This will help achieve predictable and low levels of latency for the latency-sensitive application [2].

A network management system is required to manage and monitor the communication system. It provides a comprehensive view of the communication network's configuration and performance, via periodic data collection from each node in the network. It also allows network administrators to make configuration changes and perform software upgrades from a central location.

A communication system built to serve distribution automation needs has to be scalable in order to allow a growing base of smart meters, DA devices, and future renewable energy resources. It should have the speed and capacity to support advanced grid applications in future.

Due to the mission-critical nature of DA applications, they require a communication network with high levels of availability, defined as the expected network uptime under normal conditions. It is measured by a "number of nines". For example, "four nines" equates to 99.99% availability, or under and hour of downtime in a year. The purpose of the grid automation project is to improve the electric system reliability. Events that affect the electric system can also impact the communication system. A highly available and resilient communication system is critical to ensure that the reliability improvement programs will perform properly in the midst of such challenging conditions.

Security is important to wireless networks because of the shared and accessible nature of the medium. Security requirements are also more stringent due to the mission-critical nature of distribution grid and applications that run on them [2] [3]. Multiple levels of user access with different privilege levels need to be supported and the data being transported over the network needs to be encrypted. Mechanisms need to be in place for anti-spoofing and preventing denial-of-service (DoS) attacks.

## IV. PERFORMANCE ATTRIBUTES

Figure 3 attempts to classify grid applications in three categories, based on their latency requirements. The x-axis is in log scale and indicates one way latency in seconds.

Grid applications fall in 3 major buckets:

1. Latency tolerant – AMI, CES, OMS, DMS where latency does not matter for the most part.
2. Latency sensitive – Rapid self-healing and communication enhanced coordination where an increase in latency can cause a large difference in the end result of the smart grid application.

3. Latency intolerant – within substations, or within the transmission system, where we are using sampled values.

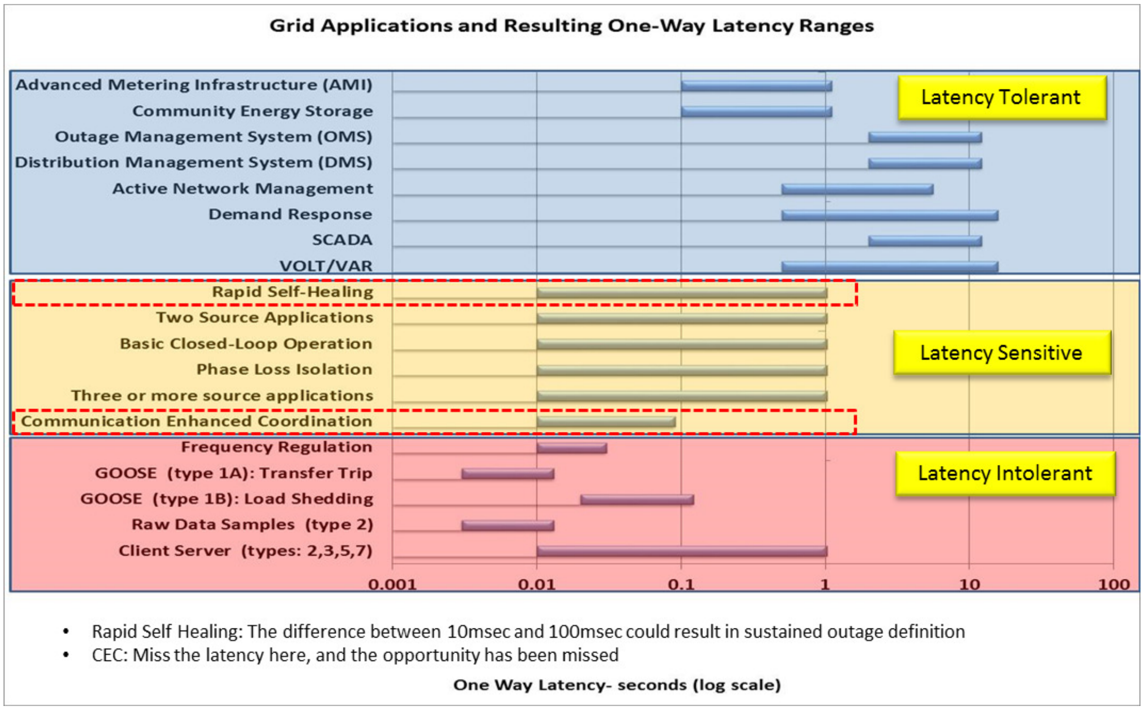


**Figure 3. Latency requirements for grid applications**

As the latency requirements get more stringent, the throughput and availability requirements are higher. This is illustrated in Table 1.

| Application | Throughput (kbps) | Latency (msec) | Availability |
|---|---|---|---|
| • AMI & Demand Response<br>• Legacy Distribution Automation (SCADA, Volt/Var, DMS, OMS) | <100 | 500 to 1000 | 2 to 3 NINES |
| Grid Automation & Control:<br>Rapid Self-Healing | >100 | <100 | 4 to 5 NINES |
| Grid Network Control:<br>Communication Enhanced Coordination | >300 | <80 | 5 NINES |
| • Frequency Regulation<br>• IEC61850/GOOSE Type 1B<br>• (Load Shedding) | >500 | 10 to 50 | 5 to 6 NINES |
| IEC61850/GOOSE Type 1A<br>(Transfer Trip) | >1000 | 3 to 10 | 6 NINES |

**Table 1. Grid application demands**

## V. WIRELESS TECHNOLOGIES

Communication networks serving distribution automation systems fall in two broad categories – public cellular networks and private radio networks. The cellular networks are owned and operated by wireless carriers. They offer various tiers of service, based on the underlying cellular technology – from first-generation analog cellular to 3G and 4G networks. Cellular networks offer data rates of upto a few Mbps and latencies in the range of 50-100 milliseconds. They are standards based (GSM, CDMA, GPRS, WiMAX, LTE) and the end nodes can be provided by multiple vendors.

Table 2 provides latency figures for major cellular networks in use today, and the grid applications they can serve.

The use of cellular networks comes with low upfront costs. But they also have significant drawbacks. Since the public cellular networks are owned and operated by third parties, the utility has no control of the communication network that is essential to improving power reliability. Messages between utility automation devices will compete for priority with consumer applications. Additionally, public cellular networks are more prone to security violations and cyber-attacks.

<table>
<tr><th>Cellular Technology</th><th>Latency (msec)</th><th>Applications</th></tr>
<tr><td>3G</td><td>80 - 150</td><td rowspan="2">• Metering/Latency Tolerant Apps<br>• Legacy “DA”<br>• Slow Self Healing (limited range)</td></tr>
<tr><td>WiMAX</td><td>50 - 110</td></tr>
<tr><td>4G LTE</td><td>40 - 100</td><td rowspan="2">• Moderate Speed Self Healing</td></tr>
<tr><td>Public Safety Broadband Network/Private 700 LTE</td><td>40 – 100</td></tr>
</table>

**Table 2. Public cellular networks and their suitability for grid applications**

Private radio networks can be point-to-point (P2P), point-to-multipoint (P2MP), or mesh. P2P and P2MP systems are good for specific primary grid applications like SCADA and latency tolerant traffic such as VoltVar. Mesh systems are superior to point-to-point and point-to-multipoint systems for advanced automation and self-healing applications that require peer-to-peer networking. Advanced protection and coordination require a low latency and high redundancy communication system which most P2P or P2MP systems cannot deliver. In a mesh network, a remote mesh radio is never out of range from a head end radio. This is a common issue with point-to-multipoint systems. Given this, point-to-multipoint systems require a tall tower at the master radio location, which can be expensive to build. In a point-to-multipoint network, if the head end node goes out or there is an issue with the backhaul system, all links are lost. On the other hand a mesh radio system has no single point of failure. A mesh head end radio does not require a tall tower like a point-to-multipoint system. This significantly reduces the infrastructure costs. If a node goes out, or a link goes down, alternate routes through the network will ensure that messages are reliably delivered to the destination.

Mesh radio systems have the resilience required for distribution automation; if some radios are damaged in a storm, the entire system will not be brought down.

Table 3 compares various private mesh radio networks based on latency, peak throughput, frequency, and use for specific grid applications.

| Mesh Type | Latency (msec) | Peak Through put (kbps) | Typical Spectrum | Applications |
|---|---|---|---|---|
| Legacy AMI | 100 - 700 | ~100/ node | 900MHz ISM | • Metering/Latency Tolerant Apps<br>• Legacy "DA"<br>• Slow Self Healing (limited range) |
| Distribution Automation | 25 - 350 | ~300 | 900MHz ISM | |
| Grid Automation & Control Layer3 | 10 - 70 | ~650 | 900MHz ISM | • Rapid Self Healing<br>• Communication Enhanced Coordination |
| Grid Automation & Control Layer2 | 1 - 7 | > 6000 | 2.4GHz<br>4.9GHz<br>5.xGHz | • Backhaul<br>• IEC61850 Type 1B/1A<br>• Future Apps (Video) |

**Table 3. Private radio networks and their suitability for grid applications**

## VI. OTHER ASPECTS IN CHOOSING COMMUNICATION SYSTEMS

The cost characteristics (CAPEX, OPEX) of building a private network as opposed to leasing a public cellular network will be different. Private networks require high upfront investment (CAPEX) but lower maintenance costs. Cellular systems are the opposite requiring negligible initial investment but higher monthly costs (OPEX).

Another important aspect is the coverage area – both size and whether it is urban vs. rural. RF propagation characteristics can be substantially different in these environments. In general, range is lower as frequency increases. That is one reason why lower frequencies have narrow bandwidths (which leads to lower throughput and message rates), because lower frequency spectrum is valuable.

Regional spectrum availability is also a key consideration. A 900 MHz unlicensed mesh system that works well in the US, Canada, Australia, and New Zealand cannot be deployed in Europe due to unavailability of free spectrum in the 900 MHz band.

Unlicensed spectrum like 900 MHz ISM band in North America can suffer from interference. This can be mitigated with the help of Frequency Hopping Spread Spectrum (FHSS) technology where the carrier is rapidly switched among many frequency channels, using a pseudorandom pattern (hopping pattern) known to both the transmitter and receiver. Another option is to lease licensed spectrum and have assurance that no other entity will transmit in the given frequency range and geographical area.

## VII. LAYERED APPROACH

When it comes to implementation, a layered communications approach works best. All communication technologies, from unlicensed and licensed frequency P2P and mesh networks to 3G/4G public cellular networks have their place in the network. For example, communication networks designed for AMI are not necessarily a good fit for distribution automation because they cannot meet the stricter performance requirements for DA. If an AMI network is chosen for distribution automation, it will prevent the utility from realizing the full benefits expected from a DA investment. Choosing a communication technology based on not only the performance requirements, but also the business aspects just discussed will provide for the most effective and efficient solution which is scalable, future proof, and provides enough margin for latency and throughput.

## VIII. CONCLUSION

Fast, reliable, and secure communication networks are a *must have* for success of the smart grid. Communication networks are not one size fits all and it is critical that grid communication system requirements (performance with respect to end-to-end delay and message capacity, QoS, network management, scalability, availability, and security) be kept in mind when designing a communication network for distribution automation. Future grid applications will more demanding and require lower latency and higher bandwidth. A layered, purpose built network approach is efficient, cost effective, and extensible.

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