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A New Approach for Classification of Data Transmission Media in Power Systems

M. Shahraeini, M. H. Javidi, and M. S. Ghazizadeh

***Abstract*--Smart Grid denotes the integration of all elements connected to a power grid with a communication infrastructure. Recent communication systems are developed by multi layer architecture. The lowest layer in such systems is transmission media. The characteristics of the communication systems will be seriously influenced by the characteristics of its media.**

This paper classifies communication media of power systems as dependent or independent ones. A dependent media is part of power system which is normally owned by Independent System Operator (ISO) or distribution companies. In contrast, as an independent media, it is not normally part of power system and can be public or provided by data service providers. In this paper, first, a brief summary of popular media used in power systems is presented. Then, the two main classes of media are compared with each other.

***Index Terms*--Mobile data communication, Optical fiber, Power line carrier, Power system communication, Power system control, Power system measurements, Power system monitoring, Power system protection, Satellite communication, SCADA systems, Twisted pair cables, Wireless communication**

I. Introduction

SMART grid is a term which has been introduced in power system literature recently. The 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 (linked to power 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, utilization of different kinds of media in power system depends on operational, environmental and economical conditions.

This paper proposes a new classification for functional communication media in power systems. Section II of this paper defines the information and communication technology (ICT) in power systems. This section introduces the ICT process blocks and maps these blocks to communication network layers. Then, considering the importance of transmission media in a communication system, Section III introduces the transmission media and its classification. Section IV proposes a new classification for transmission media in power systems. It also presents a brief summary for each popular media utilized in power systems. The comparison between these two classified media is illustrated in Section V. Finally, the paper ends with concluding remarks (Section VI).

II. Information and Communication Technology in Power Systems

Acquiring accurate data is the most essential step for developing information and knowledge about that system. This has become very vital for power systems in recent years and has been included in the framework of information and communication technology (ICT). ICT can be defined as; “The technology acquiring, storing, processing and distributing information by electronic means” [1].

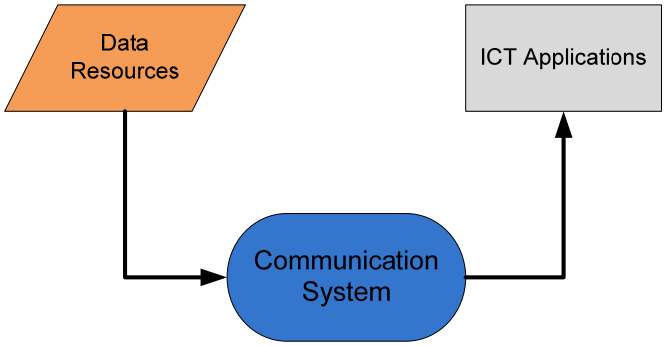

Fig. 1. Information and Communication Technology block diagram for a Power System

Processes involved in ICT (Fig. 1) mainly include data resources, communication of the information between different entities and application of the information through computing algorithms. Below is a brief summary of three blocks’ tasks.

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A. Data Resources

In a power system, data resources are distributed in the whole system. These resources are responsible for providing required data for different ICT applications. Phasor measurement unit (PMU), supervisory control and data acquisition (SCADA), remote terminal units (RTU), new intelligent devices (IED) such as digital fault recorders (DFR) and digital relays are some instances of data sources in a power grid [2]. The data provided by different data resources have different characteristics. While some resources such as a PMU provides little amount of data, some others such as a video conference set can provide a high volume of data. While some data of a power system are transmitted continuously (IP telephony), other resources send periodic messages in defined periods (feeder RTU).

B. ICT Applications

As explained before, information about any system can be extracted from measured data. In a power system, this can be achieved by a kind of computer software referred as "ICT Application". ICT applications process the data which are measured by data resources and extract usable information for operator and customers. When the data resources of an application are distributed in the entire system, the application is known as wide area measurement system (WAMS). WAMS contributes great potential for upgrading the supervision, operation, protection and control of modern power systems [3].

ICT Application can be classified in four levels [4]:

- Generation applications (GEN): Some applications run in generation level. Generator operation, status monitoring, power angle stability prediction and alarming are some examples of such applications [3].
- Transmission and sub-transmission applications (TRAN): In deregulated power industries, some applications performed at transmission (or sometimes sub-transmission) level by independent system operator (ISO). Wide area control & protection system (WACS & WAPS), state estimation (SE) and online low-frequency oscillation analysis are some examples of TANS level applications [3], [5].
- Distribution applications (DIS): Some applications such as feeder automation, distribution management system (DMS) and advanced metering infrastructure (AMI) run in distribution systems. Since there are many differences between distribution systems and transmission (or sub-transmission) systems, the DIS applications have different characteristics.
- Office management and automation (OFF): Distribution system represents the final stage in the delivery process of electricity to end users. Consequently, some ICT applications such as customer information system (CIS), billing software and geographic information system (GIS) process the customers' data and provide useful information. Additionally, some applications manage and automate office tasks. Enterprise resource planning (ERP) and management information system (MIS) are examples of these types of applications [4].

As described above, different applications may be used at different levels of a power system. However, to perform an application properly, some conditions should be satisfied. Some of critical conditions include data rate, response time and network availability. Data rate is the required bandwidth between an application and its data resources which are distributed in the whole system. Response time item specifies the upper boundary time for receiving data from data resources to an application. Finally, the network availability is the upper bound of availability for communication network of an application. Table I shows these items for some different applications in different levels [4], [5].

TABLE I
ICT APPLICATIONS IN POWER SYSTEM

Level	Application	Data Rate (Kbit/s)	Response Time (ms)	Network Availability
GEN-TRAN	WACS	1.2-64	<1000	>99.98%
TRAN	WAPS			
	Blocking	<64	<10	>99.99%
	Permissive	<64	<20	>99.99%
	Differential	<64	2-10	>99.99%
	Intertrip	<64	<40	>99.99%
All Levels	Streaming Data			
	Audio	8-64	100	>99.50%
	Video	9.6-2048	1000	>99.95%
DIS	Office Manag.			
	ERP			
	CIS & Billing	64-10240		>99.50%
	GIS			

C. Communication System

The function of communication system is to exchange data among different parts of the network through communication network. In 1977, international organization for standardization (ISO) created a subcommittee which developed a model for open system interconnection called the ISO-OSI reference model [6]. 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, design, implementation, standardization and use of communications networks. The OSI reference model consists of seven layers: physical, data link, network, transport, session, presentation, and application [6].

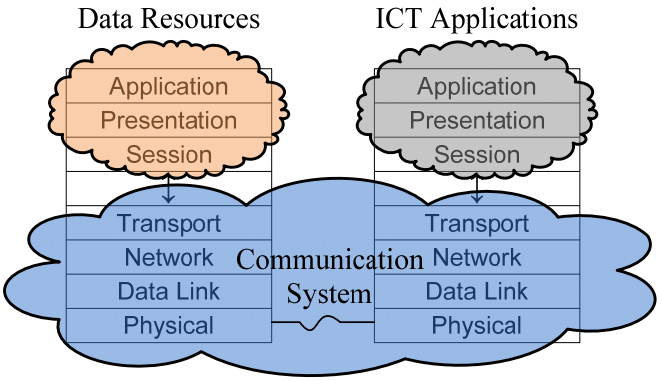

Fig. 2. Information and Communication Technology base on Network Layers in Power System

In power systems, the upper layers of this model include data resources and ICT applications blocks. Fig 2 shows the map between OSI layers and three major blocks in a power system including data resources, ICT applications and communication system.

III. 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. Transmission media, as described below, can be classified as guided and unguided ones [7].

A. Guided Media

This 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. The characteristics of the media and the signal influence the characteristics and quality of data transmission. In the case of guided media, the media itself has the most important role in characterizing the limitations of transmission [7].

B. Unguided Media

This type of 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 [7].

IV. New Approach for Transmission Media Classification in Power Systems

Historically, various kinds of media have been used in a power system. Normally, the suitable media is selected by considering financial, operational, geographical and communicational limitations. Nowadays, due the fact that more types of media are available, media selection has become a more complicated problem than before. Alternately, in recent years, new ICT applications which need more data from new data resources are added to power systems. Consequently, special attention should be paid to transmission media as the first layer of communication system.

In our approach, as described in the following section, we have categorized the communication media as dependent and independent ones.

A. Dependent Media

The dependent media is part of the power network elements i.e. PLC, broadband over power line (BPL), optical power ground wire (OPGW) and all-dielectric self supporting (ADSS) units. Therefore, the structure of such media depends on the transmission network itself. These media are often owned by independent system operator (ISO) and/or distribution companies. The following is a brief summary of popular independent media.

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 [8]. This media is also the first dependent 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 [9]. 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 other. Unlike narrowband PLC, broadband PLC establishes a high data rate (beyond 2 Mbps) between two modems [9]. 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 [8].

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 [10].

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 III, 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 industry.

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 [8].

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 [8], [10].

B. Independent Media

Independent media do not depend on the power system and is normally available to different users as an open access media such as wireless communication or those owned by data service provider companies. Public switch telephone network (PSTN), leased line twisted pair and dark fiber are examples of independent media. Popular independent media in power systems will be described in the next section.

1) Wireless

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 [11]:

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

1-1) 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 [11].

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 [11].

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 [11]. 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).

1-2) 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 [11].

- 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.

1-3) 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 [11].
- 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 [11].
- 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 [12]. 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 amalgamating 8 time slots) [13].
- 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 [13].

- 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 [13].
- 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 [14]. Another 3G standard for data communication, CDMA2000, allows a maximum theoretical data rate of 2 Mbps [11].

Fig. 3 shows the history of mobile carrier standards based on their generations [14].

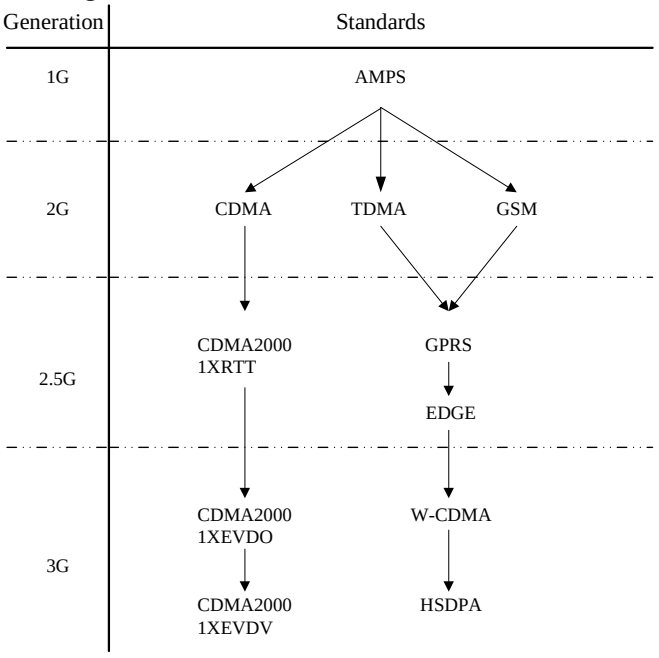

Fig. 3. Mobile carrier standards based on generations [14]

Fourty and his colleagues have compared the familiar WPANs, WLANs and WMANs shown in Table II [11].

TABLE II
COMPARATIVE ANALISIS OF AVAILABLE WIRELESS NETWORKS [11]

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

1-4) 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 [11]:

- 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 should not be implemented under WWAN technologies. Table III illustrates satellites orbit and latency [15].

TABLE III
SATELLITE TYPES [15]

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

2) Leased Line

Historically, leased telephone circuits have been used widely in electric utilities to create a point-to-point or point-to-multipoint communication [8]. 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 [9]. 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 IV [16].

TABLE IV
CHARACTERISTICS OF XDSL SYSTEMS [16]

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 IV 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. Since leased wires are not owned by power systems and some ones may have access to this type of media, the security of this type is decreased to medium level. But they are still more secure than unguided media.

V. DEPENDENT AND INDEPENDENT MEDIA COMPARISON

Although both types of media described in previous sections provide communication infrastructure, there are some differences between them. Since dependent media is owned by power systems, the security of this type of media is high. Conversely, the security of independent media may vary from low level to high level. Unguided independent media has low security level while the security of guided independent media is medium.

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

Considering that the dependent media is a part of power systems and attaches to system components, the media installation cost is high whereas, in independent media cases, no setup fee is needed. Furthermore, independent media usually is a leased media from a telecommunication company or a licensed frequency spectrum. Therefore, monthly fee should be paid for this type of media.

Dependent media is used when the security is of high concern or, because of geographical limitations; other leased guided media are not available. 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 dependent media are more suitable than other ones.

Some applications such as automatic vehicle location (AVL) connect to mobile data resources. In these cases, only unguided independent media can be used for creating a communication infrastructure. Some other types of applications such as AMI 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 dependent media, especially fiber types, is not cost effective. Therefore, independent media are better choices.

To sum up, we have compared the dependent and independent media in table V.

TABLE V
TRANSMISSION MEDIA COMPARISON

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

VI. 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 characteristics of the communication systems will be seriously influenced by the characteristics of its media.

According to this approach, for the first time, communication media may be specified as dependent or independent ones. A dependent media such as OPGW is part of power system which is normally owned by Independent System Operator (ISO). Conversely, an independent media such as air or a twisted pair leased line, which is not normally part of power system, can be public or provided by data service providers.

This article reviewed and compared the characteristics of popular dependent and independent 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 dependent type is more secure than independent type. Also it is worth mentioning that the dependent type media is normally owned by ISO or distribution companies while independent type media is typically owned by telecommunication companies or used in open access. Second, dependent type provides medium to high speed connections whereas the speeds for independent type differ from low to high. Third, dependent media usually need investment for initial installation of the media but it does not require monthly fee payment. In contrast, independent 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. Media classification may be a major concern for communication engineers to select the appropriate one. Taking media characteristics into consideration, it is possible to integrate them at various media layers. As a result, this kind of classification also can help

engineers to design hierarchical networks especially in distribution networks.

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VIII. Biographies

M. Shahraeini received the B.S. and M.S. degrees from the Department of Electrical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.

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He is currently a professor in the Department of Electrical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran. He was a board member, as well as the secretary of the electricity regulatory body in Iran for seven years (2003-2010). His research interests include power system operation and planning, restructuring and market design, and artificial intelligence.

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