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SMART GRID COMMUNICATIONS

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SMART GRID COMMUNICATIONS

THESIS

A thesis submitted in partial fulfillment
of the requirements for the degree of
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By
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ABSTRACT OF THESIS

SMART GRID COMMUNICATIONS

Smart grid technologies are starting to be the future of electric power systems. These systems are giving the utilities detailed information about their systems in real time. One of the most challenging things of implementing smart grid applications is employing the communications into the systems. Understanding the available communications can help ease the transition to these smart grid applications. Many of the utility personnel are spending too much time trying to figure out which communication is better for their application or applications. So this thesis presents the different communication types available with discussing the different attributes in which these communication types are going to offer to the utility. Then these communication types are looked such that utilities can quickly understand how to approach the difficult task of obtaining the information from the different smart grid applications by the use of different communication options.

KEYWORDS: Smart Grid Technologies, Communications, Automatic Metering Infrastructure, Supervisory Control and Data Acquisition, Communication Reliability

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December 1, 2012

SMART GRID COMMUNICATIONS

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This thesis is dedicated to my parent, Jerry and Martha Asbery, which have always encouraged me to be enthusiastic and work hard to fulfill my dreams. I would also like to dedicate this thesis to my beautiful fiancé, Kirsten Nichols, for her entire support with continuing my Electrical Engineering education by obtaining my Master's Degree from the University of Kentucky. Without my families support this thesis would not have been possible.

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Table of Contents

List of Tables:

List of Figures:

Chapter 1 - Introduction

1.1 Purpose

The purpose of this thesis is to provide a starting point for electric utilities to begin investing in smart grid applications and to provide communication options to communicate between the technology applications and the utilities central office. The servers that store the application software is stored in house at the utilities central office locations or headquarters. With some of the smart grid applications, the vendors may offer to host the software equipment at their site or a remote site in which the utility will have access to obtain their information. This allows the vendor to maintain the servers and support all the software applications such that the application runs properly. Presented within this thesis, are the various types of smart grid technologies that utilities have available to them and a discussion of what these smart grid technologies can offer. Also presented, are many different types of communication opportunities that a utility might be interested in looking at to use for networking to a particular technology in the electrical generation or distribution field. The communication options available to the utility can offer a variety of advantages and disadvantages that might be best suitable for a utilities particular application. This thesis is not a "how to" guide, it is presented to describe the different types of technologies and communications available today with describing the attributes that which each of them offers. With that said, this thesis is an effort to add guidance to a utility in such a way that the utility personnel have high success in implementing a smart grid application. In addition to describing the multiple options that utilities have available, the final decision will depend on the needs and wants out of the smart grid system.

For each of the topics described within this thesis, the characteristics that the technologies offer will be discussed. One of the main goals in any industry is cutting cost while making a project as successful as possible. This is no different for the electric industry when investing in smart grid applications. Some utilities might see that one communication type may work better than others just due to cost, while another utility may go with a different option because of other communication types only working in certain areas. For each of these technologies that are described, the reliability or speed might be of some importance, by reason of technologies have certain limitations that must be met for the application to work properly. So depending on the situation and challenges that the utility might face, some communications may be a better approach than others.

1.2 Where are Utilities Today?

The smart grid has opened many opportunities for advancement with technologies within the electric power industry. These advancements allow utilities to obtain detailed information about their systems in which utilities have never had available. Before the smart grid, the main objective for the electric industry was to keep the lights on for the customers. Other than wondering about what may be causing reliability concerns, the reliability concerns were how often do lights go out or flicker. The Department of Energy (DOE) and other federal regulatory entities have been pushing to ask the United States to go "Green" with smart grid or other renewable energy sources. With the DOE's call of the nation to go green, utilities are doing their part by starting to invest in smart grid applications. Renewable energy resources make up another group of technologies that produce electrical power such as hydro, wind, and solar power. Governments at the federal and state levels are offering incentives that allow the public to invest in renewable resources to help produce power. States are also adopting renewable energy profiles across the United States that propose a certain percentage of the power produced within that state will come from renewable energy resources. With all of the aggressive incentives and the rapid interest of new technologies within the electrical power industry, utilities have to keep up with the fast pace of technology growth. Utilities are now starting to invest in technologies that are available to help the efficiency of the business. When more technologies are implemented into a business like electrical power industry, the process to run the business seems to get more complicated and technical. The more technologies that are thrown into the mix of the utilities operation, the more the utilities will need to invest in a more technical staff. Many of the utilities that are investing in these applications have not spent any money on real time data applications for many decades or within the utilities existence. Once utilities start investing in these applications it could potentially raise the rates of electricity, in which the customers are already struggling with high the high cost of electricity in the current economic downfall.

Some of these technologies that utilities are investing in are to monitor the electrical power flow within the electric grid and the service location in which power is delivered. To do this, communications are just as important to the utilities as supplying electrical power to the consumer. If there is a poor communication path, there could be false information or no information transmitted to the utility that informs the utility about their equipment in the field. Since utilities are using communications to transmit consumer and system information back to central offices, the concern of the government is focusing on terrorists and hackers obtaining this information from these systems. The United States Government has issued the National Institute of Standards and Technology (NIST) group to set the standards for smart grid technologies. These standards cover the aspect of cyber security and what standards these Smart Grid technologies should incorporate. (NIST Roadmap) This thesis discusses the two main smart grid applications that are implemented throughout utilities, which are Automatic Metering Infrastructure and Supervisory Control and Data Acquisition.

Chapter 2 - Smart Grid Technologies

2.1 Automatic Metering Infrastructure (AMI)

The overall goal of generating electricity is to provide a reliable and inexpensive service to the consumer. The service that electric utilities are offering to the consumer allows for use of lighting, appliances, various types of equipment, and entertainment. For the distribution utilities to make their money for distributing the flow of electricity, the utilities bill the consumers on the amount of electricity in which they use over a particular amount of time. Most utilities bill their consumers or members by a monthly usage of kilowatt - hours (KWh). With the idea of a smarter grid, Automatic Metering Infrastructure (AMI) technology allows the utilities to bill their consumers through a system that reads the electrical meters on a specified period basis. This system allows the meters to get read automatically instead of using manpower or otherwise known as meter readers to read all meters visually. The problem when using visual verification of meter reading is the inaccuracy of human error. When using an automated system, the reading on the display is stored in a register then the register transmits the reading down the power line for a more exact and reliable reading. This specific period in which meters are billed upon might be a monthly, daily, or even hourly period. AMI not only allows utilities to achieve meter readings periodically, but also allows the utilities to keep track of outages interruptions and the distribution system performance. The system performance portion of the AMI system might consist of calculating line loss percentages of the system monthly, verify the billing from the Generation and Transmission (G and T) company, and allows you to monitor meter tampering on the distribution system. These systems also allow utilities to monitor system reading through historical information and to compare the difference in an automated system versus a human reading program.

AMI systems offer many obstacles within the system itself that is discussed briefly within this section. It also offers obstacles and tough decisions when thinking about the idea of how to communicate throughout the system. There are several parts within the AMI system that have to be considered when thinking about the communications. One communication path is within the system equipment. This is when the AMI equipment works together with communications to perform a certain objective. The vendor will usually advocate what you need to invest in or what specifications have to be met in order to have a successful system. The other portion of communications is how to obtain the information remotely such that the information can be accessed inside the utilities headquarters. Utilities need to consider how the information from each meter is going to be transmitted back to the substations, such that the meter information can be collected, organized, and data can be presented to the utility. There are two ideas to achieve this communication path, which are power line carrier or a radio frequency mesh solution. When thinking about how we are going to access the information from the utilities headquarters there can be many different approaches. With AMI applications, the utility needs to have an Internet connectivity address such that the information can be transmitted over the Internet. The AMI data is organized within the vendor's own secure website.

Since meters can be read automatically and even hourly this allows for the utilities to offer many different programs that could potentially help their consumers. With hourly reads, the utility can now offer time of use rates. Time of use rates is an idea that allows the utility to use different rates to bill upon at different times in the day. This will help out the generation and transmission portion of the electrical power flow because it encourages consumers to use electricity when the electrical demand is not in such high demand due to cheaper electricity rates.

2.1.1 Automatic Meter Reading (AMR)

The biggest and most important part of the AMI technology is the idea of automatic meter reading (AMR). AMR is a tool that utilities can use that is going to benefit not only the billing portion of the business but all other departments that make up our utilities. The AMR systems will not only allow the utility to obtain KWh to bill upon, but utilities can now read max demand with time stamps, voltage levels, and the number of outages on each meter per day. This technology is allowing the utilities to have a great deal of information about a specific location that was never available before while having the ability to have quick access to the information every minute of the day. For a demand read customer, utilities can now reset the demand automatically instead of depending on a meter reader to read the meter correctly and also remember to reset the demand on demand meters.

AMR not only is going to give the utilities a range of values about the amount of electricity each meter is using, but there are other indirect segments that the AMR system will report to the utility. For instance, power theft is a huge problem when serving power to a consumer. Before smart grid technologies, the only way to find out if there was an active power theft was to either go to the residence to investigate if there was theft active on a service or if a neighbor was to call into the utilities and report that there is a problem at a particular location. With the AMR segment of the AMI systems, utilities can now tell if someone is using the meter to steal power within a couple days. Before this technology power theft could be an ongoing problem for months. These systems realize that a particular meter is supposed to have no electrical usage on that meter, and if the meter reports any usage the AMI system will alert the utility that there is illegal activity active at that metering location. This technology is alarming utilities at a faster pace than ever before. It also reports if meters are stolen or tampered with while in the meter bases by the use of sustained and momentary outages.

2.1.2 Related Equipment with AMI

As mentioned above AMI systems offer more capabilities then just getting a meter reading. This is a concept that can be understood, because the meter-reading segment of the system is such a large portion of the system that it offers more information about the service location. There are other technologies and ideas that AMI brings to the table that allow the jobs of distribution utilities to be easier. One of these jobs is the idea of collecting money from consumers that have past due balances. Some of these consumers can be rude and forceful when a representative of a utility is at their location. With the idea of not going to the customer's location to disconnect the power, it will prevent the consumer from intimidating the utility representative. This idea is possible by the use of a remote service switch. A remote service switch is a device that is either internal to the meter or used as a collar between the meter and meter base in which allows for an open point of electrical current that flows into the residence. Another service that is offered to consumers is the idea of direct load control. This is a technology that helps out the generation and transmission companies that deliver power to the distribution utilities in which then the power is finally delivered to the consumers. This technology consists of a box which encompasses a couple of relays that disconnect power to either the water heater, air conditioning units or other appliances that is part of the utilities direct load control (DLC) program. Most utilities offer this as a voluntary program that is offered with some incentives to the consumer. This is a program that will drop the generation load by turning off the controlled devices at participating consumers homes to help shed electrical load during the utilities peak times of the day.

2.1.3 In Home Displays

Another big incentive that AMI systems offer to the consumer is the idea of the in home displays. In home displays are designed for the consumers to know information about their electrical usage and general information from the utility. With most appliances inside households today, most of the in home displays will show date, time, and weather. What these devices offer over the other appliances in today's homes is information about the customer's electrical usage and utility related information. For instance, the utility might give the current rate if the utility is incorporating time of use rates within the billing of that customer. The utilities might offer the ability to show actual electrical usage cost throughout each month on a real time basis. Of course this price is going to be just the price of electrical consumption not including the cost of environmental surcharge, fuel charge, and related taxes. These charges can't be included due to the fact that the charge fluctuates from month to month. One obstacle with in home displays is how to transmit the information to the device inside the household. This obstacle introduced the idea of zigbee communication. Zigbee communication is a portion of the meter that transmits the information to the in home display device through a low power radio signal.

The AMI and AMR technologies are allowing another set of eyes and ears out on utilities systems other then the use of SCADA. Many of the smaller utilities are now able to justify the high price of the initial investment when looking to install an AMI system. However like many things, there is more than one way to obtain the objective of having an AMI or AMR system. This is the reason that there are many different vendors or companies that are developing an AMI solution. Table 2.1 shows a breakdown between TWACS and Landis&Gyr's power line carrier AMI solutions.

Table 2.1 – AMI/AMR System Comparison Pricing

AMI/AMR SYSTEM PRICING		
Equipment Description	**Landis & Gyr**	**TWACS**
Substation Equipment	$30000.00/Substation	$40000.00/Substation
Software	$60000.00 (Initial)	$50000.00 (Initial)
Meters	$100.00/meter	$100.00/meter
Disconnect Collars	$250.00/Collar	$160.00/Collar

The AMI vendors base their cost on the type of meters, substation equipment, system software, and the special accessories that perform certain functions within the different systems. Other charges within installing the system come from the labor cost. There are different areas of labor cost that branch out to the personnel that install the substation equipment in the substations and the personnel that set the meters in the field that perform the AMI functions. The substation equipment incorporates all the equipment that is needed to allow for sending and receiving the data signal if 2-way communications of data is present. Some of the AMI systems only allow for one-way data traffic within the system. This path is from the meter to the substation that gives the utility information from the meter. A few of examples of the equipment in the substation equipment category from table 2.1 are transformers, injection equipment, CT's, cutouts, wire, and data collection devices. Some AMI/AMR solutions use a power line carrier technology or a RF (radio frequency) technology to transmit the data to or from the customer's meter. The meters that are listed in the table above are referenced to single-phase meters. It is known that not every customer on the utility system is considered a single-phase customer, so the price for a poly phase meter is going to be higher than the single-phase meters. The software shown in the table is the software that allows the utility to actually know the status of the each meter on their system. This software will give information in the form of the amount energy usage to bill the customer and also informs the utility the performance of the overall system. This is considered the brains of the entire operation. When talking about collected data, utilities need to think about where the data is to be stored. One option that the vendors can offer is to allow the utilities data to be stored in an off-site server that the vendor maintains. The other option is to allow the data server to be in-house on the utility premises. With the in-house option it allows the utility to maintain the server and allows for easier access to any information of interest from the AMI data. Each of these options might need to have a benefit to cost analysis performed such that the correct decision for the utility is made. The other cost that is incorporated with an AMI/AMR system is the decision upon the communication system from the substation to the central office or central server. These communication options will be discussed in chapter 3 with including the attributes each communication option provides.

2.2 Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) systems allow electric utilities to monitor and control equipment in a real time manner for their electric power system. SCADA systems aren't only limited to the electric industry, they are also available to the industries of telecommunications, water, oil, and gas. SCADA systems work by the transmission of data between Remote Terminal Units (RTU's) or Programmable Logic Controllers (PLC's) to a central host computer. The RTU's are normally placed in a closed NEMA 4 rated enclosure that protects the device from the outside environment. The central host computer is the location where all the data is stored and organized. The RTU's are the brains of the SCADA system. Like a collector in an AMI system, the RTU is going to collect and organize the data before sending the information to the central server. The central host computer then sends the data to the operator terminals for viewing and operational purposes. The central host computer is also referred to as the Master Terminal Unit (MTU). The MTU is usually a single server or a network of application servers that help store the field data. The RTU's and PLC's are equipment that is considered to be and known as the data field interface devices. The interface devices interface with the field sensing devices, which include current transformers, potential transformers, regulators, reclosers, capacitors, and switches. These devices that communicate with the interface devices are known as the "ears and eyes" of the SCADA systems in the field and are also referred to as field interface devices. The last part of the system is to incorporate the communication paths within the SCADA system. One of these data paths is between the Remote Terminal Units and the Master Terminal Units. Another communication path in the SCADA system is the communication path from the field interface devices and the RTU's. These communications are mainly to relay the information to the RTU, in such a manner that the RTU can send the information to the MTU. The RTU or PLC converts the electrical signals from the other field interface devices to a language that can be used to transmit the data over a communication network or channel. This conversion of electrical signal to a language is known as the communication protocol. These communications paths are achieved by the use of some sort of cable, fiber optics, or wireless communications. When discussing the communication path from the RTU to the MTU, there are more options that can be considered by the utility. For instance, depending on the terrain of the location of the substation, wireless or radio communications might not be an option due to valleys and hills in the area where line of sight may not be an option. So, there are many communication mediums that could be evaluated when trying to achieve this goal. The communication network needs to have a dedicated IP address for each RTU site to transmit the signal. Reliability is a very important factor when discussing SCADA systems, for example, utilities don't want the communication link to be down when trying to operate a switching procedure. To prevent this, the utility will try to incorporate the most reliable communication type available. If there is a communication failure in the field, the linemen might be danger if the switching procedures did not perform correctly when expected. This becomes more critical for the larger utilities, since they have a larger service area and more employees to perform procedures for doing certain operations. (Communication Technologies, Inc.)

2.3 Other Technologies

Throughout the industry of electric power generation and distribution, utilities are starting to incorporate many different technologies and programs they've never used. Instead of all customer records being on paper inside a filing cabinet or having meter readers read meters, there are computer programs that organize and maintain these records and allow the utility to keep them in an organized fashion. Many of these technologies are compatible enough that they can talk with each other so that all the systems and programs utilities use can work as one system. The idea of more then one system working together is called the idea of multi-speak. This is important in the fact that all the programs that utilities use stay on the same page throughout the entire company. These technologies may consist of: Customer Information Systems (CIS), Integrated Voice Recording (IVR), Outage Management Systems (OMS), Automatic Vehicle Locator (AVL), Engineering Software and Mobile Workforce. Many of these don't need a communication path since these technologies are all located within the central office and can operate on the main network. When considering other technologies and the communication path that is needed within the system, there aren't too many more technologies other than SCADA or AMI. However, Automatic Vehicle Location (AVL) and Mobile Workforce are two applications that utilities are starting to pay more attention too and are going to require a medium such that data is to be transported. Mobile workforce allows a decrease in the amount of paper work that utilities use on a day-by-day basis. For environmentalist, this helps with the aspect that less paper is used and helping with paper not being recycled properly. This technology allows us to send and receive work or service orders to the technicians in the field that need to be performed on a day-to-day basis. The obstacle with this technology is getting Internet access to the field technicians in the field. A desirable way to overcome this is by using cellular company's wireless solutions, keeping in mind that the wireless coverage in that area must be accessible. The other obstacle pertained to this technology is educating the field personnel to use personal computers everyday to access their jobs. Along with SCADA systems, another device that utilities are using more and more are fault indicators. Fault indicators allow utility personnel to be notified when a fault has occurred for a limited amount of time. Utilities are also using these devices to help locate the position of the fault for faster power restoration and to locate the problem that is causing the faults on the power lines. This thesis is going to mainly be looking at the options with AMI and SCADA applications in how utilities get the information back from these systems.

Chapter 3 - Communication Techniques

As the smart grid technologies continue to develop, they continue to help utilities become more aware of their system. The struggle with how to utilize and keep communications to these smart grid applications to obtain the information is continuing to increase. Determining the communication types continues to be the most difficult portion with any smart grid application. One reason for this struggle is the increase in prices from the different communication types. This becomes a problem when determining the benefit to cost analysis for the different communication options. This means that the cost is out weighing the benefit for obtaining the system information. This section will describe different communication options briefly, determine an average cost for the technology, and discuss the strengths and weaknesses that each option provides. Understanding that each utilities needs for one communication type over another communication type might be more effective for the utilities application. During this chapter there is going to be some terms that need to be discussed. These key terms are defined below and will be used through this chapter.

Throughput - Describes the rate of which data packets or data that is successfully transmitted over the communication link or path. This rate is usually presented in bits per second (bit/s). The throughput is usually slower than the advertised transmission rates. This term is also used reversely with the system data speeds.

Latency - Describes the time delay in which data packets are transmitted to the time it takes for the data packets to be received. Depending on the communication type this rate will vary. This measurement is usually measured in seconds.

Range - Describes the length in which the data communication path can travel with low dB loss in the signal. When the range is too long in distance, the reliability of the data transmission can be very poor.

Bandwidth - Describes the measure of data carrying capabilities when transmitted over a communication channel. Systems will be classified as wide band or narrow band to refer to the size of the data carrying capacity.

3.1 Dial-up Communications

Dial-up is a communication option that allows the customer to have access to the Internet. The Internet is retrieved through the users ISP's (Internet Service Providers) using the existing installed telephone infrastructure. Even though this technology is almost extinct, some utilities are still using dial-up for some AMI communications. Of course this technology has very limited amounts of bandwidth. With this limitation, it makes this solution not suitable for all vendors that offer AMI technologies and other smart grid technologies. This technology uses the Internet through the ability of using public switched networks. The one-line diagram in figure 3.1 represents a normal dial-up Internet communication system.

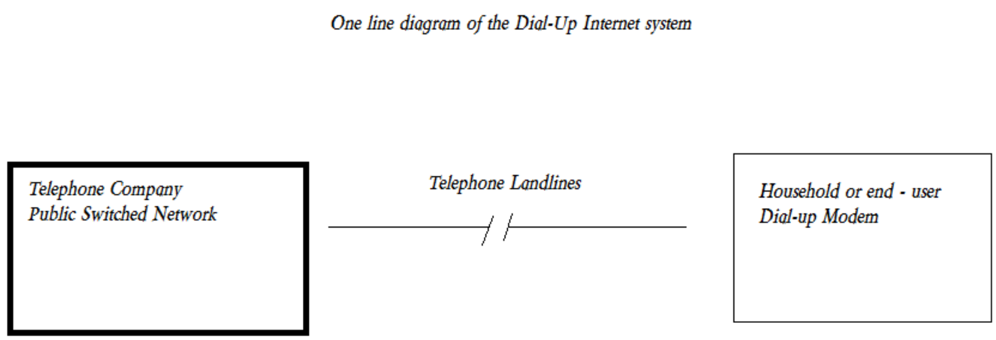

Figure 3.1 - One Line Diagram of the Dial-Up Internet System

This communication is called dial-up because it uses the telephone landlines or twisted pair wires to call into an ISP or also known as IP addresses were a dial tone is heard during the process of connecting to the Internet. Since the telephone lines are used during this process, a dial tone would be expected since that is what is heard when picking up the telephone. Dial-up communications is the slowest but cheapest communication type that is available on the market today. The data speeds that are presented with dial-up communications range from 10 kilobits per second (Kbit/s) up to 56 Kbit/s. In most cases a user is going to experience approximately a 40 to 50 Kbit/s Internet connection on an advertised 56 Kbit/s service. The 56 Kbit/s throughputs is the maximum data transfer speed that can be obtained in an ideal environment. Using the Internet with dial-up will also occupy one landline. So if only one landline connection is purchased, there can be no calls made with the telephone service when the Internet is being used. This communication technology is mainly used in the rural areas where there is no high speed Internet available. With the option of satellite Internet now available, higher throughput speed can be accessed nearly everywhere in which makes the use of dial-up communications extinct. Many electric power utilities will use a telephone in the substations that have no access to cellular or radio coverage. This gives the opportunity for the utility to also use a dial-up connection at this location if Internet is to be used at that particular site. This technology is known to have a very poor reliability mainly due to the speed of the service. If data speeds get so low, certain applications can possible time out and cause an application failure. As discussed above dial-up provides very slow data speeds, which is considered to be one of the disadvantages of this communication option. Other disadvantages of dial-up becomes when accessing the Internet connection it takes up one line of the landline service. This can cause no use of a telephone service until the Internet connection is terminated. When reliability is considered within a communication system the type of communication, the construction of the system, and the physical terrain where the system is located will impact the reliability. Since using dial-up uses the existing telephone infrastructure the reliability is considered to be good in the aspect that the existing infrastructure can be used. The reliability is only going to be poor when equipment or telephone lines fail within the telecommunication system. These lines can be ripped down during a storm or equipment might go bad, which is going to require attention from the telephone company before gaining access to telephone system. The terrain does not effect this communication, since telephone lines are threaded all over the nation. Utilities always want to know what problems are going to be introduced with each technology, but they also like to know what advantages they introduce. Dial-up doesn't bring a great amount of advantages to the table, but the biggest advantage is the cost of the service. Dial-up will cost about 10 ten 15 dollars a month on average for one 56 Kbit/s line of service. Throughout this thesis, there will be statistics that are presented to show that each technology available is going to allow a utility to gain in one area but give up some feature in another area. For dial-up communication, the utility will obtain a cheap price for Internet, but the utility is going get very poor throughput speeds and reliability. (Dial-up Internet Access)

Table 3.1 - Advantages and Disadvantages of Dial-Up Communications

Dial-Up Communications	
Advantages	**Disadvantages**
Price - Approximately 15 dollars per month	Speed - Maximum of 56 Kbit/s (very low bandwidth)
Reliability - Great (Uses existing Infrastructure)	Only one user per line
Availability - Everywhere including Rural Areas	Can't use voice and data communications at the same time
Monthly Bill, no start up investment	Subject to long outages - infrastructure failures
	Poor Reliability

3.2 DSL/Broadband Communications

As discussed last section, dial-up communications is a technology that allows the use of the existing telephone infrastructure to gain access to the Internet. This is a service that is offered by the telephone companies. Broadband communications is a technology that has been offered during the new millennium, which in addition allowed access to the Internet using the same existing infrastructure. Cable companies also use their existing infrastructure to offer Internet connectivity services. Cable and telephone companies are going to offer the service with use of a digital DSL or cable modem located at the customer's location. But like any other company or utility that uses cables or wires for data transmission, there is going to be some right of way issues that need to be addressed when feeding the physical lines through consumer's properties. One of the biggest differences between broadband and dial-up communications is going to be the data speeds in which they provide. Broadband is advertised to be a high speed Internet service, in which it uses different techniques to accomplish the higher data rates. DSL is a type of broadband communication that stands for Digital Subscriber Line. This technology transmits a digital data signal over a higher frequency to allow for faster throughput speeds and larger bandwidths. Since broadband and DSL offer such a higher throughput speed and larger bandwidth, they have more practical uses then the still older style of dial-up communications. Utilities are using this technology for AMR, SCADA, and their central office communication in the form of accessing the Internet or transmitting data over an IP address. DSL uses either an ADSL or SDSL technology to offer the service of higher data speeds to access the Internet. ADSL stands for Asymmetric Digital Subscriber Line, in which offers a faster download speed then upload data speed. This technology is the most popular DSL communications that is offered from the telephone companies to their customers. ADSL basically splits up all the available frequencies that the Internet signal can be transferred on. These small splits can be known as channels. The channels are then evaluated on their signal to noise ratio at all times by the providers equipment, which is to determine the channel that will maximize the data speed for the customer. Some businesses are being offered the SDSL technology from the communication companies. SDSL is an acronym that stands for Symmetrical Digital Subscriber Line that allows for the download data speeds and upload data speeds to be approximately equal. (Symmetrical Digital Subscriber Line) These techniques are being used to offer DSL communications can be researched more under the reader's discretion. Filters are used in the transmission path to separate frequencies that the data and voice communications are transmitted on. This process helps with the inference that voice might hear from the data communications. (Asymmetrical Digital Subscriber Line) Figure 3.2 shows a basic representation of the communications path for a DSL/broadband communication system.

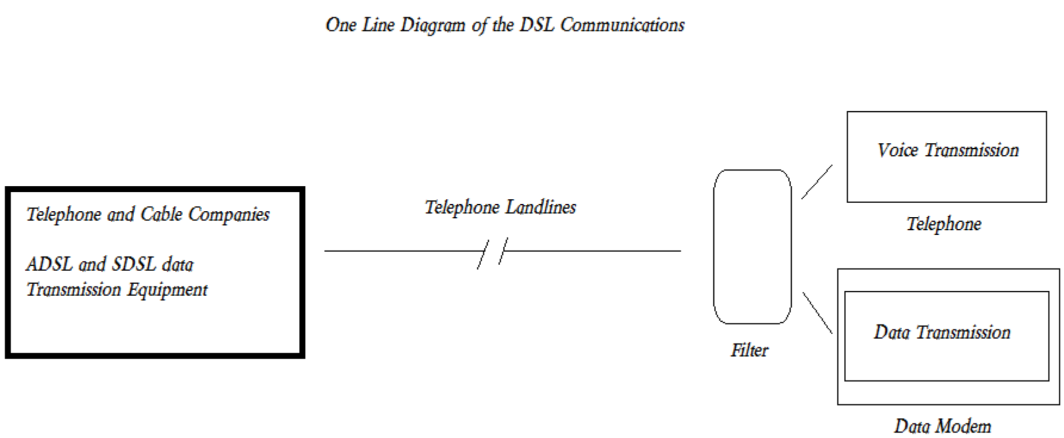

Figure 3.2 - One Line Diagram of DSL Communications

Most providers advertise download data speeds around 3 Mbit/s up to 12 Mbit/s. The price for this communication is ranging around a monthly charge of 20 to 50 dollars a month depending on the company and the data throughput speed available. Again, DSL and broadband is like dial-up in the sense of there is no equipment investment charge when using this communication other than the one time installation fee. Broadband Internet through a cable modem is going to offer a little higher data speeds but the price is going to be approximately the same. The biggest price difference is going to be from the slower data speeds from one Internet Provider to another. (Broadband) Table 3.2 compares DSL and broadband Internet prices with their advertised data speeds.

Table 3.2 - DSL Internet Data Speeds with Pricing

DSL Internet Speeds with Pricing			
Internet Provider	**Download Speed**	**Upload Speed**	**Price per Month**
Time Warner Cable	20 Mbps	1 Mbps	$44.95/month
Time Warner Cable	10 Mbps	512 Kbps	$34.95/month
AT&T	6 Mbps		$19.95/month
AT&T	3 Mbps		$14.95/month
Windstream	12 Mbps		$57.99/month
Windstream	6 Mbps		$54.99/month

With prices being an issue when trying to determine which communication type to go with, utilities have to keep in mind the range at which the communication transmission can work properly and reliable. When talking about DSL communications, the distance at which the signal is transmitted over is dependent on the data speed available. On that note, DSL and broadband service is said to work in the area of 2 to 5 miles from the service provider's equipment. A good thing when going with broadband or DSL is that the provider that is providing the Internet service is going to determine if the customers location is capable of handling a reliable service. In which, if the service is not reliable this can cause problems for the service provider and the customer. The provider is going to be responsible for all outages within the communication link. DSL reliability is said to have a great reliability since outages on the system don't happen very often. The most outages in the communications link come from the failures within the Internet modem. Since the utility is depending on another company to keep the communication paths up and working, outages can possibly be longer than expected. Below in table 3.3, a summary of the advantages and disadvantages of DSL and broadband communications are presented.

Table 3.3 - DSL/Broadband Advantages and Disadvantages

DSL/Broadband Advantages and Disadvantages	
Advantages	**Disadvantages**
Able to use existing Infrastructure	Outages are out of Utilities control
Monthly Cost and No Equipment Investment	Service is dependent on distance from equipment
Service Provider responsible for equipment failures	Right of Way clearance
No license fees	Outages could be extensive
Reliability	

3.3 Fiber Optic Communications

The fastest communication type available with smart grid applications would be the use of fiber optic networks. This is going to offer the transmission of data from one location to another. It will not offer access to the Internet like DSL, Satellite, Cellular, or Dial-up communications. Fiber optic is an optical tube cable that is designed to transport data threw glass over an optical light. An optical light has the capability to travel at a distance of 126,000 miles per second within an optical fiber. There are many components that make up the fiber optic cable. The first section of the cable is the optical fibers. The optical fiber is the component that actually transports the data in the fiber optic cable. The optical fiber component is made up with 3 different parts: the buffer coating, the cladding, and the core. The buffer coating, which is the outer portion, provides the cable its strength and support in that helps prevent the cable from breaking. The cladding and the core both are designed to help enhance the transmission of the optical signal. The second section of the fiber is designed for the outdoor environment. Many cables have different designs, but for most cables today they are designed with a Kevlar portion that helps add extra strength to the cable. To support the optical fibers inside the cable there is an outer sheath coating that is a made of an extremely hard plastic material. This is to help the bending radius of the cable and add support through the lifetime of the cable. Fiber optics can operate in the range of 850 nm (nanometers), 1300 nm, or 1550 nm wavelengths for data transmission. (Thorsen)

There are 2 different types of fiber optic cables that are used within fiber optic networks. One of these is the single-mode fiber and the other is the multi-mode fiber cable. The single-mode fiber carries an enormous amount of information in one direction. Single-mode fiber is used if there needs to be no return path for the communication network. For instance, a return path would be used if data is to be transmitted and received in data transmission. The case for accessing and using the Internet, the data needs to travel in both directions of downstream and upstream. The multi-mode fiber can travel in more than one direction. Multi-mode fiber is mainly used where a signal needs to be transmitted and received from multiple locations. Many applications of multi-mode fiber are used within networks in industrial or commercial buildings and around college institutions to allow for high data transmission rates.

Fiber optic networks are not different from any other network in the sense that it offers opportunities for failure. Fiber optics have many other applications that makes fiber optics very versatile. When running communications like a DSL line into a substation, the provider's ground potential and the substation ground potential might be at different levels. This can cause failures with equipment inside the substation or the communication company's equipment. For this reason, many utilities require the two grounding systems to be isolated. One way to do this is with fiber optics. An Ethernet cable is used when a data signal exits or enters the modem for data transmission. This media of Ethernet can be converted into a fiber signal and then transported into the substation with no worries about the two grounding potentials. This is a form of isolation. The failure classes that are associated with fiber optic networks are classified as patch panel failures, installation failures, and construction failures. Patch panel failures are failures that create malfunctions in the system by high attenuation. Poor connection points can cause some of these malfunctions when the fiber was terminated with the appropriate connectors. When the fiber is spliced together poorly the signal inside the fiber optic cable can have large dB losses. If the connections were not inserted in the connectors correctly or the fiber cable has fractured parts in the glass, there can be very high attenuation to no signal propagation into other parts of the communication network. This is going to possibly show communication outages within the system. Installation failures are associated with failures that are caused when installing the fiber optic network. If a fiber optic cable is bent past the specification bending radius of the cable then the cable can fail instantly or could possible fail over time. This might not be an automatic failure as mentioned but could be failures later in time as the fiber optics weaken. This mainly happens when the installer is not aware of the specification of the cable and not paying attention to what he or she is doing. Failures in fiber optics can also be caused by improper dressing and from terminating the fiber optic connections. This kind of installation failure is sort of an overlap from a patch panel failure. When fiber optic cable connections are terminated to the cable poorly, weather it be ST connectors, SC connectors or similar connectors for example, these cables can present a point of failure in the installation process. Terminating fiber optic cable can be a very hard skill to master. The last failure class is the failures that are related to the construction of the fiber optics networks. These cables are always going to be buried in the ground at a specified deep or strung from pole to pole, similar to the high or medium voltage lines that form our electric grid. When these cables are buried they are usually placed in a specific grade of conduit and markers are placed on top of the ground to identify that fiber optics are buried in the area. When doing construction around these cables there are liabilities of digging into or hanging something into one of these fiber optic lines. When this is done this can be a major repair in terms of cost and labor. There are organizations devoted to locate these lines that will allow for personnel digging in the area to be aware that fiber optic lines, water lines, gas line or even buried electrical lines are located around the designed digging area. Also when cables are being pulled into conduits, the cables can be braised which will cause the optical light to be exposed. With the optics exposed, the optical fiber signal is applicable to have larger attenuation losses in the data path that can cause failures. When fiber optic cables are to be repaired the cost can devastating to an individual having to pay for the repair.

As for the other communication types described within this thesis, there are going to be advantages and disadvantage associated with each of the communication types discussed. There is also going to be points in the network that are going to be classified as a point of failure. The hardest job is to determine if the advantages outweigh the disadvantages in each communication type to benefit the utility. One of the biggest disadvantages against fiber networks is ultimately the cost. This will usually force a utility to invest in a different type of communication network. For fiber to be run for long distances, it can be a huge cost to the utility and not reasonable to purchase this technology using a benefit to cost analysis when other technologies are available in the area. Not to mention the cost it takes to maintain the fiber optic networks. One of the other disadvantages against this communication type is the skilled personnel it takes to install it and or maintain it. Most utilities will hire contractors to do this work in which they are susceptible to large labor cost. Since most people do not react well with change, fiber optic networks itself is considered to be another disadvantage when we talk about installing this technology. Fiber optics can be very overwhelming when it is being talked about and can scare many utilities away from this technology. When installing the cables in the field from one location to another, we don't need to forget of the concept that right of way issues that may arise. Since utilities are trying to install new lines to serve new consumers electricity, they deal with trying to obtain and maintain right of way everyday. So this could be another obstacle that utilities are going to have to deal with and overcome. Looking at all the disadvantages of going to fiber optic cables, a utility might get a little concerned that it might be a lot to deal with. The advantages of fiber optic cables can be very convincing in the way that it transmits data to the devices in the field. Fiber allows for enormous amounts of data to transmit due to the size of the bandwidth it provides. Most fiber optic networks are going to vary on the data speed due to different types of fiber networks. On average though, fiber optics networks are going to transmit data at approximately 100 Mbps.

Many of the technologies that utilities are going to be using with the smart grid are going to require a minimum amount of bandwidth with the communication path. Of course this amount of bandwidth is going to depend on the amount of data that the utility wants to transmit. Bandwidth may be a significant portion for the technology in question. Many of communications system may introduce large amounts of noise within the system. Fiber optics introduces very little noise within fiber optic systems. Since fiber is made from glass and glass is a very good insulator, no electric current can flow into the glass and no electric signal such as electromagnetic waves can interfere with the optical data signal. So this allows for fiber to be invulnerable to electrical interference. Since no electric signal can pass through two different optical fibers, this shows those fiber optics are not susceptible to cross talk between the multi-mode fiber networks. With no radiation possible when using fiber optics, this communication type introduces that it has high security attributes. Another advantage when dealing with fiber optic cables is when installing the cables, it's so small and lightweight that it allows installation of these systems to be performed as an easier task.

Communication systems can be very pricey, and fiber optic networks are on top of that list. Fiber optic networks are usually a last resort for some utilities due to the price for installation and maintenance of the network. For a multi-mode 62.5/125 µm duplex fiber optic cable with no pulling eye will cost $28.11 per meter. (Stonewall Cable) This price could be variable dependent on the company that is selling the product or the date of purchase. Since meters are not the standard measurement used, this value can be converted into feet to a unit price of $8.57 per foot. To put this in perspective, for a job that is a mile long without the labor cost included, the cable itself would cost $45,238.66. Labor is going to depend on the contractor that is hired and can vary drastically reliant on the contract agreed upon. The same goes with letting hired contractors do the maintenance on the fiber optic cables. Which some utilities might look into training some of their personnel to do the maintenance on the cables, such as splices and repairs to possible save the utility some money. Table 3.4 is going to summarize the advantages and disadvantages described with fiber optic networks.

Table 3.4 - Fiber Optics Advantages and Disadvantages

Fiber Optic Communications	
Advantages	**Disadvantages**
Small and Lightweight	Price of Fiber, Installation, and Maintenance
Low/No Signal Loss	Skilled Personnel to work on
No Crosstalk	Building Taps off of Existing Fiber Networks
Very High Bandwidth	Obtaining Right of Way for Installation
Very High Data Speeds	
No noise components	
High Security	
Operating Temperature Ranges	
Long Distances for Data Transfers	

3.4 Power Line Carrier (PLC)

The idea of power line carrier (PLC) is a technology that has been used for a long period of time. But it has not been since recently that the use of PLC has grown substantially within the electric utilities with the idea of AMI. Power line carrier uses the existing 50 or 60 hertz power system infrastructure that feeds the customers their electric power. The power system infrastructure used is the medium voltage lines that are maintained by distribution companies. The data is placed on the power lines through the use of some injection equipment and taken off the power line through the use of data detection equipment. During this process the data is modulated at a higher frequency than the electrical system frequency such that the data can be transmitted over the power line from one point to another. Figure 3.3 shows the basic communication path of the PLC technology.

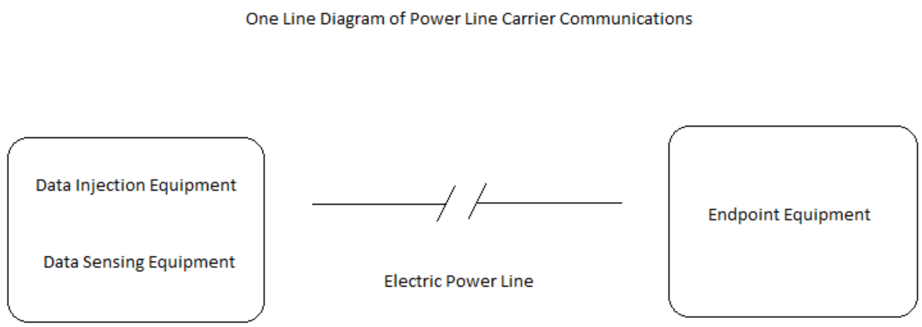

Figure 3.3 - One Line Diagram of PLC Communications

This modulated frequency will vary with dependence on the type of technology of PLC that is used. Within the operation of the PLC technology, there are 3 different operational modes which will achieve data transmission over the power line. One of these modes is using the Ultra Narrow Band (UNB) that operates in the frequency range of 300 Hz to 3000 Hz (3 KHz). This class of PLC offers extremely low data speeds that allows for very slow access of data information. These data rates can range in the area of 100 bps. The Landis & Gyr Turtle system 1 (TS1) and 2 (TS2) operates on this Ultra Narrow Band technology. The next class is going to be the narrow band (NB) which offers the higher data speeds between 2 kbps to 500 kbps. This class operates in the frequency range of 3 KHz to 500 KHz. The last class is the broadband (BB) technology in which offers access to the Internet over the power line.

AMI is one of the biggest users for utilities when considering power line carrier applications. Some of the other uses that might consider a PLC technology are cases where information of a utilities system needs to be known, where large amounts of latency or slow data access is manageable. Some examples might include a confirmation signal from a device that has opened or closed, sending a command to open or close a device, or obtain power related measurement as of voltage, current, volt-amps, VARs, or watts in which this data might be available in a SCADA system. Since PLC uses the existing infrastructure, the power grid, to transmit data packets from one location to another there is no cost in building the infrastructure to transmit the data. With that said, this allows a independency from a communication company for data transmission. Utilities can experience problems with bad data decoded off the power line if the power system has excessive amounts of noise. Many things on the power systems can cause noise like: capacitors, loose hardware on utility poles, and broken down insulators or arresters. As mentioned above data speeds on the power line will vary depending the on application and class of PLC used. When PLC is used with

AMI/AMR the data speeds will be approximately 60 bps with the Landis & Gyr's turtle 2 system, and the data speed will be 180 bps with the TWACS system. Since there are always different designs between vendors to do the same applications, the price will also vary between the vendors. So when considering PLC the only cost is sending and retrieving the information off the power line. This price will be dependent on the type of technology used to achieve the goal of the process. (CRN) Below in table 3.5, the advantages and disadvantage are summarized as discussed with power line carrier.

Table 3.5 - Power Line Carrier Advantages and Disadvantages

Power line Carrier Communications	
Advantages	**Disadvantage**
Existing Infrastructure	Noise on Power Lines
Overall System Pricing	Capacitors
No Radiated Signals	Price for Data Injection Equipment
	Outages on power lines will result in no data transmission

3.4.1 Broadband over the Power Line (BPL)

Broadband over the power line communications was a technology that is offered to customers that allow access to the Internet with higher data speeds. This technology of broadband Internet is being offered by the electric utilities, in which they are transmitting the data signal over the medium electric power lines called broadband over power lines (PBL). PBL uses the PLC technology. PBL is modulated on the power line at a frequency range of 2 MHz to 80 MHz. This is a technology that still has many obstacles to overcome before this communication type can be used and offered by many utilities. This is used whenever the Internet is to be used to pass data from one location to another. Many vendors tried different beta sites in 2004 and after the testing period was over it was up to the utility to continue the service. Duke Energy tried a beta system in 2004 in which they discontinued their BPL service in 2007 due to interests in other areas. A standard was in put in place by IEEE, IEEE P1675, which supported the safety and installation practices when working with BPL technology. The price for this service was approximately 40 to 50 dollars a month with download speeds ranging from 1 Mbps to 3 Mbps. Vendors were telling the industry in 2004 that speeds would increase to 5 Mbps in the future. Unlike the DSL option that provides an ADSL technology, BPL offered a symmetrical DSL option. This option allows the consumer to have equal throughput speeds in the download and upload directions. Which this option would allow customers to have a higher upload speed then they normally would with a normal DSL service provider. One of the major problems with BPL is sending the signal through the distribution transformer to the customer. When doing this, the high frequency signal will die out after going though the transformer. As a fix for this problem, there are 3 different options available when sending the data signal through the distribution transformer. One way is to pass the signal through the transformer hoping that the signal does not get totally obstructed or attenuated. Another is to by-pass the transformer by using equipment to take the high frequency data off the power line then coupling the signal back on to the service wire on the load side of the transformer. The last way proposed is to generate a Wi-Fi device on the transformer pole that transforms the data signal into a wireless signal before the transformer and have a Wi-Fi receiver placed on the house to receive the data signal that will feed into the customer premises.

BPL could have a bright future in the broadband communication sector, but this technology is going to have to overcome some big disadvantages. The biggest problem with this technology right now is the radio frequency interference (RFI). Broadband over the power line has been known to produce radio frequency interference with radio receivers within a specific range. Vendors are claiming that they can adjust the operating frequency of the broadband signal that they can minimize this interference with surrounding radios. Other than the signal emitting radio frequency to interfere with other radio frequency signals, other components on the electrical system can act as an antenna to this inference. These components may consist of either loose hardware on the utility poles, faulty connections within the power grid, or dirty of broken down insulators and arrestors. This brings up some of the other disadvantages of the BPL technology, of attenuation problems that are caused when sending high frequency signals over the electric power lines. The high attenuation has to do with the configuration changes from pole to pole with the number of splices or connections that are made and when a line goes from overhead to underground power lines. It is common that the BPL data signals will have to be amplified around every mile of line they travel. With attenuation, a utility has to keep in mind the difficult problem passing the signal through a distribution transformer which steps the voltage down to an operational voltage. When this high frequency signal is sent through the transformer, it obstructs the signal such that it can't be reconstructed after exiting the transformer. Since we are trying to inject a signal through the power line, the utility will need to invest in some signal injecting equipment. Although since the signal we are trying to inject is on our existing infrastructure, there is no cost or investment that needs to be made on the construction of an infrastructure. Also since the BPL service is offered by the utility, there are no cost to pay a company for the Internet services they would have provided the utility. Table 3.6 below summarizes the advantages and disadvantages that were discussed above. (Gellings, and George)

Table 3.6 - Broadband over the Power Line Advantages and Disadvantages

BPL Advantages and Disadvantages	
Advantages	**Disadvantages**
Offering an Internet Service for the Utility	Passing the BPL signal through the Distribution Transformer
Using the Internet Service to provide communications to Subs	Low attenuation on power line
High speed throughputs	Cost of equipment to offer service

3.5 Wireless Communications

One of the biggest problems in most communication technologies is the fact that they transmit data on a physical cable. Either that be and optical wire (fiber optic) or a physical copper wire. This becomes a problem when the line brakes or data signal is interrupted that causes an outage. Once the communication path is down, the utility could see a service interruption for up to several hours if not longer. During times when the smart grid application needs to be used and the communications to the application are down, there is nothing that the utility can do to perform their appropriate actions. This can cause major frustration when it comes to using their smart grid applications. With wireless communications the data is to be transmitted through the air between antenna's, satellites, or cellular carriers. Wireless will also have its problems like any other communication type does. This chapter is going to review all the wireless communications available and what they may offer over the other communication options available.

3.5.1 Satellite Communications

One of the biggest barriers that utilities face when dealing with communications, is communicating with devices that are located in such rural areas. More often than not utilities with these issues are the electric cooperatives. Electric cooperatives serve mainly the rural areas and Electric Cooperative will serve electricity to approximately 7 customers per mile. These areas can be located where no terrestrial network companies are available. Usually the only options available in these areas are dial-up Internet, which does not provide the bandwidth needed for the some of the smart grid applications. This attribute is one reason many cooperatives and other rural utilities look at investing in satellite communications. Satellite communications are designed to provide Internet connectivity over long distances. Companies are starting to provide this technology more and more. Two of the biggest vendors for satellite communications are Hughes Net and WildBlue. This technology is mainly being used for AMI/AMR and for some SCADA applications.

Satellite communications consist of two segments, which include the ground segment and the space segment. The earth or ground segment is made up of gateway stations, a network control center (NCC), and the operation control center (OCC). The portions that make up the ground segment of the satellite path are the devices that transmit the data signal up to the space segment and the devices that retrieve the data signal back from the space segment. The other portion of the system is the space segment, where the actual satellites are placed into the atmosphere. As mentioned above this portion retrieves the signal from the ground transmitters and sends the retrieved signal to the final destination dish at the customer's premises. Below is a one line diagram that shows the basic transmission path for satellite communications.

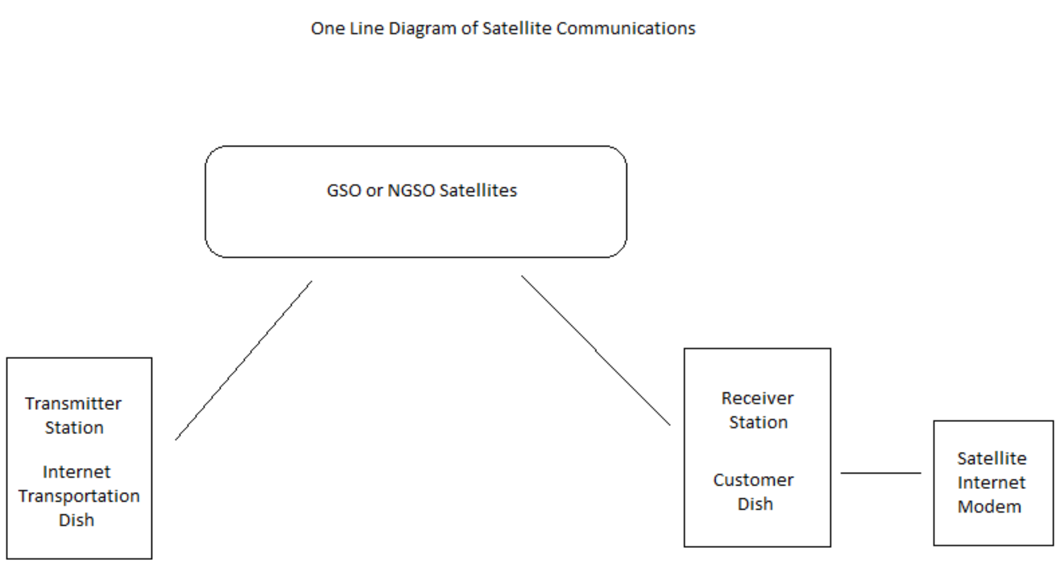

Figure 3.4 - One Line Diagram of Satellite Communications

These satellites in the space segment are classified as either geostationary orbit (GSO) or non-geostationary orbit (NGSO). The NGSO satellites include medium earth orbit satellites (MEO) or low earth orbiting (LEO) satellites. The GSO satellites are placed approximately 36000 km above the earth's equator and are the most commonly used satellites. The MEO satellites are located around 3000 Km from the earth's surface up to the range of the GSO's. LEO's are set around 200 Km to 3000 Km above the earth's surface. The MEO and LEO satellite's are viable to lose the communication link for a period of time from day to day. So when using the MEO and LEO satellite's reliability is greatly reduced. Satellite communications operate on many different frequency bands. The frequency bands that are going to be discussed are the ones that are most commonly used. These bands consist of the C band, Ku band, and Ka band. The C band ranges in the 4 to 8 GHz range using larger antennas. The Ku band uses a higher frequency of 10 to 18 GHz, which is mainly used with direct broadcasting satellites. This band is also used for broadcasting Internet connections from servers to the consumers. The Ka band operates around 18 to 31 GHz, and offers a much larger bandwidth and uses much smaller antenna's with the larger operating frequencies. (Yurong Hu)

As already stated, satellite communication offers a high throughput rate to access the Internet in most rural areas. The advantages of getting high speed Internet to rural areas could possible outweighing the cost of the technology. Since the satellite vendors can offer this service in rural areas, it is stated that an Internet connection is available anywhere it is desired. Most of the satellite services are offered at a global wide service area. Since there are no wires to be ran with this technology, satellite communications introduce no right of way obstacles to overcome. Probably the biggest disadvantage of this technology is the fact that there is a daily or monthly download limit from the providers. If the limit is exceeded, there are more charges added onto the monthly bill. When investing in satellite communications there is no initial investment other than the providers' installation fees. When satellites are being considered for the utilities communication link, the idea of latency needs to be considered by the utility. Satellite technologies offer the most latency delay of any system. Table 3.6 shows prices for satellite communications and the data speeds in which are being paid for.

Table 3.7 - Satellite Communications Pricing Options

Satellite Communication Pricing Options				
Company	**Data Plan**	**Advertised Download Speed**	**Advertised Upload Speed**	**Price (per month)**
WildBlue	7.5 GB/month	12 Mbps or 5 Mbps	3 Mbps or 1 Mbps	49.99
WildBlue	15 GB/month	12 Mbps or 5 Mbps	3 Mbps or 1 Mbps	79.99
WildBlue	25 GB/month	12 Mbps or 5 Mbps	3 Mbps or 1 Mbps	129.99
HughesNet	250 MB/day	1 Mbps	200 Kbps	39.99
HughesNet	350 MB/day	1.5 Mbps	250 Kbps	79.99
HughesNet	450 MB/day	2 Mbps	300 Kbps	109.99

Again these data speeds are maximum data speeds and the actual throughput will be at a lower rate. WildBlue now offers a 12 Mbps is some areas in the United States but not everywhere. This is the reason why there are 2 download and upload speeds in the table. WildBlue also requires a 150 dollar initial set up fee and a 10 dollar monthly equipment leasing fee for the use of their equipment. (WildBlue Website) Information included in the table above was formulated from the vendor's websites using residential pricing. The vendors that are using the GEO satellites offer this service. As discussed above the table 3.7 summarizes the advantages and disadvantages of satellite communications.

Table 3.8 - Satellite Communications Advantages and Disadvantages

Satellite Communications	
Advantages	**Disadvantages**
Offer High Speed Internet to Rural areas	Daily Download limits
Wide area Coverage	Less Control over transmission
No right of way issues	Transmission time delay's
Ground Segment equipment Located at premises	Monthly operational costs

3.5.2 Radio System Communications

When utilities are considering investing in a radio communication system, the type of system will need to be determined based on the actions that the utility wants to perform. There are various types of radio communication systems. Microwave communications is considered a type of radio communication that sends information at a higher frequency that usually propagates information in the range of giga hertz. Some radio systems will use these higher frequencies also. The next section in this chapter will discuss microwave communications and its attributes. Radio communications are going to be considered to operate in the range of 900 MHz to 2.4 GHz. These systems such as radio and microwave are not going to give the utility direct access to the Internet. Instead these systems are going to transfer information from one location to another similar to fiber optic networks. If one location has an active IP address, that address can be transferred to another destination through a radio link. This application will provide Internet access into an area where no Internet services are available or can't be accessed. These types of applications can be known as radio hops. Below is a diagram of a typical radio hop that would be installed within a valley or mountain that can't get line of sight of another radio antenna.

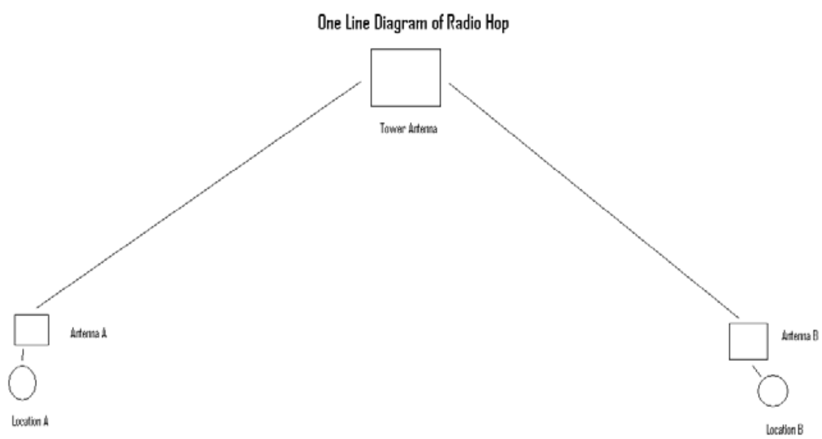

Figure 3.5 – One Line Diagram of a Radio Hop

Radio link systems can be bundled into two different types. One system is the point-to-point system and the other is the point to multi-point system. The point-to-point system is a system that transmits the information signals between antenna modules. Most antenna modules are in the physical shape of a dish or in a shape of a rectangular box. Most of these systems operate in the higher giga-hertz range around 2.4 to 5.7 GHz. These are mainly microwave systems and a few radio systems. Most of the radio systems are going to be point to multi-point system that sends information to many locations from an access point (AP) antenna. These systems work with most of frequency ranges and are going to depend on the installed equipment and the vendor's network. The radio system described above in figure 3.5 would be an example of a point to multi-point system. Most of the radio systems that are operating throughout cities work at a 900 MHz frequency. An access point antenna or module operating at the 900 MHz frequency can deliver up to a maximum of 4 Mbps download throughput. With higher propagation frequencies, the maximum data speed can be increased. The range that a 900 MHz system will propagate information reliable is approximately 20 to 40 miles. Depending on the system installed the higher frequency systems could have lower ranges for a reliable service. For most of the applications, latency will not be a problem for most to all utilities. But there maybe some situations that utilities may encounter that they want to make sure that the latency of the system will not cause any problems. Motorola claims that their canopy system can have a latency of approximately 40 milliseconds.

One of the biggest concerns when a utility is installing any radio communication system is the initial investment cost. Of course it is hard to predict an average cost for a system, because it is dependent on the number of towers to be used and the design of the system. As an estimate cost for an radio system, like the system shown in the diagram above in figure 3.5, it would cost around 10,000 dollars which would include the contractors labor cost but considering the towers are already constructed. As mentioned above latency can also be a disadvantage for any radio system. Other communication technologies can offer less latency times that some utilities might need to consider. These systems are cheaper if they can be placed on existing tower infrastructures. If there are towers available in the area of interest, the owners of the towers could require an point of attachment charge to place the antenna's or modules on the tower. Wireless interference is another big problem when dealing with wireless communications. Many of the applications today work in the 900 MHz spectrum, which is going to cause interference within multiple applications that use this same frequency. This is the reason for the installers or the designers of any system to run a spectrum analysis, such that every frequency range can be analyzed to determine if a system is going to work in an area reliably.

Even though cost can be a major setback when installing a radio system, radio communications can also offer advantages that make this technology very suitable and attractive. After the cost of the system is paid, there is no monthly charge other than when maintenance that is needed on the system. So after the payback period of the cost is recovered, the utility is using a service with no fees or charges. If the utility that is implementing the system can install the antennas or modules on their own towers then the cost of the system will be lower and there will be no attachment charges month to month. For most of the smart grid applications, the multi-point system is going to be the radio system to be implemented. If the data throughput of the communication system that is being fed into the radio system is less than the throughput of the radio system, then the throughput of the data rates will not differ. Table 3.8 below shows a summarized version of the advantages and disadvantages of radio communication systems.

Table 3.9 - Radio Communications Advantages and Disadvantages

Radio Communications	
Advantages	**Disadvantages**
System Designs from Contractors	Poorly Wireless Propagation Line of Sight
Transfer Data at Higher Throughputs	High Initial Cost
No Monthly Cost expect for Maintenance Cost	Tower Attachment Monthly Charges
Independent of Power Lines	Wireless Interference from Different Systems

3.5.3 Microwave Communications

As with radio communications, microwave communications has been around for a long period of time when considering the different types of communication options available. Microwave communications is considered to be a line of sight communication type. This is because it is so hard if near impossible to transmit data or voice signal through obstacles at the higher frequencies in which microwave communications use to operate. Microwave systems use frequencies in the range of 5.8 GHz (giga-hertz). Microwave communications use antennas to transmit and receive information over long distances. This communication is used more often over long distance transmission then over short distances. The reason for this is due to the cost it takes to transmit information over long distances with other communication technologies. There are different designs of microwave communication systems, in which the design of the system will result in the characteristics of the equipment used and the needs and wants out of the system. One of the most common designs for a microwave system is the loop design. This design incorporates many microwave dishes that are oriented in such a way that the dishes can transmit information to each other in a loop pattern. This design helps in a way of trying the resolve an area that has many dead spots in the service area. Repeaters will also be used in the designs that will help with the line of sight clearances. Figure 3.6 shows the basic design of three microwave dishes in a loop system that would send information to each other. The dishes work together to send the information to its correct destination in which the active application can receive or send the data signal by pooling the connection from any of the dishes in the loop system. This also helps with wireless reliability issues.

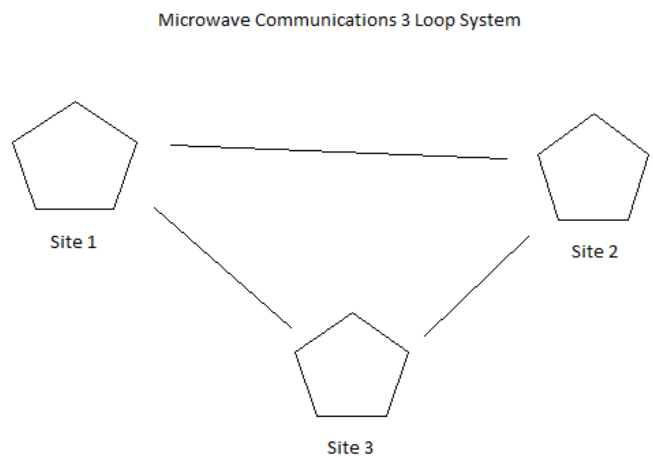

Figure 3.6 – Microwave Communication Loop System

A communication engineers that works for a contractor will design and understand the systems that will be proposed to the utilities. Designing and implementing these systems is what they do on a day-by-day basis. This type of job for a utility engineer can be overwhelming and very challenging. For a designer the challenges that need to be accomplished is to maximize the reliability of the system, determine the correct antenna heights, the approval of all the correct permits and licenses to operate the system, determine the volume and density of information to be transmitted for one location to another, and understand the characteristics of the geographic region for data propagation. Before a designer can ever start to think about these obstacles, the designer needs to be aware of the owner's present and future needs of the system. This is to be known such that the system designed will accommodate all the needs throughout the life of the system. A utility is not going to want to invest in a microwave system that is going to support their current applications but will not suffice for the amount of data that needs to be transmitted in the near future. After determining the size of the system, the geographical location at which the system is to be located is another important design factor. This is going to affect the antenna heights at which the system will operate reliably. A signal propagation analysis can be studied to see if the signal is going to propagate between all antenna sites to keep high reliability within the system. Designers try to design the systems in such a way that it performs a zero outage performance for the entire life of the system. Other then deciding on the design of the system, gaining all the permits for the system can be become very challenging. If there has to be towers constructed to place the antenna's on, then there will need to be some construction permits approved. Not to mention that the FAA (Federal Aviation Administration) has to approve the tower sites before construction. The last part of the permits and licenses is to gain the approval of the FCC (Federal Communications Commission). This process to gain the licenses from the FCC can be very cumbersome. Also if the FCC is used for some services, the FCC may require some sort of fees that can be substantial. When dealing with any kind of wireless system, interference may become a problem to the users systems and other systems in the area. This is why a interference analysis needs to be done before investing in the system as well. If there are interference problems with other systems, then the microwave system may never work to the utilities expectations.

The biggest disadvantage for the communication system is the initial investment cost as with the radio communication systems. Obviously the cost is going to depend on the size and type of system in which the utility decides upon. If the use of existing towers is available to place the antennas on, the cost and time in deploying the system may be reduced. As mentioned above there are many challenges with designing a system, but obtaining the correct permits for the system can be a huge disadvantage for the system when the utility is the one designing it. If contractors are hired to implement the system, then it could be agreed upon to let the contractors handle all the permits and license procedures. Since these systems are line of sight communications, being able to obtain the clearances such that all antennas have line of sight to each other can be another nuisance with microwave communications. With the different uses of frequency bands, either the frequency bands be narrowband or wideband, microwave communication systems can offer high channel capacity. This is going to offer the possibility of enormous amount of data transmission. This is going to give the utility a rising edge on the data rates achieved since they will be higher. This is also going to allow the utility to use this system for many of their applications. Another big advantage for microwave systems is the fact that the information is transmitted through the air and does not depend on any cables. Which takes away the concern for broken wires or faulty equipment that might cause outages and also there is no right a way clearances to worry about. It needs to be understood that microwave communications will only transport the data from one location to another. It is not a technology that is going to allow the utility access to the Internet. In table 3.9 the advantages and disadvantage are summarized.

Table 3.10 - Advantages and Disadvantages of Microwave Communications

Microwave Communications	
Advantages	**Disadvantages**
High Channel Capacity	Permits and Licenses
Independent of Power Lines	High Investment Cost
No Right a Way Clearances	Difficulty of Line of Sight Clearances
Contractor Designs System	Signal Quality
	Interference Problems

Pricing can change any utilities mind on investing in a technology if there is not a huge benefit for the cost of the investment. Microwave communications can be very pricey which is dependent on the system design, but the system can help with many applications due to the system capacity. Utilities need to expect to pay around 15000 dollars to 30000 dollars per microwave site. (Clark County Energy) These pricing ranges are going to pay for the antennas, the repeater sites, and also the labor it will cost to install the system. This does not include the cost if tower sites that need to be built and the permits that need to be obtained for the system.

3.5.4 Cellular Data Communications

The last major wireless technology is the use of cellular communications that is offered by the cellular companies. The most used cellular companies are AT&T, Sprint, T-mobile and Verizon Wireless. Cellular data telecommunications started out in the early 1980's by sending voice communications from one destination to another. Since then utilities are now able to sending voice messages over the cellular systems to millions of people throughout the world. The era that feeds off the need of real time communications is now witnessing the benefits that cellular communication is allowing access to a high speed Internet technology. This provides the use of cellular technologies to be used with the AMR, SCADA, AVL, and mobile workforce applications. Of course when using the cellular network a utility needs to be aware of the wireless coverage area that provides a good and reliable connection. The provider's area coverage maps can be obtained from the provider and also found on the cellular provider websites.

As with any other form of communication, data is transmitted over a channel. In cellular communications a channel is going to be made up of two different frequencies in which one is used for the forward download direction and the other is the reverse upload direction. When trying to understand how the cellular network works or how any system performs, the system design needs to be understood. The cellular networks are designed to work on a cell overlap design system. These cells are set up in a polygon configuration were each one of these sides on the polygon is formed by a low power transmitter. These cells are placed on top of a large self supported structure that can be seen in the fields within the geographical areas. When using the cellular networks, reliability is a high priority that the cellular companies want to achieve. So many different technologies have been introduced to help with this. These technologies that allow an increase in the reliability of the system are: cell splitting, frequency reuse, hand-off, and mobility. When designing these systems, the capacity and the efficiency that the system can handle are very important factors that are to be considered. The cellular network is made up of a cell site, a mobile telephone switching office and a cellular handset. Inside the data communications the cellular handset is replaced with the cellular modem. When data is sent over the cellular network, the data is transmitted on the channels that are setting in an idle mode. This allows for no interference between the voice and data transmission. (Matthew N.O. Sadiku)

Cellular communications are limited to a range of the cellular coverage area. Cellular offers one of the most reliable communication types available. As a result of the mobile voice traffic, the data throughput can slow down and possible hurt the system reliability. The data speeds within the networks are going to also vary depending on the specific location within the cellular coverage area. The cellular companies are now offering data at 3G and 4G speeds, which offer the user around 5 Mbps to 12 Mbps of download speed and 2 Mbps to 5 Mbps of upload speeds (Cellular Websites). With cellular as the data communication type, there is going to be a monthly charge and an initial activation charge with all cellular companies. The monthly charge is going to be around 50 to 100 dollars a month depending on the service plan the utility purchases. Utilities need to also keep in mind that the service monthly charge is going to vary from company to company. Along with many of the other communication types that were discussed, the reliability of cellular is good for the most part. If a cellular company has a tower goes down, then the data has to find another tower close by such that the information can be transmitted. If there are no other towers in which the data can transmitted to then the data speed can drop out or even lose the entire signal. So the reliability of the service is dependent on the outages that the cellular company experiences when offering the service. Below in table 3.10, the pricing for the different cellular companies are presented. The table shows the difference in throughput rates, price, activation fees and data overage fees.

Table 3.11 - Cellular Broadband Pricing

Cellular Broadband Pricing						
Company	**Allowable Data Transfer**	**Price**	**Activation Price**	**Data Overage Price**	**Contract**	**Download Speed**
Verizon Wireless	5 GB of Data Transfer	$59.99	$35.00	$0.25 per MB	2-year contract	10 Mbps
AT&T	5 GB of Data Transfer	$59.99	$36.00	$.49 per MB	2-year contract	10 Mbps
Sprint	5 GB of Data Transfer	$59.99	$36.00	$0.05 per MB	2-year contract	10 Mbps
T-Mobile	5 GB of Data Transfer	$59.99	$35.00	No overage cost but Data Speed Will Reduce	2-year contract	10 Mbps

The cellular companies are always trying to implement ways to help enhance their coverage area. This can be a huge advantage when trying to implement a cellular communication system. Utilities need to have a way to access the signal strength of the wireless data signal in such that the cellular service will meet the needs of the utility. When trying to use cellular within the communication system, many utilities are going to have to implement a hybrid network. Using the cellular data technology doesn't automatically mean that service will be automatically provided. Some of these carriers that provide the service don't provide the equipment needed to access the data network. This cost can be another set back due to the initial investment of the equipment. This equipment will be the utilities responsibility to maintain. Most of cellular carriers or companies are starting to have data service plans that limit the amount of data that can be used within with a particular data plan. As shown above in table 3.11, data plans are compared from different companies that offer the 5 GB data limits. With this limit in place and the data used goes over this limit there is are additional charges. This charge is usually priced on a per MB rate of data used. So if large data files are being transferred everyday, this could cause a major concern due to the extra charges or fees this may accrue. This is a change from the past where many of the data plans that cellular companies advertised stated that the service included unlimited amounts of data with no toggling of the data speeds. T-mobile on the other hand does not charge for overage fees, instead they've start to toggle the data speed down once the limit of data is achieved.

With many of the smart grid devices, security is a large concern. Many of these devices will only allow for the use of one IP address or a static IP address. So to achieve this, the utilities needs to ask the communication companies for the correct assigned IP's to be static IP's. This option does not allow for a range of IP address as with a dynamic IP address. With the static IP many of the communication companies can add an extra charge for this particular setting. Along with these disadvantages that cellular communications offer, cellular proposes some advantages that make the communication type a very attractive option. One thing cellular communications offer is the use of higher maximum data speeds within their systems. Of course this is going to depend on the coverage area. With higher data speeds, the utilities are presented with larger bandwidths. With higher bandwidths more data can travel along the communication path. When outages are of concern, the utility is not responsible for the outages. The cellular companies are responsible for the operation of their own network. Once the communication path to the antennas at the service location is restored, it is the responsibility of the utility to maintain the modem side of the network. Below in table 3.12, the advantages and disadvantages of cellular communications are summarized.

Table 3.12 - Cellular Communication Advantages and Disadvantages

Cellular Communications	
Advantages	**Disadvantages**
Set monthly Cost	Range: Carrier Coverage Areas
Potential fast data speeds	There is only an allowable data usage limit
Potential high bandwidths	Data Overage fees
Third part company maintains communication system	Extra charges for static IP address
	Carrier do not provide the customers equipment
	Equipment investment

3.5.5 Other Wireless Solutions

Another option which cellular companies can offer is the use of air cards. Air cards are devices supplied by the cellular companies that are placed in a PCI slot on the side of a computer that allows access to the Internet. This is a technology that allows for mobile Internet that can be used on mobile applications. This access to the Internet is assuming that the air card is located inside the cellular coverage area. The coverage area is another big problem when considering this technology. Many of the utilities using this technology mainly use this technology for mobile workforce applications. This allows for the field lineman to access their work by computer in the field. With these air cards there is an initial investment charge, then after this initial charge there is a continuous monthly charge on the cellular bill. The initial investment charge is going to cost around 35 dollars per line for a data only plan. The monthly charge for a data only plan is going to cost the utility about 60 dollars per month depending on the device that is used and the amount of data on the data plan. (Verizon Wireless Share Everything Data Only Plans)

The last wireless solution available is depending on local Wi-Max Internet solutions. This technology allows high speed Internet access that follows the IEEE 802.16 standard. Wi-Max solutions are known as wireless metropolitan area networks (WMAN), in which the range for the system is usually stated to be within a city or metropolitan area. Since this technology uses high frequencies to transmit the signal, the system is very sensitive to RF interference. From this it is best for the reliability that the system has line of sight between the transmitting and receiving antennas. As with radio communications, Wi-Max solutions have many different operating configurations. The most popular configurations is the point to multi-point configuration for offering Internet services to multiple customers or sites. As with the cost of this service, each site is going to cost around 50 dollars per month. This is going to be dependent on the location in which the local provider is located. (Scarfone, Tibbs, and Sexton)

Chapter 4 - Interfacing Smart Grid Applications with Communication Options

So with utilities gaining interest in smart grid applications, some of the personnel that utilities have on staff can be amateurish in the aspect of communications. Not only are utilities inexperienced in the different types of communications available, but also in understanding the attributes in which each type of communication can provide. This chapter discusses which communication options to look at over other communications options depending on the utilities needs. Such that utilities don't need to attempt trial and error approaches with the different communication systems to suit their needs. Most systems that utilities are going to implement are going to be hybrid systems. Utilities decide hybrid systems due to many factors that will be discussed within this section.

4.1 Physical Location

When utilities are beginning to invest time in determining the correct communication system for their smart grid applications, one question comes up about the physical locations. That question determines where the applications are located. To begin with, the communications that are available should be determined on which is available for that location. For instance, if there is a DSL or broadband style connection available at the substation then there is probably no use for the utility to do a propagation analysis to determine if a wireless system is needed. Unless a wireless communication such as cellular can be implemented at a cheaper price for better reliability. There might be certain locations where there is no terrestrial communication lines available which would mean some kind of other solution would need to be used at that location. Either that be through means of wireless technologies or other utility installed transmission lines. Once the available communications types are known for an area, the actually terrain needs to be studied and evaluated. These evaluations need to determine if the terrain is very hilly with locations in valleys and mountains or is the terrain more flat land where long distances can be seen with no obstruction.

If it is determined that the terrain is hilly, it might not be possible to have any wireless transmission from the two locations from a radio communications style. Still a satellite or cellular type of communications might still an option if the utility wants to go with a wireless solution. If a utility is skeptical that the information will not transmit through their hilly terrain, a signal propagation analysis can be performed to determine how well a particular wireless system is going to perform. When dealing with these kinds of terrains, a utility might not have many options when deciding on a communication path for their application. This could possible cause a utility to have to budget more money for that particular location. More than likely, if the system terrain is more of a flat area, almost any communication type would be feasible to obtain the information from the application of interest. Although determining the physical terrain of the location is a very important aspect to understand, it is also important to know if there are many forest style areas that could possible block the transmission path of wireless signals. When higher frequency signals are used, the information signals can't transmit thought forest type terrains. This is why line of sight is very important in radio style communications and is the reason why this is a disadvantage to that technology.

The terrain of an area is very important to the reliability of a communication system also, but for most engineers and lineman within the utility they are going to know the terrain of the area and be very knowledgeable since these people work within these areas every day. When knowing this kind of information about a system, it takes most of challenge out to understand what communication types could work. When also deciding on the correct option to go with, the personnel of the utility or the designer of the system needs to be aware of how much money is budgeted to spend on a application basis per location or on the entire project.

4.2 Communication Analysis

The process of analyzing the different types of communication types available is more than less the most important part in deciding on the communication type. This step allows the utility to process and analyze the attributes of each communication type. Within this analysis the utilities personnel will study the reliability of the communication system, the strengths and weaknesses of the communication system, and the price at which each communication type is going to cost the utility. Each of these communication systems is studied and compared to determine which communication type is going to better suit the needs of the utility. This analyzing process is more often than none done differently at every utility. This needs to be done in a way that the personnel doing the analysis can present the data to the utility effectively. Also it needs to be considered that contractors outside of the utility might be doing some of the analysis work. This section is going to discuss the best available options for either AMI or SCADA applications for all communication paths.

For an AMI solution, the best communication solutions available are investing in third party communication companies. In which this is going to let the utility achieve the high throughput speed with also offering high levels of reliability over other communication options. These technologies are going to include DSL or broadband, cellular broadband, or satellite communications. These options give access to the Internet, which AMI needs. The other promising attribute with these third party communication companies is the price. Since the initial investment of these communication technologies are very limited and have only a monthly charge, the communication budget for the AMI project can be smaller. Dial-up is a technology that is rarely used, but could be an option if the data throughput speeds are not of any interest to the utility and if the application is not limited to a minimum bandwidth. This technology is most likely not going to be of any interest to the utility if the limitations are not suitable for the application of interest. The most appealing part of dial-up is that it offers the cheapest option available. When dealing with AMI applications there are different forms of communications that need to be obtained. The communication path from the equipment to the central server is most thought of communication path that needs to be defined. This communication path needs to have Internet activity or an active IP address. One problem that a utility might encounter is feeding a DSL line into the substation. Since the communication grounded system is not physically grounded to the ground grid of the substation, there needs to be some means of ground isolation. This can be achieved by either investing in equipment to isolate the two grounding systems or to use fiber optic cable. Another way to get around the grounding isolation problem is the use of wireless connectivity through cellular or satellite communications. Other communication paths involved with AMI is the path from the substation to the meters and then from all the equipment that helps send and retrieve information. When determining the communication solution for the path from the substation to the meter and the meter to the substation there are only two available options. These options are introduced with the different designs of AMI solutions. One option available to achieve this information transmission is the use of radio frequency mesh. This solution allows the electric meters and the substation equipment to transmit and receive data signals through the use radio frequency systems. Landis and Gyr's RF solution is known as the RF mesh AMI solution. This allows for other meters to act as a repeater, such that the signal from the meter reaches the substation with accurate information. The other AMI vendor's will offer comparable solutions to Landis and Gyr's RF solution. Most rural utilities use another option known as power line carrier, in which they use the electric power system wires to transmit the data signals. This option is mostly used when there are mountains or valleys present in the utilities service territories where no wireless or radio frequency signals can be transmitted or received. The last portion of the AMI applications is the communication path between different types of equipment inside the substation. This solution usually gives the utility no communication options to choose from. This communication type is decided upon the vendors design for their technology application. This communication type is mostly likely going to be achieved with fiber optic cable. The good thing for utilities is the fact that the distances between the devices are fairly short. Since the price for fiber optic cable is dependent upon distance, the price for this communication path should be limited.

SCADA applications are going to require that the system have strong reliability standards. This is very important to understand when deciding on the communication path to send and retrieve information to and from the field RTU devices back to the MTU at the utilities headquarters. Thus cellular might not be an suitable solution depending on the coverage area to where the equipment is located. If the SCADA equipment is located in the so-called "Gray Areas" of the coverage area, the cellular signal strength could drop out with no warning. Since this signal strength can drop out at any time, the cellular reliability is considered to be average to poor in parts of the cellular coverage area. This also might be a big concern with AMI applications, due to the utility downloading meter information when the communication link to the substation is down or broken. Good thing with AMI though is the AMI substation equipment can hold a limited amount of data until downloaded. When performing the communication analysis of any wireless system, it would be in the best interest of the utility to determine the signal strength of the location. This can be done with equipment that the communication vendor can provide. With cellular communications the signal strengths can also be tested with personal or company smart phones. Just be aware that the same company serving the phone service must be the same company that the utility will use with their smart grid applications. As with the other terrestrial networks, such as DSL and satellite, the reliability of the service will need to be studied. With these networks, the biggest concern for error is with the Internet modem, where the modem provides a weak link within the communication network. Since SCADA data is transmitted in such low data packet sizes, the bandwidth does not have to be very large. With this known, a wireless system with a narrow bandwidth can be used to transmit the data back to the utilities office. This allows for the use of a radio system to transfer the data. Most utilities are going to try to implement these systems for SCADA, since the utilities can meet the strict standards from NERC on cyber security. Only obstacle that utilities need to overcome with the use of radio communications is making sure that the signal will propagate to the specific location of interest.

4.3 The Final Decision

After all the different communication types have been analyzed with all the different communication paths considered, it is now time to decide on which communication type the utility is going to invest in. As mentioned throughout the communication analysis section, the different communication paths need to be understood that make-up the different smart grid applications. Most of the smart grid applications require three different communication paths. These paths are classified from the field devices to the central focus point, which could be an example of a substation, between different components of the smart grid application, and the path from the central focus point to the utilities headquarters. It's known that the communication path from the central focus point to the utilities office or headquarters is the most considered and disputable communication path between utility personnel. This is because of all the different options and range of pricing options that are available today. Since this communication path needs use of Internet, most of the communication technologies studied within this thesis offers this service. Again, these technologies include satellite, DSL/broadband technologies, and cellular communications. The other communication paths don't offer as much flexibility. For the path between different application equipment, the vendor decides on what works best with their application. With SCADA and AMI this is most likely to be fiber optic cables. Good thing about this is that the distance between the application's equipment is short. Thus the pricing for this communication path is small. The final communication path that was analyzed was the path from the field devices back to the substation. There are normally two options that the utility has to achieve this communication path, which is using PLC or radio frequency style communications. Within this communication path, the utility wants to have a way to send the information from the field devices to the substation. Both of these technologies have advantages and disadvantages that were discussed in chapter 3. The radio frequency option seems to be a better solution for large populated areas where there are no obstructions for the radio signal propagation. In rural areas where mountains and valleys may cause obstructions to the signal propagation, PLC seems to be more of an attractive solution. Most cooperative tend to invest in the PLC option due to the fact that their terrain is so rural.

There are many decisions to formulate when supplying smart grid applications with communication options. There are some communication options that were discussed in chapter 3, that have not been discussed within the final decision section of this thesis. This is the use of certain wireless communication technologies, such as microwave and using the use of radio communications to transmit data through the air. Microwave communications are mainly used as the backbone communication system for a utility. These systems can be very costly, but they are very helpful when having many dead spots within the utilities handheld radio systems. These systems help with lowering the number of dead spots and allow for more reliability within the radio system. These systems are to transfer information for one location to another. They don't allow access to the Internet unless an Internet signal is placed into the system. This is no different with radio systems. With communications that are in hard to get locations for signal propagation, the Internet signal can be placed within a radio signal and transferred around until the signal can be propagated to that substation with high reliability. When using these technologies, they do offer the disadvantage of interference either with other nearby systems or other systems interfering with the utilities radio system.

There is no one-way to supply communications to all smart grid applications. This is very dependent within the area the applications are located in, the applications of interest, how well different communications perform in the area, and the utilities confidence in the operation and reliability of the communication systems. Most utilities are going to invest in a hybrid system, where different communication systems are used for the same communication paths at different locations. These communication systems are decided upon by the best performing communication technology available to the utility.

4.4 The Decision Flow

There has been lots of information provided throughout this thesis containing the different applications available and the communication options that will be used to communicate to these different applications. To many readers it could by difficult to nearly impossible to understand the entire process of implementing an application to gathering the information that the applications will provide to the utilities. So within this section of the thesis, the goal is to present a progression flow chart for an AMI application to help understand the flow of implementing the smart grid technology. Below in figure 4.1, a flow chart is presented to visually represent the process for implementing communications to an AMI system.

AMI Application Flow Chart

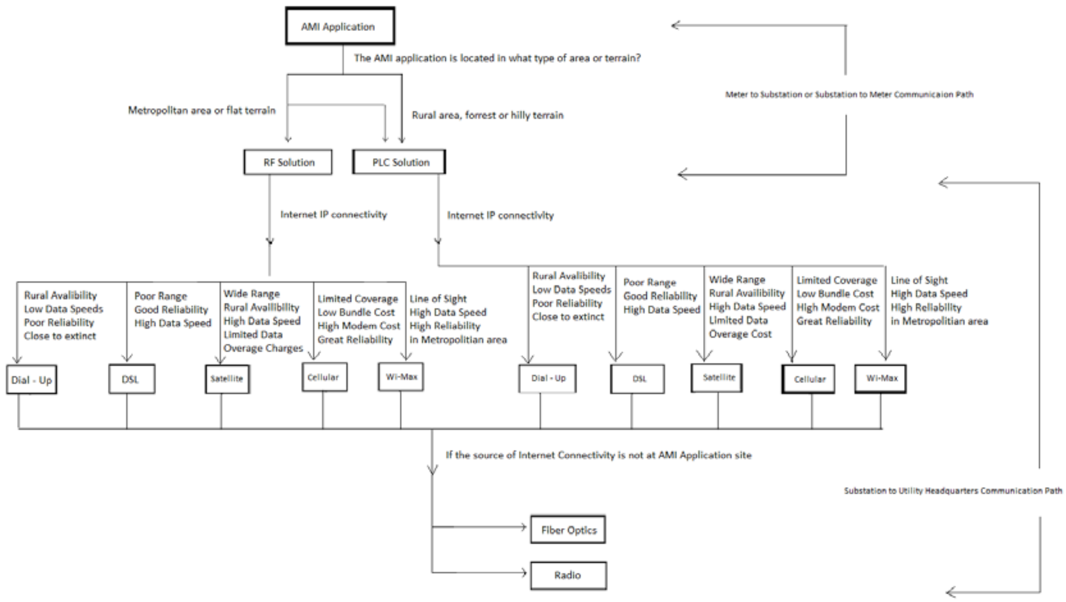

Figure 4.1 - AMI Application Flow Chart

To begin, the first step is to determine the style of AMI application that is going to be used within the utility. As stated earlier, the different AMI styles are going to be the radio frequency solution or the power line carrier solution. The reason this step is the most important is it determines the type of equipment and meters that need to be purchased from the AMI vendor. This decision is going to have the most cost associated within the decision making process. So once the equipment and meters have been purchased and installed, it is now time to start discussing the different options available to obtain the information that the AMI application is going to provide. The decision of determining the style of AMI application has no effect on obtaining the information from the system. Now it is the job of the utility personnel to determine the different types of communications which they have available at each of the substations. Once the communication types are known and the communication analysis on the different types are studied, utility personnel can then determine which option they want to use with their application. For some reason if the communication option is not located near the substation, then the utility can now look at how they are going to get the service at that location. This is done be either investing in a radio hop system or using the technology of fiber optic cables.

Chapter 5 - Conclusion

5.1 Conclusion

Throughout the industry trying to develop smarter technology applications and the government trying to mandate the use of these smarter technologies, utilities have to do their part in utilizing these technologies within their everyday workload. This may cause many obstacles and hoops for the utilities to overcome due to the lack of experience or knowledge within the company. Since there is such a lack of knowledge, some companies might start hiring experienced personnel to install and maintain these smart grid applications. Along with the cost of the equipment for the applications and the hiring of other personnel, this could potentially raise the cost of the electricity that utilities supply to its customers. This is always a concern for utilities and customers trying to survive through the rough economic time.

There are many solutions available for providing communications to smart grid applications. Determining the best communication system is the hardest part of implementing a smart grid application. Which is good thing since one solution might not always be able to provide the productivity in all geographical areas. Since there are multiple communications paths that need to be considered with these smart grid applications, almost all the communication technologies could potentially be used. So it is in the best interest of the utilities to understand the difference in the communication types, and the advantages and disadvantages that the communication types provide. Before these communication types can be implemented, analysis needs to be performed within the utilities service territory to see which technologies could possible out perform the others. These analysis procedures could potentially take up a considerable amount of time before a communication decision is made. Within most of these applications that utilities are trying to implement, the decision of the communication type and the security at which the utility needs to protect the information flowing throughout the communication system are very important.

On the final thought of implementing these smart grid applications, it is important to understand the communications that are available. Not only should the utilities know what is available, but have a good idea of which communication types will outperform others in all areas the service territory. This knowledge could help ease the design of the project budget and also keep speed bumps out of the implementation process of the project. Not only does the performance of all the communication systems determine the correct system to invest with, but the maintenance and reliability within maintaining the system needs to be studied as well. This could be done by asking or getting advice from different utilities that might use that technology in the operation of the different applications they might have. Before the utilities budget is reviewed, it could be in the best interest that the utility personnel study and understand the amount of money that each communication type could cost.

5.2 Contribution of Thesis

Throughout this thesis, many technologies were studied and analyzed in the form of smart grid applications to the communication options that help obtain the information in which these applications obtain. The smart grid applications were described briefly to help the reader understand the reasons and purposes behind the designs of these technologies. Much of the discussion with the smart grid applications came from experience gained while working within the power distribution field. With the experience in implementing the automatic meter infrastructure (AMI) system, the knowledge was not only limited to just understanding the components of the systems and how the systems operated but how the overall system improved the efficiency of the electric cooperative. The other technologies discussed, were studied with the help of other electric cooperatives and from technical documents found within the coopertive.com website.

With the brief understanding that the reader obtains in chapter 2, the next step was to study the options available to obtaining the information from these technologies. This information was retrieved by the utilities by use of different communication options. The communication types were analyzed and presented in a way that each communication type discussed the range at which point the communication type is reliable, the advantages versus the disadvantages for each option, and the cost of operating the system. These attributes were presented in that the reader could understand the design of system and what the communication option would offer to the utility. Also, with the work experience at Inter County Energy Cooperative, the presented material of the communication options were supported with the research of each communication option discussed.

The last part of this thesis was to give guidance to any utility or utility personnel when trying to provide a suitable communication option to obtain the information from the different smart grid applications. Since there were no case studies presented inside the thesis, the endorsement of this concept was presented with the experience gained with implementing the AMI system at Inter County Energy Cooperative. Within the experience gained, the personnel at Inter County Energy Cooperative studied different options available for their AMI system by weighing the different features in which each communication option provides to determine the correct solution for Inter County Energy Cooperative's needs and wants.

So since there was so much information presented within this thesis, it was the idea of the author to present a sample flow chart to determine communication options for the AMI application. This idea was to give the reader's a more visual understanding of what is available for communications in a downward approach. So with the material presented within this thesis, hopefully utility personnel can gain some guidance and direction when starting to implement different smart grid applications within their utility.

Appendix A - Bibliography

[1] "Multimode 62.5/125 Duplex Fiber Cable." *Stonewall Cable Inc.*. Stonewall Cable, Web. 2 May 2012. <http://www.stonewallcable.com/product.asp?dept_id=241&pf_id=F625-D>.

[2] "Dial-up Internet Access." *Wikipedia*. Wikimedia Foundation, Inc., 09 Sep 2012. Web. 13 Jul 2012. <http://en.wikipedia.org/wiki/Dial-up_Internet_access>.

[3] "Digital Subscriber Line." *Wikipedia*. Wikimedia Foundation, Inc., 24 Aug 2012. Web. 12 Jun 2012. <http://en.wikipedia.org/wiki/Digital_subscriber_line>.

[4] "Asymmetrical Digital Subscriber Line." *Wikipedia*. Wikimedia Foundation, Inc., 31 Aug 2012. Web. 12 Jun 2012. <http://en.wikipedia.org/wiki/Asymmetric_digital_subscriber_line>.

[5] Communication Technologies, Inc., . United States. National Communications System. *Supervisory Control and Data Acquisition (SCADA) Systems*. Chantilly: Communication Technologies, Inc., 2004. Print. <http://www.ncs.gov/library/tech_bulletins/2004/tib_04-1.pdf>.

[6] "Broadband." *Wikipedia*. Wikimedia Foundation, Inc., 12 Sep 2012. Web. 29 Jun 2012. <http://en.wikipedia.org/wiki/Asymmetric_digital_subscriber_line>.

[7] Gellings, Clark, and Karen George. "Broadband Over Powerline 2004: Technology and Prospects." *EPRI*. EPRI, Oct 2004. Web. 22 Jul 2012. <http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=000000000001011264&RaiseDocType=Abstract_id>.

[8] *Sadiku, Matthew N.O. *Optical and Wireless Communications Next Generation Networks*. Print

[9] Motorola, Inc., . "Motorola Canopy Wireless Broadband Platform Configuration Guide." *Motorola*. Motorola, Jun 2005. Web. Aug 2012. <http://ap.cgiss.motorola.com/wibb_extranet/pdf/ptp/network-planning-guides/ConfigGuide_062305.pdf>.

[10] Top Ten Reviews, . "Cell Phone Providers Review." *Top Ten Reviews*. N.p., n.d. Web. July 2012. <http://cell-phone-providers-review.toptenreviews.com/>.

[11] "Power Line Communication." *Wikipedia*. Wikimedia Foundation, Inc., n.d. Web. May 2012. <http://en.wikipedia.org/wiki/Power_line_communication>.

[12] Schmidt, Rick. "Communication Technologies for SCADA, AMR, Mobile Radio, and Distribution Automation." *Cooperative*. National Rural Electric Cooperative Association, 01 Apr 2004. Web. 19 May 2012. <https://www.cooperative.com/about/NRECA/CRN/Results/Pages/CommunicationTechnologiesforSCADA.asp&xgt;.

[13] Dollen, Don Von. United States Department of Commerce. National Institute of Standards and Technology. *Report to NIST on the Smart Grid Interoperability Standards Roadmap*. EPRI, 2009. Print.

[14] Scarfone, Karen, Cyrus Tibbs, and Matthew Sexton. United States Department of Commerce. National Institute of Standards and Technology. *Guide to Securing WiMAX Wireless Communications*. Gaithersburg: National Institute of Standards and Technology, 2010. Print. <http://csrc.nist.gov/publications/nistpubs/800-127/sp800-127.pdf>.

[15] Verizon Wireless, . "Share Everything Data Only Plans." *Verizon Wireless*. N.p., 2012. Web. 1 Oct 2012. <http://youreguide.vzw.com/pg/share-everything-data-only-plans/>.

Appendix B - Communication Summary Table

Communication System	Current Uses	Future Uses	Data Speeds		Range
			Download	Upload	
Air Cards	Mobile Internet IP Applications (Mobile Workforce)	Mobile Internet IP Applications	4G: 5-12 Mbps	4G: 2-5 Mbps	Cellular Coverage Area
Broadband over the Power Line (BPL)	Not Used at the Moment	Internet Services on the Power Line	5 Mbps	5 Mbps	Distribution System Power Grid Medium Voltage Power Lines
Cellular	Data Transmission Internet IP Applications (AMI,SCADA, AVL, Mobile Workforce) Cell Phones	Internet IP Applications, Fault Indicators	4G: 5-12 Mbps	4G: 2-5 Mbps	Cellular Coverage Area
Dial-Up	Landline Telephones Internet IP Applications (AMI)	Extinct	56 Kbps	56 Kbps	Telephone Infrastructure
DSL/Broadband	Internet IP Applications (AMI, SCADA)	Internet IP Applications	3 Mbps to 20 Mbps	512 Kbps to 1 Mbps	Telephone Infrastructure Cable Company Infrastructure
Microwave Systems	Communications Backbone Transfer of Data for many applications Truck Radios	SCADA, Mobile Workforce, Fault Indicators	10 Mbps to 300 Mbps	10 Mbps to 300 Mbps	Up to Approx. 100 Miles
Power Line Carrier (PLC)	Transmission of Data on Power Line (AMI, BPL, Fault Indicators)	Transmission of Data on Power Line (AMI, BPL, Fault Indicators)	40 bps to 180 bps	40 bps to 180 bps	Distribution System Power Grid Medium Voltage Power Lines
Radio Systems	Truck Radios Radio Hop for Data Transfer SCADA	Mobile Internet IP Applications (Mobile Workforce)	6 Mbps to 20 Mbps	6 Mbps to 20 Mbps	20 to 50 Miles Line of Sight needed
RF Mesh	AMI Solutions	AMI Solutions	100 Kbps to 250 Kbps	100 Kbps to 250 Kbps	In Flat Terrains
Satellite	Internet IP Applications (AMI, SCADA, AVL)	Internet IP Applications and AVL	1 Mbps - 12 Mbps	200 Kbps to 1 Mbps	Everywhere
WiMax Internet	Internet IP Applications (AMI, SCADA)	Internet IP Applications	1.5 Mbps to 6 Mbps	256 Kbps to 512 Kbps	Metropolitan Areas 5 Miles to 30 Miles

Communication System	Range	Reliability	Strengths	Weaknesses	Cost
Air Cards	Cellular Coverage Area	4 - Dependent on Coverage Area	Reliability System Controlled By Third Party Set Monthly Fees	Rural Coverage Areas Equipment Investment Overage Fees Charges for Static IP	$30 for the device $50 for a 5GB data Plan with overage fees requires 2 year contract
Broadband over the Power Line (BPL)	Distribution System Power Grid Medium Voltage Power Lines	1 - High attenuation problems	Offers an Internet Service Higher data speeds	High Attenuation Difficulty sending signal through distribution transformer Radio Frequency Interference	Free for the communication system Equipment for Injection to power line - in vendor design
Cellular	Cellular Coverage Area	4 - Dependent on Coverage Area	Reliability System Controlled By Third Party Set Monthly Fees High Data Speeds	Rural Coverage Areas Equipment Investment Overage Fees Charges for Static IP Cellular company does not offer or support modems	Modems cost $500.00 Monthly Cost of $50 to $100 dependent on the data plan Now able to group services in share group for lower prices per service
Dial-Up	Telephone Infrastructure	1	Low Monthly Price Availability in rural area	Reliability Very low data speeds Voice and data comms can't be used at same time	10 - 15 dollars per line
DSL/Broadband	Telephone Infrastructure Cable Company Infrastructure	3 - Modem is weakest link on Comm system	Reliability Higher Data Speeds Provider is responsible for outages	Short Ranges in 2 to 5 miles Outages out of utilities control	50 - 80 dollars for each service
Microwave Systems	Up to Approx. 100 Miles	3 - line of sight needs to be achieved	High channel capacity Contractor designs the system	Line of sight clearances Permits High investment cost	$15,000 to $30,000 per antenna site does not include tower, permits or labor
Power Line Carrier (PLC)	Distribution System Power Grid Medium Voltage Power Lines	4 - Noise and Outages cause poor reliability	Uses power system Infrastructure AMI solution to make customers happier	Slow data rates Noise on system Cost of injection equipment	Free for the communication system Equipment for Injection to power line - in vendor design
Radio Systems	20 to 50 Miles Line of Sight needed	3 - line of sight needs to be achieved	Contractor designs system High Channel Capacity No monthly cost	High Initial investment Line of sight clearances Cost of tower attachments	Dependent on the style of system Approximately $10,000 for radio hop
RF Mesh	In Flat Terrains	4 - in Flat Terrain 2 - in Hilly Terrain	Air data transmission No injection equipment	Hilly terrain May receive many customer complaints	Included with AMI solution
Satellite	Everywhere	3 - available everywhere except for forest terrains	High data speeds in rural areas Monthly payments Wide area coverage	Leasing charges for equipment Latency Monthly/Daily download limits	$60 - $130 dependent on the data plan $10 monthly leasing fee
WiMax Internet	Metropolitan Areas 5 Miles to 30 Miles	3 - Other technologies that use the same frequencies cause Interference	Internet IP connectivity High data rates Reliability	Radio Interference Line of sight clearances	Approximately $50 per month

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