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A Review on Transmission Media in Power Systems

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Abstract− Smart Grid denotes the integration of all elements of a power system with a communication infrastructure. Nowadays, communication systems have been developed by multi layer architecture in which the transmission media is the lowest layer of these systems. The characteristics of the communication systems will be influenced by the characteristics of its media. Generally, transmission media can be classified as guided and unguided ones.

In this paper, a brief summary of popular guided and unguided media used in power systems is presented. Then, the two types of media are compared with each other.

Keywords− Power System Communication, Guided and Unguided Transmission Media, Power Line Carrier, Optical Fiber, Wireless Transmission

1. Introduction

Smart grid is a term which has been introduced in power system literature recently. This term implicitly implies the integration of all elements connected to a power grid with a communication infrastructure. In other words, for establishing a smart grid, a two way communication network should be created. Recent communication systems are normally developed by a multi layer model. Such systems are preferred to old ones. This is because while they benefit being less expensive than old systems, they are more qualitative. The lowest layer of these systems referred as the physical layer, is a kind of medium that establishes the physical connection between transmitter and receiver. The characteristics of the communication systems will be seriously influenced by the characteristics of its media. As a result, the transmission media characteristics play an important role in power system communication infrastructure. Historically, different kinds of media have been utilized in power system depends on operational, environmental and economical conditions.

This paper reviews functional communication media in power systems. Section 2 of this paper defines the communication system in power systems. Then, considering the importance of transmission media in a communication system, Section 3 introduces the transmission media and its classification in general. Section 4 and 5 review guided and unguided transmission media in power systems, respectively. The comparison between these two classified media is illustrated in Section 6. Finally, the paper ends with concluding remarks (Section 7).

2. Communication Systems

The function of power grid communication system is to exchange data among different nodes of the power system through communication network. These nodes may be measuring devices in substations, utilities and customers side (which are known as data resources) or decision making location (which is known as control center). In 1977, international organization for standardization (ISO) developed a model for open system interconnection which is called the ISO-OSI reference model [1]. This model was revised in 1995. The OSI model is a kind of architecture for exchanging information among systems. In fact, this model is an effective architecture for the explanation, implementation, standardization and utilization of communications networks. The OSI reference model consists of seven layers: physical, data link, network, transport, session, presentation, and application [1]. The lowest layer of this model is a kind of medium that establishes the physical connection between transmitter and receiver. The characteristics of the communication systems will be seriously influenced by the characteristics of its media. As a result, the transmission media characteristics play an important role in power system communication infrastructure.

3. Transmission Media Classification in General

As explained in previous sessions, the transmission media is the physical path between transmitter and receiver in a communication system. All transmission media transmit network signals in the form of a wave. The characteristics of the media and the signal influence the characteristics and quality of data transmission. Transmission media, as described below, can be classified as guided and unguided ones [2]. Guided media guides the waves through a solid medium. Twisted pair, coaxial cable, power transmission/distribution line and optical fiber are some examples of guided media. In the case of guided media, the media itself has the most important role in characterizing the limitations of transmission [2].

On the other hand, unguided media provides a means for transmitting electromagnetic waves. However, this media does not guide the signals. The atmosphere and outer space are some examples of this case and usually referred to as wireless communication. Unlike guided media, in the case of unguided media, the signal strength provided by wireless antenna is more important than the media itself [2]. The next sections review these two groups of media.

4. Guided Media in Power Systems

4.1 PLC

Power line carrier (PLC) has used transmission lines as medium for communication. This type of transmission media has been one of the first reliable media utilized in power system for critical communications [3]. This media is also the first guided media commonly utilized in power system and is a part of power system infrastructure. As a result, failure in power system infrastructure such as line outage causes communication difficulty. PLC systems may be classified as two groups in common, narrow band and broad band PLC.

Narrow band PLC usually has low data rates (up to 100kbps). It is used for automation and control applications or few voice channels [4]. However, due to the fact that the narrowband PLC works in low data rates, this system is very reliable and PLC modems can be installed far from each others.

Unlike narrowband PLC, broadband PLC establishes a high data rate (beyond 2 Mbps) between two modems [4]. This kind of communication can be used for multi services such as automation, internet access and telephony at the same time. Broadband PLCs work in high data rates; therefore, distance between two modems is short and modems require more maintenance. This type of communication is not recommended for noisy power lines [3].

When power lines are used for broadband internet access, power line communication is known as broadband over power line (BPL). BPLs use spread spectrum techniques to deliver data rates previously inaccessible. But because of the fundamental physical constraints, successful data rates will be achieved much above several megabits per second [5].

4.2 OPGW/ADSS

Optical fiber can be used as a medium for communication. Because of its flexibility, fiber optic can be bundled as a cable. As mentioned in section 3, signals are transmitted through the media by a type of waveform. In fiber cables, the signal is a light wave; either visible or infrared light. Essentially, two types of fiber optic cables including optical power ground wire (OPGW) and all-dielectric self supporting (ADSS) are used in power industries.

OPGW cable combines the function of grounding and communication. This kind of cable can be used in transmission or distribution lines. In transmission lines, OPGW is replaced with shield wire and is suspended above the lines [3].

Unlike OPGW, ADSS is a self supporting cable and it does not include any metal component and are designed to be fastened to towers or poles underneath the power conductors. ADSS is ideal for installation in distribution poles as well as transmission towers, even when live-line installations are required [3], [5].

4.3 Leased Line

Historically, leased telephone circuits have been used widely in electric utilities to create a point-to-point or point-to-multipoint communication [3]. The first version of DSL was defined in 1988 and called ISDN (Integrated Services Digital Network). ISDN provides a maximum of 128 Kbps in both uplink and downlink directions [4]. Other DSL versions have appeared in different forms, such as high-data-rate DSL (HDSL), single-line DSL (SDSL), asymmetric DSL (ADSL), rate-adaptive DSL (RADSL), and very high-data-rate DSL (VDSL), all of which utilize copper lines. The differences between xDSL technologies are their data rates and directionality of transmission, distances to which those rates can be supported, and the size of the wire. Dixit has compared xDSL technologies shown in Table I [11].

TABLE I: Characteristics of xDSL systems [11]

Acronym	Data rate	Mode	Max. dist. (km)	No. of wire pairs
DSL	160 kbps	Duplex	6	One
HDSL	1.544 Mbps 2.048 Mbps	Duplex	4	Two, Three
SDSL	1.544 Mbps 2.048 Mbps	Duplex	3	One
ADSL	1.5 to 6.144 Mbps 16 to 640 kbps	Downlink Uplink	4 to 6	One
RADSL	Adaptive to ADSL rates	Downlink Uplink	4 to 6	One
VDSL	13 to 52 Mbps 1.5 to 2.3 Mbps	Downlink Uplink	0.3 to 1.5	One
(A)DSL Lite (or UADSL)	1.5 Mbps 512 kbps	Downlink Uplink	6	One

A careful study of table I illustrates that there are many kinds of DSL technologies with different data rates which work in various distances. Consequently, a low to medium speed connection can be established in a metropolitan with PSTN leased line wires, especially for distribution applications.

5. Unguided Media in Power Systems

Wireless transmission is used when we have several challenges such as environmental or financial limitations for utilizing a guided media. However, as signals transmitted using wireless communication can be accessed by anyone, the security of wireless communication is reduced. On the other hand, various data by different sources may be transmitted at the same frequency and collision may happen. It can be concluded that the reliability of wireless transmission is less than the reliability of transmission through a guided media. In wireless transmission, signal can take the form of waves in the radio spectrum, including very high frequency (VHF) and microwaves, or it can be light waves including infrared or visible lights such as laser.

The first important parameter in wireless communication is its range. In accordance with wireless ranges, four wireless types are defined [6]:

- Wireless Personal Area Network (WPAN)
- Wireless Local Area Network (WLAN)
- Wireless Metropolitan Area Network (WMAN)
- Wireless Wide Area Network (WWAN)

5.1 Wireless Personal Area Network (WPAN)

Personal networks make a small area networking for a variety of devices. The most popular WPAN is Bluetooth, firstly developed by the Sweden Ericsson. Bluetooth operates in unlicensed 2.4 GHz spectrum is also used by Wi-Fi. IEEE 802.15.1 standard for Bluetooth allows data rates up to 3 Mbps and at a range of up to 100 meters. Tow industrial technologies, UWB (Ultra Wide Band) and Zigbee, make high data rate and low cost WPAN, respectively [6].

UBW, which is standardized under the name IEEE 802.15.3, can use frequencies from 3.1 GHz to 10.6 GHz. UBW allows data rate up to 480 Mbps at the range of several meters and a rate of 110 Mbps at a range of up to 10 meters [6].

Zigbee has been created to become a wireless standard for remote control in industrial fields. It makes very low-cost WPAN for applications which are not too much bandwidth hungry [6]. Zigbee allows data rate of 250 Kbps at 2.4 GHz at the range of up to 10 meters (IEEE 802.15.4) and data rate of 20 Kbps at 900 kHz at the range of up to 75 meters (IEEE 802.15.4a).

5.2 Wireless Local Area Network (WLAN)

A WLAN connects devices via a wireless distribution method (typically spread-spectrum or OFDM). Wi-Fi is a popular WLAN technology which provides high speed connection on short ranges. In recent years, because of the lack of more suitable metropolitan wireless networks, Wi-Fi has been used at the metropolitan level. Wi-Fi networks are not suitable for moving devices and they take down in a few kilometers per hour movement. IEEE 802.11 is a set of standards carrying out Wi-Fi [6].

- IEEE 802.11: theoretical data rate 2 Mbps - 2.4 GHz unlicensed band (The first standard of the series. It was released in 1997 and clarified in 1999).
- IEEE 802.11b: theoretical data rate 11 Mbps - range of 100 meters to a maximum of a few hundred meters - 2.4 GHz unlicensed band.
- IEEE 802.11a: theoretical data rate 54 Mbps - range of approximately thirty meters - 5 GHz band.
- IEEE 802.11g: theoretical data rate 54 Mbps - range of a hundred meters - 2.4 GHz unlicensed band.
- IEEE 802.11n: theoretical data rate 320 Mbps - about thirty meters range - uses two bands 2.4 GHz and 5 GHz.

5.3 Wireless Metropolitan Area Network (WMAN)

WiMAX: Worldwide Interoperability for Microwave Access (WiMAX) is a communication protocol which provides fix and fully mobile data networking. WiMAX is based on the IEEE 802.16 standards which its most popular one is 802.16e-2005. Unlike WLAN technologies such as Wi-Fi, WiMAX is designed to operate as a WMAN. Various kinds of WiMAX work with both FCC licensed frequencies and unlicensed frequencies. Licensed WiMAX works in the range of 10 to 66 GHz and unlicensed WiMAX works in the range of 2 to 11 GHz. WiMAX theoretical data rate is 70 Mbps with a range of up to a maximum of 50 km with a direct line of sight (LOS). Near line of sight (NLOS) conditions seriously limit its range [6].

MBWA: Mobile broadband wireless access (MBWA) which is standardized under the name IEEE 802.20, creates mobile metropolitan networks with a speed up to 250 km/h. It uses licensed frequency band below 3.5 GHz and allows maximal data rates of 1 Mbps for downlink and 300 Kbps for uplink. The maximum range of the cells is 2.5 km. MBWA (which has short latency time) is a good choice to mobility data and can be compared with 3G mobile networks which focus on the voice [6].

GPRS: General Packet Radio Service (GPRS or sometimes called 2.5G) is a packet data bearer service for wireless communication over GSM (Global System for Mobile). It applies a packet radio principle to transfer user data packets efficiently between mobile stations and external IP networks. GPRS allows IP-based applications to run on a GSM network [7]. It provides moderate speed data transfer, by using unused channels in the GSM network. The data speeds can range from 9.6 kbps (using one radio time slot) to 115 kbps (which can be achieved by merging 8 time slots) [8].

GSM: It is the most popular second generation standard for mobile telephony systems in the world. There are some differences between GSM and GPRS. GSM is based on circuit-switching technology whereas, GPRS makes packet switching network over GSM. GPRS bandwidth is higher than GSM; thus, GPRS has higher data speed toward GSM. In packet switching networks, bandwidth is used only when a device transmits data. Conversely, connections are “always on” in circuit switching networks. Therefore, GPRS network charges are lower than GSM networks since the billing is based on data volume and not on call time [8].

CDMA: Code Division Multi-Access (CDMA) is another data networking technology for mobile communications. It allows all the users to utilize the entire frequency spectrum for all the time. Multiple simultaneous transmissions are separated by using coding theory. Only users associated with a particular code can understand each other. Using 66 Walsh codes in CDMA create 64 logical channels whereas 8 channels are available in GPRS [8].

3G mobile Carrier services: 3rd Generation networks provide new data carrier services for mobile users. For example, some networks support High Speed Packet Access (HSPA) data communication with HSDPA standard to provide improved downlink speeds. Furthermore, HSUPA standard is used for uploading speed enhancement. HSDPA provides downlink data rates up to 14.4 Mbps and uplink data rates 384 Kbps. HSUPA provides improved upload data rates of up to 5.76 Mbps [9]. Another 3G standard for data communication, CDMA2000, allows a maximum theoretical data rate of 2 Mbps [6].

Fig. 1 shows the history of mobile carrier standards based on their generations [9].

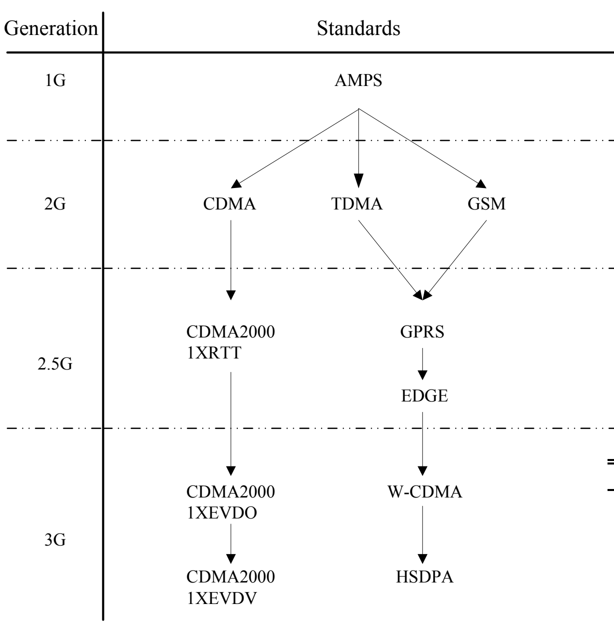

Fig. 1: Mobile carrier standards based on generations [9]

Fourty and his colleagues have compared the familiar WPANs, WLANs and WMANs shown in Table II [6].

TABLE II: Available Wireless Networks Comparison [6]

Commercial name	Standard	Theoretical data rates	Max Range	Frequency (GHz)
Bluetooth	IEEE 802.15.1	2 Mb/s	100 m	2.4
UWB	IEEE 802.15.3	Up to50 Mb/s	10m	
Zigbee	IEEE 802.15.4	250 Kb/s	10 m	2.4
Zigbee	IEEE 802.15.4a	20 Kb/s	75 m	0.9
Wi-Fi	IEEE 802.11b	11 Mb/s	100m	2.4
Wi-Fi	IEEE 802.11a	54 Mb/s	30 m	5.5
Wi-Fi	IEEE 802.11g	54 Mb/s	100 m	2.4
Wi-Fi	IEEE 802.11n	320 Mb/s	30 m	2.4 – 5.5
WiMAX	IEEE 802.16a	70 Mb/s	50 km	2.5 – 3.5 -5.8
MBWA	IEEE 802.20	1 Mb/s	100m	<3.5

5.4 Wireless Wide Area Network (WWAN)

When a guided media cannot connect a remote site to control center in power systems, satellites can provide a reliable connection. Moreover, new data resources such as PMUs use another satellite opportunity and synchronize data provided for some applications. Synchronization is introduced by Global Position System (GPS) satellites. Satellites may be classified as geostationary, medium earth orbiting, or low earth orbiting satellites [6]:

Geostationary satellites (GEO) are at an altitude of 35786 kilometers above the equator. GEO rotate around the earth at the same speed of earth rotation; thus, they appear to be fixed from the surface of the earth.

Low orbit satellites (LEO) rotate between 750 and 1500 kilometers orbit. They can provide data communication for remote sites. Iridium, Globalstar and Orbcomm are some examples of LEO satellites.

Medium earth orbiting satellites (MEO) are at altitudes between nearly 10,000 and 20,000 kilometers. From the view point of the earth, MEO rotate slowly in longitude; feel like 6 hours to circle the earth.

These three types of satellites cover surface of the earth almost everywhere, hence; WWAN technologies provide remote sites connection. Although satellites are connecting remote sites, high latency of these connections may create some problems. As a result, some critical applications such as WAPS (Wide Area Protection System) should not be implemented under WWAN technologies. Table III illustrates satellites orbit and latency [10].

TABLE III: Comparison of Different Satellite [10]

Type	Distance (km)	Latency
Geosynchronous Earth Orbit	35,786	540 ms
Medium Earth Orbit	10,000 – 20,000	200 ms
Low Earth Orbit	750 – 1,500	Sub 100

6. Guided and Unguided Media Comparison

Although both types of media described in previous sections provide communication infrastructure, there are some differences between them. Since guided media is a private solid medium, the security of this type of media is high. Conversely, unguided media has low security level since signals transmitted using unguided media can be accessed by anyone.

In the terms of bandwidth and speed, guided media provides medium to high speed connections while the speed of unguided type differs from low to medium.

Considering that the guided media is a solid medium and install between different nodes in a power system, the media installation cost is high whereas, in unguided media cases, no setup fee is needed. Furthermore, unguided media normally is a licensed frequency spectrum. Therefore, monthly fee should be paid for this type of media.

Sometimes, the latency is the critical factor of an application. For example, for WAPS application, in addition to security, the latency is very important. For these types of applications, the guided media are more suitable than other ones.

Some applications such as AVL (Automatic Vehicle Locator) connect to mobile data resources. In these cases, only unguided media can be used for creating a communication infrastructure. Some other types of applications such as AMI (Advanced Metering Infrastructure) communicate with huge amount of data resources distributed in wide geographical area. Since the data provided by these resources are not in high priority, investment on guided media, especially fiber types, is not cost effective. Therefore, unguided media are better choices.

To sum up, we have compared the guided and unguided media in table IV.

TABLE IV: Transmission Media Comparison

Media Type	Media	Bandwidth	Latency	Security
Guided	Fiber	High	Low	High
	Power Line	Medium	Low	High
	Leased Line	Medium	Low-Medium	High
Unguided	Wireless			
	WPAN	Low-Medium	Low-Medium	Low
	WLAN	Low-Medium	Medium	Low
	WMAN	Medium	Medium	Low
	WWAN	Low-Medium	High	Low

7. Conclusion

Smart Grid implies the integration of all elements connected to a power grid with a communication infrastructure. Recent communication systems are normally developed by a multi layer model. The lowest layer of these systems is a kind of medium that establishes the physical connection between transmitter and receiver. The communication systems will be characterized by their transmission media.

This article reviewed and compared the characteristics of popular guided and unguided media utilized in power systems. The comparison shows that there are some differences between these two types of media. First, in the case of security, the guided type is more secure than unguided type. Second, guided type provides medium to high speed connections, whereas the speeds for unguided type differ from low to medium. Third, guided media usually need investment for initial installation but it does not require monthly fee payment. In contrast, unguided media normally need monthly payment.

Critical factors of an application and the fanatical and geographical limitations of system are responsible for making decisions about media selection for communication infrastructure development. Taking media characteristics into consideration, it is possible to integrate them at various media layers. As a result, this kind of integration also can help engineers to design hierarchical networks especially in distribution networks.

References

[1] Kevin M. Middaugh, “A Comparison of Industrial Communications Networks,” *IEEE Transactions on Industry Applications*, vol. 29, no. 5, pp. 846 – 853, Sep/Oct 1993.

[2] W. Stallings, *Data and Computer Communications*, fifth edition, Prentice-Hall Inc, 1997, ch. 3.

[3] Donald J. Marihart, “Communications Technology Guidelines for EMS/SCADA Systems,” *IEEE Transactions on Power Delivery,* vol. 16, no. 2, pp. 181 – 188, Apr. 2001.

[4] Halid Hrasnica, Abdelfatteh Haidine, Ralf Lehnert, *Broadband Powerline Communications Networks: Network Design*, John Wiley & Sons, Ltd, New York, 2004.

[5] Daniel E. Nordell, “Communication Systems for Distribution Automation,” in *Transmission and Distribution Conference and Exposition, 2008. IEEE/PES*, Apr. 2008, pp. 1 – 14.

[6] Nicolas Fourty, Thierry Val, Philippe Fraisse, Jean-Jacques Mercier, “Comparative analysis of new high data rate wireless communication technologies "From Wi-Fi to WiMAX",” in *Joint International Conference on Autonomic and Autonomous Systems and International Conference on Networking and Services - (ICAS/ICNS 2005)*, Oct. 2005, p. 66.

[7] C. Bettstetter, H. Vogel, J Eberspacher, “GSM Phase 2+ General Packet Radio Service GPRS: Architecture, Protocols, and Air Interface”, *IEEE Comm. Surveys*, Third Quarter 1999, vol.2 no.3.

[8] Ranjeet Vaishnav, Prasanth Gopalakrishnan and Jose Thomas, “Using public mobile phone networks for distribution automation,” in Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE, Jul. 2008, pp. 1-5.

[9] Wang, Charles and Feng, Yanming and Higgins, Matthew and Looi, Mark (2009) “Communication infrastructure study for precise positioning services in regional Queensland,” In *Proceedings of International Global Navigation Satellite Systems Society Symposium*, Queensland, Australia, Dec. 2009.

[10] D. Proudfoot, “Information Technologies for Substation Automation Applications,” in *Transmission and Distribution Conference and Exposition, 2001 IEEE/PES*, vol. 1, 2001, pp. 349 – 361.

[11] Sudhir Dixit, “Data rides high on high-speed remote access,” *Communications Magazine, IEEE*, vol. 37, no. 1, pp. 130-141, Jan 1999.