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Last mile connectivity challenges in Smart Grid by

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SUMMARY

Automatic data collection from utility energy meters (HT, LT and consumer) is the first step towards making the power grid smarter. A complex network of these meters all the way to the substation is called Advanced Metering Infrastructure (AMI) and the last mile of this network is called the Automated Meter Reading (AMR) network.

This paper describes a number of technologies that can be utilised in setting up an Automated Meter Reading network in India and the challenges involved in this process. The establishment of Smart Grid is at an advanced stage in some other countries of the world. This paper also tells which of these technologies are selected by these countries and the reasons for their selection with respect to geographical and infrastructural factors.

The paper describes both wireless and wired technologies and also compares the advantages and disadvantages of both. In setting up wireless networks, ensuring a sustained connectivity is one of the biggest challenges because of a wide variation in the location of meters in different localities of the same area. In this paper, various factors like the frequency band (2.4GHz or Sub-1 GHz), network topology (peer to peer, star and mesh networks) and various standards like Zigbee, WM-Bus, WiFi are introduced and compared. This paper illustrates the steps that can be taken to ensure continued connectivity.

For wired connectivity, power line communication is the only viable alternative for AMI. In power line communication, the noise generated by different loads on the power line and the dynamic changes in the line impedances is the major challenge. This paper shows the latest advancement in PLC technology which makes the use of OFDM modulation as compared to SFSK which was used in yesteryear installations and explains how it helps in addressing the challenges mentioned earlier. This paper also gives an update on the standardizations that are happening and being followed worldwide.

Given the diversity of urban planning architectures and geographical and infrastructural differences at various places in India, it may be possible that instead of selecting a single technology, a hybrid AMR network has to be designed. This paper also describes the challenges involved in commissioning of such networks and what steps can be taken to make these networks more reliable.

KEYWORDS

Automated Meter Reading, AMR, Advanced Metering Infrastructure, AMI, Low Power RF, Zigbee, Wireless M-Bus, Power Line Communications, PLC, PLCC, WiFi.

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1. AUTOMATED METER READING

Reading the meters automatically and providing real time information to the utility about the individual consumptions of the users can provide a lot of advantages to the utilities. A few of these advantages are listed below:

1. **Omitting the Human Error:** Without implementation of AMR, most of the data collection and processing is done manually. A large number of consumers file complaints to the utilities every year due to errors in their bills. If an AMR system is put in place, there is least possibility of human errors in the billing and the data processing is much quicker.
2. **Reducing Manpower and quicker billing:** In big metropolitan cities, a huge manpower is needed for data collection from the meters installed in hundred thousand households and industries. Additional manpower in needed for processing the data to impose penalties etc for incorrect usage. Many utilities increase the meter reading cycles to bi-monthly or six-monthly to save cost on manpower. An AMR system helps in reducing manpower and the cost associated with it. Thus, it also helps in reducing the billing cycle time so that the utilities get the payments within a month of power being provided.
3. **Increase the resiliency of the Grid**: With the capability to get real time information from the consumers directly, the utilities can come to know about a power outage in a certain area or from a specific consumer directly without the need of anybody making a telephone call. This will help in maintaining a shorter power outage times in case of faults.
4. **Help in implementation of dynamic tariff**: The number of electric appliances and electrical machinery being used is rising exponentially. The capability to generate the electric power is not rising at the same rate. It is required to limit the use of electric power at certain times of the day when the demand is very high. This, if not done, makes the utilities to do load shedding by stopping the supply to certain areas. If a dynamic tariff is maintained, where the user has to pay higher at times when the utility is seeing a higher demand the user may prefer to postpone the task to a time when the rate is lower.
5. **Catch Power Theft directly from the power lines:** A vast amount of electricity is stolen by putting jumpers on the power lines from the poles. With a smarter grid and a smart meter network, it is easy and quick to check the unbalance in the billing and consumption, and identify the location where this theft is taking place.
6. **Catch tampering of Energy meters instantaneously:** A lot of consumers in India tamper their electrical meters. The meters have the capability to record tampers but this comes to known to the utilities only when somebody from the utilities goes to read the meter. If it is a long time back, the consumer may not agree that a tamper was done. With the real time information transfer to the utilities, this notification can reach the utility instantaneously and the utility can take action immediately.

Establishing a smarter grid and AMR network is a complex task which needs a lot of technical and infrastructural advancements. The complete automation of meter reading may not happen in one go but would need multiple steps. The AMR network may have the following three evolutions in automated data collection from the meters:

- **Walk-by Data collection**: A meter reader carries a handheld computer with a built-in or attached receiver/transceiver (radio frequency or touch) to collect meter readings from an AMR capable meter. The meter reader walks by the locations where meters are installed as they go through their meter reading route. For such mode of data collection, a point-to-point RF connection can be utilized for reading the meters. The RF protocol may be non-standardized in this case.
- **Drive-by Data Collection**: “Drive-by" meter reading is where a reading device is installed in a vehicle. The meter reader drives the vehicle while the reading device automatically collects the meter readings. With mobile meter reading, the reader does not normally have to read the meters in any particular route order, but just drives the service area until all meters are read. The network topology used here may be star network where the data-collector acts as the central access point and all the other meters connect to this access point to transfer the data.
- **Fixed Network Installation**: Fixed Network AMR is a method where a network is permanently installed to capture meter readings. There can be a single network to which all the meters in a locality are connected. The best topology for such a network should be a mesh or an ad-hoc network. Ideally the meters or some meters in the locality have to act as router and there should be at least one coordinator. Data concentrators can be installed at distribution transformers level which can provide the connectivity to the backbone networks. Such an installation is called Advanced Metering Infrastructure (AMI) which should be the target of all the utilities which are looking for moving towards the smarter grids. There can be different technologies used for such networks and different protocols for reading the meters. The next section of this paper describes these technologies in a greater detail.

2. AMR TECHNOLOGIES

A lot of factors have to be taken into account while choosing a right technology and the topology of AMR networks. The following is a brief list of the requirements that a utility will have from its AMR network:

1. Reliability or sustained connectivity
2. Interoperability
3. Security
4. Ease of installation and commissioning
5. Lower Cost

It is impossible to meet all these requirements to a one hundred percent level for a given technology. Therefore, it becomes very important for the utilities and the meter manufacturers to work together to finalise on which technologies to work on and which to discard.

Different AMR technologies may be divided into two broad categories - Wireless and Wired technologies. Wireless technologies can be used for all three levels of automated meter reading i.e. walk-by, drive-by and fixed network while wired technologies can directly be used in case of fixed networks only.

2.1. **Wireless AMR technologies**

From several decades, RF communication technology is being used for various communication requirements. The most widespread are those for military purposes, entertainment purposes and personal mobile communications. Until recently, the radio communication has started being used in data communications. There is a specific branch of RF communications which is called Low Power RF which is finding a greater use in industrial sensor networks and home automation. The Low Power RF is a very good choice for AMR networks as well because of the following reasons:

- Most of the Low Power RF networks work on ISM (Industrial, Scientific and Medical) bands. This means that there is no need for the meter manufacturers to get a license for using a specific band.
- As the name suggests, the Low Power RF networks consume much lesser power as compared to conventional RF applications like mobile phones. Thus, these can be used for battery run devices like water and gas meters.
- There are standardizations already in place for these networks. There are a few organisations like Zigbee which have a standardized the networks topology and the data communications. These standards can be directly applied to the tenders for these applications.

From the description above, it is easy to say that Low Power RF should be a preferred technology for the AMR networks. But to make real use of this technology, the meter manufacturers and the utilities has to make tough decisions on the various sub choices that are needed to be made while actually designing Low Power RF based Smart Meters.

Depending upon the country where the AMR network will be installed, the ISM band frequency might vary. The following table shows the different ISM band frequencies available in different countries.

USA/Canada:	
260 – 470 MHz	FCC Part 15.231; 15.205
902 – 928 MHz	FCC Part 15.247; 15.249
2400 – 2483.5 MHz	FCC Part 15.247; 15.249
Europe:	
433.050 – 434.790 MHz	ETSI EN 300 220
863.0 – 870.0 MHz	ETSI EN 300 220
2400 – 2483.5 MHz	ETSI EN 300 440 or ETSI EN 300 328
Japan:	
315 MHz	Ultra low power applications
426-430, 449, 469 MHz	ARIB STD-T67
2400 – 2483.5 MHz	ARIB STD-T66
2471 – 2497 MHz	ARIB RCR STD-33
India :	
2400 – 2483.5 MHz	FCC Part 15.247; 15.249
865 – 867 MHz	*www.wpc.dot.gov.in/Static/RFIDDelicensing.doc*

The performance of an AMR network depends to some extent on the RF frequency being used in the network. The lower frequencies tend to provide a better distance coverage for a given output power as compared to 2.4GHz but have some drawbacks as well. From the table above, it is clear that the solutions which do not work at 2.4GHz tend to be very country specific while the solutions on 2.4GHz can be universally accepted. The second disadvantage with sub 1GHz solutions is that the size of the antenna will be larger. But due to a significant gain in range, a sub 1GHz solution is seen to be preferred by many utilities and meter manufacturers for Wide Area Networks and 2.4GHz for Home Area Networks.

The second major decision that the utilities have to take is on the wireless standard that the instalments need to be compliant. Following a standard helps in inter-operability of the networks that is one of the key requirements. The following are some of the wireless standards that can be used for AMR:

1. **Zigbee with SE:** Zigbee finds its use in the Smart Grid for local area or home area networks. The Smart Energy sub standard within Zigbee is specified for communication between the energy meter and the in home display or a home gateway solution. This provides a channel for the consumer to know the existing tariff in a multirate tariff plan. This may also help the consumer to have the appliances directly controlled by the Home Gateway to optimise the cost of power based upon the feedback from the meter. Zigbee follows the IEEE 802.15.4 for its PHY and MAC layer and has a separate standard for the upper layers. The Zigbee network follows a mesh topology with dynamic healing capabilities. Due to these advantages, some utilities have tried to utilize the Zigbee standard with a custom application layer for Wide Area Network. But since this is specified to work in 2.4 GHz, it suffers from range issues. Recently, Zigbee IP, specification have been finalized which now adds IPV6 networks support and Sub 1GHz support in Zigbee. It also adds AES128-CCM based security to this standard's requirements.

2. **6LowPAN:** 6LowPAN is the name given to IPv6 networks over RF. The biggest advantage of 6LowPAN networks is that they can be merged with the IPV6 based internet. The disadvantage of these networks is the interoperability challenges that are involved in putting the IPV6 over IEEE802.15.4 which needs adaptation layers in between. This also supports mesh networking and can work on Sub 1GHz frequencies. Some companies have come up with open source stacks for 6LowPAN implementation which can be beneficial to the meter manufacturers.

3. **Wireless M-Bus:** Wireless M-Bus is the wireless counterpart of Metering-Bus or M-Bus standard (EN 13757-2 physical and link layer, EN 13757-3 application layer) which is being widely used in European countries for electric and gas meter AMR. This is published as a European standard EN 13757-4:2005. Wireless MBUS is targeted to operate in the 868 MHz band. Thus, it can provide a good range as compared to 2.4GHz based networks. The disadvantage with Wireless M-Bus is that it is based upon a star network topology which is not as rugged as the mesh networks. The security is not inherently available in the standard but has to be added in the upper application layers.

4. **Wi-Fi:** Wi-Fi technology is ubiquitous around the world in personal computing devices and cellular phones. While talking about AMR, this technology can be a viable alternative. It is based upon IEEE 802.11 standard and can run TCP-IP stacks. There is a newer Wi-Fi Direct standard coming up which can help in reading the meter consumption directly on a Wi-Fi enabled cell phone without need of an external access points. There are semiconductor chips which provide lower power consumption for running these kinds of applications. The major drawback of this technology again comes back to range. As it also works on 2.4GHz band, this technology is able to provide a range of around 20-30 meters only. Moreover, on a comparative basis, the power consumption of Wi-Fi solution is still much higher as compared to Low Power RF solutions.

Comparing the disadvantages and advantages of all the above wireless technologies and standards, it seems that Zigbee (with its latest evolution Zigbee IP) is the most suitable solution for this application. The advantages of Zigbee are complemented by a mature and already evolved ecosystem like ready certified stacks, certification labs, semiconductor solutions etc.

2.2 Wired AMR networks

Though not much widespread today, the use of wired networks in AMR is imminent. The wireless networks suffer from problems with sustained connectivity due to unlimited environmental and infrastructural factors. Wireless technologies also suffer from interference from other applications like Smartphones, Tablets, Laptops, and Microwaves etc. In wired AMR, there had been some instalments based on RS485 but these are confined to small localities like a meter-room in an apartment complex. For putting RS485 based fixed network, it is needed to connect an extra pair of wires to each meters. For localities, where houses are a long distance away, the cost of putting extra wire becomes significant. An alternate technology that is coming up is the Power Line Communication where the data is transmitted over the power lines that connect to each individual meters. The biggest advantage is that no additional infrastructures like extra wires or antennas are needed outside the meter. There are different ways of modulating the data over power lines e.g. SFSK, OFDM etc. The yesteryear installations on PLC were mostly based upon SFSK modulation. The SFSK based solutions suffered sustained connectivity problems because the line conditions and the load conditions on the power lines can vary drastically.

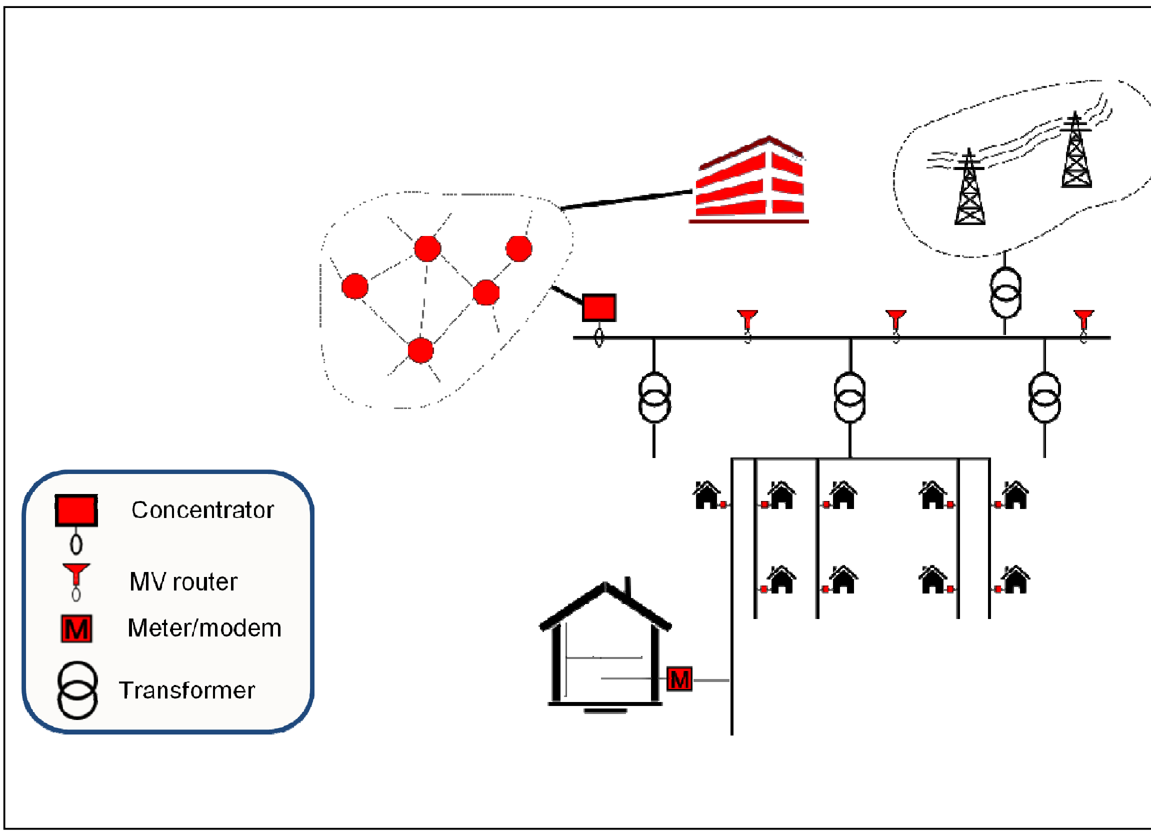

Figure: Topology of a Power Line Communications based AMR Network.

With the evolutions of semiconductor chips and the communications technologies, now there are solutions in the market which work on OFDM modulation. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate inter-symbol interference (ISI) and utilize echoes and time-spreading (on analogue TV these are visible as ghosting and blurring, respectively) to achieve a diversity gain, i.e. a signal-to-noise ratio improvement. This mechanism also facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.

In 2009, a group of vendors formed the PoweRline Intelligent Metering Evolution (PRIME) alliance. As delivered, the physical layer is OFDM, sampled at 250 kHz, with 512 differential phase shift keying channels from 42–89 kHz. Its fastest transmission rate is 128.6 kilobits/second, while its most robust is 21.4 kbit/s. It uses a convolutional code for error detection and correction. The upper layer is usually IPv4.

In 2011, several companies including distribution network operators (ERDF, Enexis), meter vendors (Sagemcom, Landis&Gyr) and chip vendors (Maxim Integrated, Texas Instruments, STMicroelectronics) founded the G3-PLC Alliance to promote G3-PLC technology. G3-PLC is the low layer protocol to enable large scale infrastructure on the electrical grid. G3-PLC may operate on CENELEC A band (35 kHz to 91 kHz) or CENELEC B band (98 kHz to 122 kHz) in Europe, on ARIB band (155 kHz to 403 kHz) in Japan and on FCC (155 kHz to 487 kHz) for the US and the rest of the world. The technology used is OFDM sampled at 400 kHz with adaptive modulation and tone mapping. Error detection and correction is made by both a convolution code and Reed-Solomon error correction. The required media access control is taken from IEEE 802.15.4, a radio standard. G3-PLC has been designed for extremely robust communication based on reliable and highly secured connections between devices, including crossing Medium Voltage to Low Voltage transformers. With the use of IPv6, G3-PLC enables communication between meters, grid actuators as well as smart objects. In December 2011, G3 PLC technology was recognised as an international standard at ITU in Geneva where it is referenced as G.9903, Narrowband orthogonal frequency division multiplexing power line communication transceivers for G3-PLC networks.

3. HYBRID AMR NETWORKS

The above two sections of this paper talk about wireless and wired technologies that can be used for the AMR. After careful comparison of all the technology options available, one can come to a conclusion that it is impossible to find out a technology that can be free from all the issues. One option is to use more than one technology and make the AMR network a hybrid of two technologies. An ideal combination can be one wireless (e.g. 6LowPAN) and one wired (e.g. PRIME PLC). The two technologies can complement each other in different scenarios. For example, in a locality where there are some row houses and some apartments, it is better to use RF for apartments and PLC for Row houses. Though the commissioning and installation of such networks will be further more difficult, but if a significant effort is put in this by the utilities and meter manufacturers together, then this can be achieved.

4. CHALLENGES IN INSTALLATION, COMMISIONING & MAINTENANCE

Selecting a proper technology for AMR is just the first step in moving towards smarter grids using AMR. Once the meters which are based upon a specific AMR technology are produced, the next step is the installation and commissioning of such networks. Some of the challenges faced by the utilities are listed below:

1. Sustained connectivity is the biggest issue that the utilities face while commissioning and maintaining the networks. Whichever technology is used for AMR, it is difficult to maintain a sustained connectivity while limiting the output power to be compliant to various standards. A serious evaluation of the conditions is required before installing any AMR networks.

2. Isolation of AMR networks is another problem. Both wireless and wired network signals cannot be restricted to a specific locality. For self healing and mesh networks, this requires careful commissioning as the meters may tend to join other networks. Since the commissioning also has to be done via the same communication channel on which the AMR network will be formed, the installer needs to take utmost care while installing the networks and each meter has to be programmed not to join any other network except the desired one.

3. Most of the protocols and standards which can be used for AMR are still in the evolution stage. The speed with which the automation of the grid and meter reading is achieved by a given utility, it is possible that there are newer versions or newer requirements are added by the standardization bodies. When equipments from different manufactures are being used in these networks, it is possible that one manufacturer complies to an older specification while the other complies to a newer one. It is required the meter manufacturers and utilities remain in constant touch with the standardization bodies and get the latest technology.

4. The AMR based meters run on complex software stacks. It is always a possibility that the meter manufacturers find out a bug in the software stack or the rest of the software running on controllers inside the meter after the meter has been installed in the field. It will be helpful if the utilities require the meter manufactures to put the field firmware upgrade option in the meters.

5. As the data that is exchanged in the AMR network is important financial data, the security of this data is utmost important. The AMR networks are needed to be hack-proof. The data transfers should be encrypted with proper and standardized encryption methods. The meter manufacturers should provide a feature of programming secret keys in each meter which is known only to the utility.

6. With a high degree of automation in the grid, a huge responsibility lies on the utilities for the managing and storing the huge amount of data and maintenance of such infrastructures. Third party telecom and software companies are needed to be involved in this process that have expertise in such advanced technology. A close collaboration is required between meter manufacturers, utilities and the third party companies for accomplishing the task of building smarter grids.

5. CONCLUSION

In this paper, we have described different technologies which are being used worldwide for AMR networks in Smart Grid. It is concluded that each technology, whether wired or wireless has some advantages and disadvantages. It is very important for the electricity utilities to understand these pros and cons of each technology. With these in mind, based upon the urban planning architectures and different geographical and urban planning architectures, the utilities have to select the most suitable technologies. If the requirements are very diverse, then hybrid networks should also be considered. The paper has also described the challenges and the right ways to tackle these challenges while implementing the AMR networks.

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