Comparative Study of Various Wireless Technologies for Smart Grid Communication: A Review

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***Abstract*—**Since 2005, Smart Grid technology has been revo-lutionizing the power sector due to facilitation and opportunities offered by ICT (Information and Communication Technology), to modernize the operation of electrical networks. This is possible by de-carbonizing them as well as monitoring and controlling them with sophisticated communication standards. For this purpose, utilization of various emerging and existing technologies offered by electrical and telecommunication sector is very important. Various wireless communication standards *viz.* WiMAX, Zig Bee, Bluetooth, Wi-Fi, GSM, GPRS, UMTS *etc.* can be exploited to develop Smart Grid Network. This will facilitate in establishing a two-way communication between customers and distribution substations. Moreover, this will also help to extend the communication. This paper gives a detailed comparative study of various communication protocols that can be used for implementation of Smart Grid Network. It focuses on various aspects such as network spanning, data rates, power consumption, data security and encryption standards, dataaccess and spread techniques, modulation and duplexing schemes for all the communication standards in Smart Grid. The paper illustrates all these metrics with various graphs and depicts the physical layer parameters comparison.

Keywords:- *Smart Grid, ICT, Communication Standards, GSM, GPRS, Zig Bee, WiMAX, Wi-Fi, UMTS, Communication Protocols, Distribution Substation, Network establishment,power consumption, physical layer parameters.*

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I. INTRODUCTION

The need to revolutionize the existing electrical power grid in order to meet the growing demand for electricity, began in early 2000. For many years there has been absolutely no change in the basic structure of the grid. This has led to deficiencies in automation system and analysis, slowresponses from switches, absence of sensing and controlling systems, equipment failures, energy storage issues, lack of communi- cation in grids, greenhouse gas emission problems*etc*[1]–[3]. To top it all there has been serious concern pertaining to network congestions leading to blackouts, bymorethan40 years. Hence, with a view to suggest a solution to these problems a new concept of *Smart Grid* has emerged.

In the field of electrical power systems, Smart grid is defined as an intelligent infrastructure [4] integrating power generation, power distribution, and modernizing interconnect between power substations to consumer-end systems, by Secure means. Several researchers all over the world have been analyzing industrial and commercial consumer demand curve for electricity, providing real-time billing information, installing infrastructure for the same and emphasizing on the deployment of various communication protocols that support controlling and data transmission in Smart Grid. Moreover, their main aim has been to carry out the exchange of this critical information over the standard protocols, in a very secure manner.Thetechnologiesbeingconsideredforcommunication in smart grid are GSM, PLCC, 3G, Wi-Fi, Zig Bee, GPRS, Bluetooth, WiMAX*etc.*

Researchesallovertheworldhavebeenstudyinginnovative methods for establishing a reliable and real-time monitoring and controlling infrastructure for power delivery from smart grid substations to end-user units. Gungor*et.al* in [2] lists down the challenges and opportunities of implementing Wire- less Sensor Network (WSN) in smart grid infrastructure. The main of this paper is to provide the detail comparative analysis of various wireless technologies which can be utilized for smart gridcommunication.

In this paper, the comparative study of various wireless communication standards is illustrated in detail. The paper is organized as follows; Section II gives a brief overview of the wirelesstechnologiesavailableforSmartGridcommunication. It proposes the basic grid infrastructure. Section III presents a comparative analysis of various communication standards being considered in smart grid. Whereas, taking motivation from latest advances, efforts have been carried out to empha- size Section IV on qualitative analysis of these protocols on the basis of power consumption, network span and data rate. Section V concludes the paper by summarizing the overall study.

II. WIRELESS TECHNOLOGIES FOR SMART GRID COMMUNICATION

Unlike the conventional power systems, contemporary systems are more advanced and enriched with various features which allows ease of operation. The research carried out in various fields has resulted in advancement of such systems. Instead of carrying the research independently, several

Emerging technologies have been merged for revolutionizing the conventional systems. Smart grid is one such area where efforts have been initiated since a decade ago to modernize the conventional power grid and to facilitate the seamless operation of the electricity delivery system even in harsh environment, reducing the probability of failures. The typical implementation of Smart Grid infrastructure is depicted in Fig.1[4].

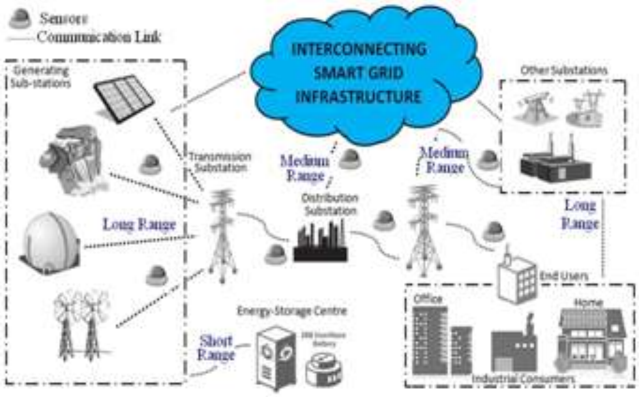

Fig. 1. Smart Grid Communication Infrastructure

The task of converting *power grid* to *smart grid* is not possiblewithouttheincorporationofsuitablewiredorwireless technology for enabling communication across the grid. One of the report released by National Institute of Standard and Technology (NIST) presents framework for smart grid interop- erability standards[6]and provides generalized view of several wired and wireless communication technologies that can be implemented for smartgrid.

Initially,whenthewirelesstechnologieswererelativelynew, they had slow rate of acceptance in electrical and power industries. It was because of the following issues; [5]

- Primarily, practical data rates were low
- Unavailability of well-defined and standard interface
- Protocols were vulnerable to various attacks
- Interference relatedissues
- Threat to security being compromised
- Limited productavailability

Several amendments have carried out in existing standards and all these issues were solved at certain level, for estab- lishing a trusted standard for reliable communication. Now-a- days, wireless technologies are proving their dominance over wired ones, due to their remarkable pros [7]. Hence we are confining our discussion to the implementation of suitable wireless technology for Smart Grid.

A. ZigBee over IEEE802.15.4

ZigBee is a low data rate and ultra-low power con- sumption wireless communication technology developed by ZigBee Alliance in 2002, specifically designed for control and sensor networks. It restricts the data rate to 250 kbps in the global 2.4-GHz Industrial, Scientific, Medical(ISM) Band. Zig Bee provides self-organized, multi-hop, and reliable mesh networking, [9] along with long battery life. Hence it facilitates low complexity and low cost of deployment. It is thus suitable for automation and control applications, [7], [9]–[11] as its primary aim includes energy and power monitoring, building and home automation, home area network, smart lightning control and remote meter reading *etc*. The U.S. National Institute for Standards and Technology (NIST) [6] [8] has described Zig Bee Standard and Zig Bee Smart Energy Profile (SEP) [2], [15] as the most suitable communication standards for smart grid residential network domain. InZig Bee implemented integrated smart meters, Smart Home Automation System (HAS), Home Area Network (HAN) or in any automation system [9], [10], Zig Bee Coordinator manages network configuration, exchange of information and packet routing. Zig Bee SEP facilitates reliable communication and enables user to control and monitor the real-time energy consumption.

B. Bluetooth over IEEE802.15.1

Bluetooth is a standard designed for short-range wireless radio systems to be configured as Wireless Personal Area Network (WPAN). It can be used to replace cables for computer peripherals such as mouse, keyboards, joysticks and printer [9].There are two connectivity topologies defined *i.e.* the piconet and scatternet. Piconet is a type of connection that is formed between two or more Bluetooth-enableddevices such as modern cell phones or PDAs. Whereas, scatternet is the number of interconnected piconets that support communi- cation between more than 8 devices. All these features enables bluetooth to be implemented in smart grid application like home area network and home automation.

C. WiMAX over IEEE 802.16

Overall interoperability for Microwave Access (WiMAX) innovation is one of the real remote broadband innovation. It is for the most part expected for Wireless Metropolitan Area Network (WMAN). It is a piece of IEEE 802.16 arrangement, began with an intend to accomplish overall interoperability for microwave access. The long separation scope and high information rates are fundamental destinations of WiMAX. Fundamentally, it gives information rate of 70Mbps and scope of 50Km [16]. The reach is distinctive for Line Of Sight (LOS) and Non LOS application. Portable WiMax makes utilization of Orthogonal Frequency Division Multiple Access (OFDMA) air interface to expand the execution in the Non-Line of Sight environment. [16] The groups which are committed for altered and portable correspondence are; 3.5 and 5.8GHz for settled and 2.3,2.5 and 3.5GHz for versatile correspondence. It has data transfer capacity of 1.25-20MHz and 128,256 channels separately. WiMax frameworks give broadband access benefits productively at longer separation and thus known as 'Last Mile' innovation. WiMAX innovation is along these lines another option to wired advancements, for example, link modem, Digital Subscriber Line (DSL) and T1/E1 joins.

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D. WLAN over IEEE802.11

Wireless Local Area Network (WLAN) over IEEE 802.11 provides uninterrupted communication to user at higher data rates. It allows multiple user to access the service [5] without interfering much with the coexisting technologies; the use of spread spectrum technologies such as Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) and access technique *viz.* Carrier Sense Multiple Access-Collision Avoidance (CSMA-CA) have made it pos- sible. IEEE 802.11a was the first standard in WLAN. In 1999 further amendments were carried out by Wireless Ethernet Compatibility Alliance (WECA) to bring interoperability [22] amongst IEEE 802.11 products of various vendors. Theefforts have resulted into formation of ubiquitous *Wireless-Fidelity* standard over 802.11b that became famous with acronym *Wi- Fi.* Under WLAN project many standards have beendeveloped as depicted in Table IV. [22], [23] Though IEEE 802.11a provides data rates up to 54Mbps but is operated on 5.8GHz licensed frequency band. Wi-Fi operates on 2.4GHz ISM frequency band with DSSS modulation, yielding maximum data rate of 11Mbps. Further the use of Orthogonal Fre- quency Division Multiplexing (OFDM) [22] in packet based communication has enhanced data rates up to 54 Mbps on ISM band. This formed the base for enhanced Wi-Fi over 802.11g. Further, Multiple Input Multiple Output (MIMO) technology is introduced to form IEEE 802.11n standard to achieve data rates up to 600 Mbps. IEEE 802.11i was developed as a more secure standard. Though coverage area provided by WLAN is just 100m but it is suitable in medium range smart grid applications like remote monitoring, Home Area Network (HAN), distribution protection systems and Advanced Metering Infrastructure(AMI).

E. Cellular NetworkCommunication

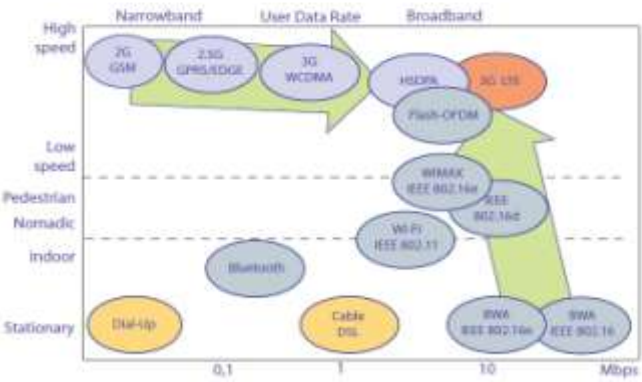

Fig. 2. Evolution of cellular technologies

The explosive growth in cellular communication can beseen from past few decades. Spearheaded by Global System for Mobile (GSM) system, the cellular technology has been improving in terms of data rates and coverage and leaning towards the upcoming 4G and 5G standards. After 1G, GSM had formed concrete base for cellular communication by Providing real time voice and SMS service over a circuit switch network [18].

Further, the GPRS standard had built on top of GSM for providing data access feature to user, yielding data rate of 115 Kbps. To satisfy the never ending demands of user, under 3GPPP program 3G standards *viz.* UMTS (WCDMA) and CDMA2000 were developed; yielding data rates up to 2Mbps with maximum throughputs. Now, 4G technology is on the verge of occupying the market and soon will revolutionize the already existing systems by transferring voice and data over Inter Protocol (IP). It promises data rates more than 100Mbps. Evolution of cellular technologies [19] over time is depicted inFig.2.

Since, cellular technologies possess already existing well developed infrastructure, they can be efficiently used for Smart Grid communication without adding up to the cost of deployment. Hence 2G, 2.5G, 3G, and Long Term Evolution (LTE)canbeusedforsmartmeteringdeploymentsoverawide coverage.Mostlypowerstationsaresituatedfarawayandneed to be communicated. They generate large amount of data *viz.* electrical parameters, meter readings *etc.* In order to process such huge amount of data, high data rates are required along with large network span. In such situations cellular technology serves as the backbone for smart grid communication. In fact, commercially such ventures have already been s t a r t e d .

VehbiC. Gungor*et. al* [15] have provided detailed survey of various companies who are using GSM, GPRS, CDMA, WCDMA and UMTS technologies for smart grid communi- cation. Telenor, Telecom Italia, China Mobile, Vodafone are on the way to use their GSM network for smart metering communications.ItronSENITELhasexploitedtheuseof2.5G *viz.* GPRS by integrating itselectricity meter with it. Verizon and SmartSynch smart grid solutions are exploiting 3GCDMA network, whereas Telenor with Cinclus technology is exploit- ing the use of UMTS [20] for smart grid communication.

III. COMPARATIVE STUDY OF VARIOUS WIRELESS TECHNOLOGIES FOR SMART GRIDCOMMUNICATION

The different wireless technologies are mainlycharacterized by the range of operation and maximum data rate provided by them. They are also categorized by various parameters such as available number of channels, frequency bands, and access and modulation techniques. Further the qualitative analysis of technology is carried out with various performance metrics such as power consumption, on-air privacy, security in data communication, network node acquisition time *etc.* It is found that, no single technology possesses all required properties. Hence a suitable technology can be implemented according to the primary requirement, quality metrics and area of applica- tion.

Table I [9], [10], [15] below illustrates performance metrics of wireless technologies and provides detailed comparison among, short range *viz.* ZigBee, Bluetooth; Medium range*viz.* Wi-Fi; Long range *viz.* WiMAX and cellular technolo- gies (GSM, GPRS, UMTS). The key differences between these

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Wireless technologies are listed. Various papers have also elaborated these parameters in detail [4], [9], [10], [12]–[14]

IV. QUALITATIVE ANALYSIS OF VARIOUS WIRELESS TECHNOLOGIES FOR SMART GRIDCOMMUNICATION

The performance of the network depends on various quality metrics. Selection of the technology depends on quality parameters such as power consumption, data rate, network span *etc.* This section deals with analysis of these parameters and illustrates the key points pertaining to standardcommunication protocols.

A. PowerConsumption

For any technology, power consumption plays a crucial role as it estimates the battery life for portable node/transceiver. Bluetooth and ZigBee are mainly intended for portable nodes, short range and limited battery power enabling them to work on low power. Whereas, Wi-Fi consumes relatively more power as it provides higher data rate.

TABLE II
POWER CONSUMPTION OF CHIP SETS FOR SHORT/MEDIUM RANGE TECHNOLOGIES

Standard	Bluetooth	ZigBee	ZigBee	WiFi
Chipset	BlueCore2	XB24-B	XBee-PRO	CX5311
VDD (volt)	1.8	3.3	3.3	3.3
TX (mA)	57	40	205	219
RX (mA)	47	40	47	215
Nominal power (mW)	1 to 10	0.00316 1	1 to 63.1	31.6 to 100
Nominal TX power (dBm)	0 to 10	-25 to 0	0 to 18	15 to 20
Normalized power (mJ/Mb)	1 to 10	0.0126 to 4	4 to 252.4	0.5852 to 1.852
Battery Life (days)	1 - 7	100 - 1000	100 -1000	0.5 - 5

Table II above provides comparison of various electrical parameters for different chip sets of BlueCore2 [24] from Cambridge Silicon Radio (CSR), XB24-B [25] and XBee-PRO [26] from Digi International Inc. and CX53111 [27] from Conexant (previous Intersils Prism). Fig.3 depicts the power consumption for short range technologies.

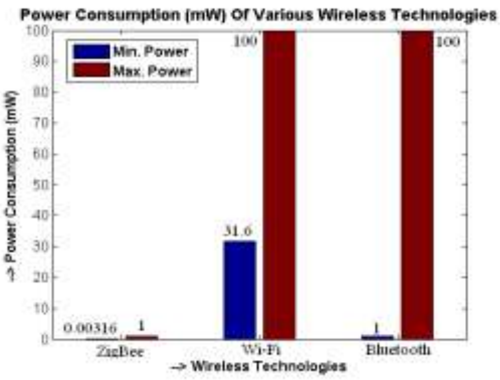

Fig. 3. Comparison of Power Consumption for shortrange wirelesstechnologies in Smart Grid Communication

Limited network span of short and medium range technologies can be increased at the expense of increase in power utilization. Table III compares the power utilization of long range technologies.

TABLE III
POWER CONSUMPTION OF CHIP SETS FOR LONG RANGE TECHNOLOGIES

Standard	WiMAX	GSM	GPRS	UMTS
VDD (volt)	12	3.4-4.5	3.4-4.5	3.7
Nominal power (mW)	100 10000	500- 2000	500- 2000	500- 600
Nominal power (dBm)	20-40	27-33	27-33	77-27.78
Normalized power (mJ/Mb)	2-200	52083- 208333	4347.83 17391.36	250- 300

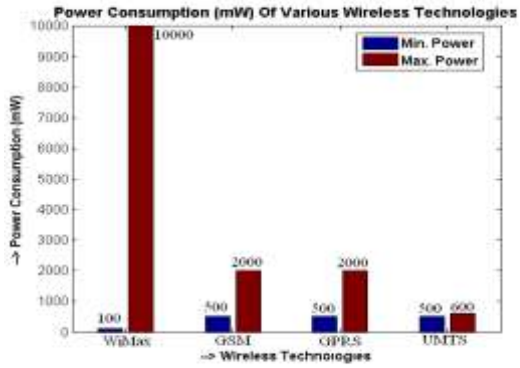

Fig.4. Comparison of Power Consumption for long range wirelesstechnologies in Smart Grid Communication

It can be observed that power required by them is significantly high which restricts the mobility of node. Fig. 4 demonstrates comparison of power consumption for WiMAX, GSM, GPRS and UMTS.

B. Supported DataRates

Low power consumption feature of short rangetechnologies restrict their data rates. Table IV provides comparison of data rates for short range technologies. It can be seen that data rates provided by ZigBee and Bluetooth are suitable for monitoring and control application. Whereas, Wi-Fi provides high data rate for applications such as internet access. Fig. 5. Illustrates comparison of data rates for ZigBee, Bluetooth, WI-Fi.

TABLE IV
DATA RATES COMPARISON FOR SHORT RANGE TECHNOLOGIES

Standard	Bluetooth	ZigBee	ZigBee	WiFi
Chipset	BlueCore2	XB24-B	XBee-PRO	CX5311
Range (m)	10	40	90	100
Min. Bit rate (Mbps)	0.72	0.02	0.02	11
Max. Bit rate (Mbps)	1	0.25	0.25	54
Bit Time (μSec)	1	4	4	0.0185

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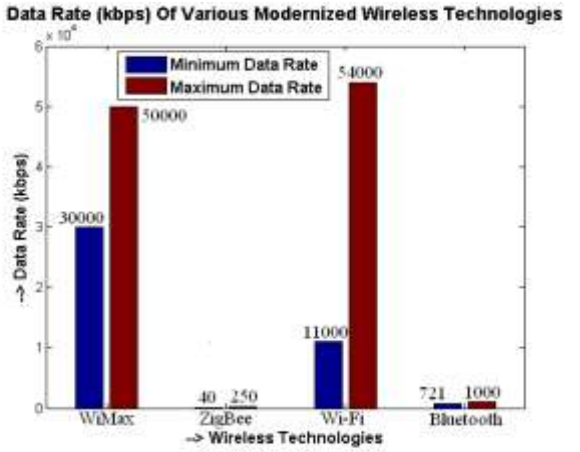

Fig. 5. Comparison of Data Rates for short range wireless technologies in Smart Grid Communication

TABLE V
DATA RATES COMPARISON FOR LONG RANGE TECHNOLOGIES

Standard	Bluetooth	ZigBee	ZigBee	WiFi
IEEE Standard	802.15.1	802.15.4	802.15.4	802.11b/g
Chipset	BlueCore2	XB24-B	XBee-PRO	CX5311
Range (m)	10	40	90	100
Nominal Range (m)	1 to 10	10-100	10-100	10-100

VI provides range comparison for various short and medium range standards. Fig.7 provides pictorial representation of communication range provided by Bluetooth, ZigBee, Wi- Fi. Basically, ZigBee and bluetooth can be used for PAN (Personal Area Network) Communication over short range of 10 to 100m. Whereas, Wi-Fi can be used over 100m range. Hence, for short or medium range communication in smart grid network, these technologies can be exploited.

TABLE VI
RANGE COMPARISON FOR SHORT/MEDIUM RANGE TECHNOLOGIES

Standard	WiMAX	GSM	GPRS	UMTS
IEEE Standard	802.16	2G	2.5G	3G
Min. Bit rate (Mbps)	30	0.0096	86.4	0.384
Max. Bit rate (Mbps)	50	0.0096	0.115	2
Bit Time (μSec)	0.020	104.166	8.696	0.500

Data rates provided by cellular technologies are relatively lower than WiMAX [17] but it provides widespread network span in urban and rural areas. WiMAX provides very highdata rate along with large network span. This is possible because it implements SOFDMA and improved adaptive modulation scheme. Table V provides data rate comparison for long range technologies. Fig.6 demonstrates variation of data rates for WiMAX, GSM [29], GPRS and UMTS.

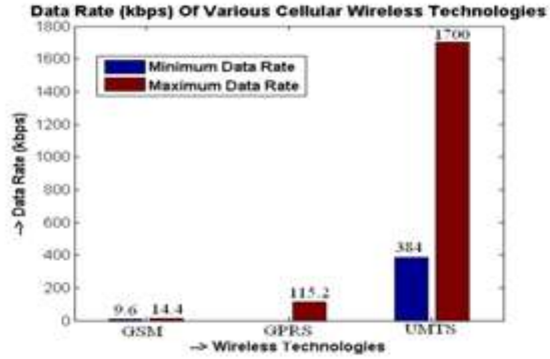

Fig. 6. Comparison of Data Rates for long range wireless technologies inSmart Grid Communication

C. *Range ofTechnology*

In short range technologies, the distance is confined to10m- 100m, and hence mostly suitable for HAN in smart grid.Table

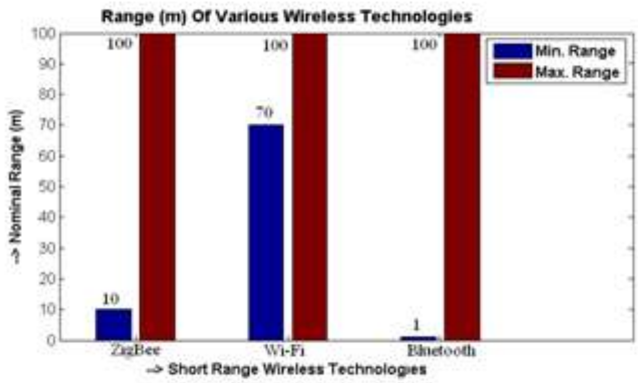

Fig. 7. Comparison of Network Span for short distance wireless technologies in Smart Grid Communication

Cellular provides widespread network span in urban and ruralareasastheyhavewelldevelopedinfrastructure.WiMAX popularly known as *Last Mile*, *rev*, *wimax*technology provides network span of 50Km in LOS, whereas 30Km in NLOS. Table VII provides communication range comparison for long distance technologies. Fig.8 demonstrates variation of network span of WiMAX, GSM, GPRS and UMTS. Hence, forlong range communication in smart grid network, these technologies can beexploited.

TABLE VII
RANGE COMPARISON FOR LONG DISTANCE TECHNOLOGIES

Standard	WiMAX [28]	GSM [29]	GPRS	UMTS
IEEE Standard	802.16	2G	2.5G	3G
Min Range (Km)	10	0.5	0.5	0.1
Max Range (Km)	50	35	35	10

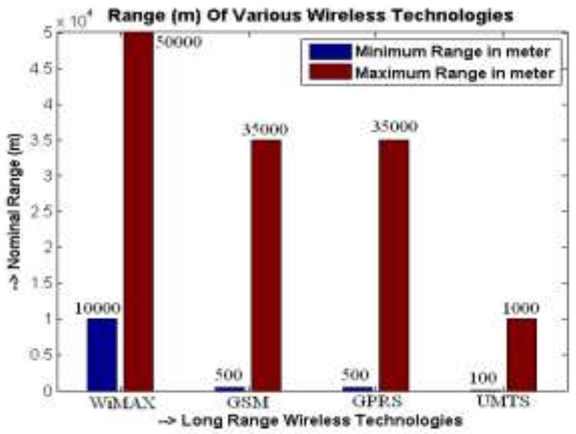

Fig. 8. Comparison of range of long distance wireless technologies for Smart Grid Communication

V. CONCLUSION

Smart Grid is on the verge implementing all emerging technologies and it is revolutionizing the conventional electric power and distribution systems. For carrying out reliable and seamless communication within well developed and dedicated architecture, suitable wireless technologies have to be imple- mented. Selection of technology depends on various param- eters (on the basis of required range, reliable architecture, limitation of power consumption) *viz.* network span, data rates, security and reliability, number of channels, available bandwidth *etc.* which influence the application area in Smart Grid. This paper illustrates the various wireless technologies such as WiMAX, ZigBee, Bluetooth, WI-Fi, GSM, GPRSand UMTS with respect to smart grid. Further it provides a quantitative evaluation and qualitative analysis in terms of the data rate, network span and power consumption. Further- more, the radio channels, network span, data security and encryption standards, access and spread technique,modulation and duplexing schemes *etc.* are compared. Hence, this paper provides the detail comparative analysis of various wireless technologies and illustrates all the crucial parameters. Hence, it enables the user to understand which particular wireless technology can be used as per the application spectrum in smartgrid.

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TABLE I
COMPARISON OF THE WIMAX, ZIGBEE, BLUETOOTH, WI-FI, GSM, GPRS AND UMTS TECHNOLOGIES

Standard	WiMAX	ZigBee	Bluetooth	WiFi	GSM	GPRS	UMTS
Application Focus	Lsat Mile Broadband Access	Monitoring and Control	Cable Replace-ment	Web, Email, Video	Audio Call, SMS	Data Service on GSM	Video calls mobile Internet
Smart Grid Potential Application	Wireless Automatic Meter Reading(WM	Automation, Remote Load [9] Control [7]	Automation HAS	Distribution Protection Automation HAN,HAS [10]	AMI,HAN Demand Response	AMI,HAN Demand Response [15] AMI,HAN [15]	Monitoring for Remote Distribution [5]
IEEE Standard	802.16	802.15.4	802.15.1	802.11 a/b/g	GSM1900	Virtual Circuit Packet Switch	Composite CDMA,TDMA
Technology/ Generation	Broadband (MAN)	LR-WPAN	WPAN	WLAN	2nd Generation	2.5 Generation	3rd Generation
Range Categorized	Long distance Technology	Short Range Technology	Short Range Technology	Middle Range Technology	Long Range Technology	Long Range Technology	Long Range Technology
Frequency Band	10-66GHz* 2-11GHz**	868/915 MHz; 2.4 GHz	2.4 GHz	2.4 GHz; 5GHz	900-1800MHz	900-1800MHz	1.92-1.98GHz 2.11-2.17GHz
Number of Channels	128,256 512;1024	1/10 ;16	79	14 (2.4GHz)	125 (900MHz)	125; 1000!!	12
Access Technique	Scheduling Scheme	CSMA-CA	TDMA (Centralized)	CSMA/CA,	TDMA	TDMA	CDMA
Spread Technique	OFDMA; SOFDMA	DSSS	FHSS	DSSS FHSS	TDMA	TDMA	DSSS
Duplexing Technique	TDD; FDD	TDD	FDD	TDD	FDD	FDD	FDD
Modulation Technique	AMC;QPSK; 16-QAM 64-QAM [16]	O-QPSK [16]	GFSK	OFDM;DSSS, CCK; DSSS, CCK,OFDM [16]	0.3 GMSK	0.3 GMSK	QPSK,OQPSK
Encryption	128-bit AES, 3-DES, EAP	40-bit RC4 block cipher	128-bit AES, block cipher	128-bit RC4, stream cipher (WEP)	A5 and A8 Algorithm	Token based, WAP,IPSec	Token based Security
Maximum Data Rate	30 Mb/s- 50 Mb/s	250 Kb/s	1 Mb/s	54 Mb/s	9.6 Kb/s- 14.4 Kb/s	115.2 Kb/s	0.384Mb/s- 02 Mb/s
Nominal Range	10-50Km; 1-5Km	10 - 100 m	10 - 100m	100 m	0.5-35Km	0.5-35Km	0.1-10Km
Channel Bandwidth	1.25-20 MHz	0.3/0.6 MHz; 2 MHz	1 MHz	22 MHz	200KHz	200KHz	5MHz
Data Protection	AES CMAC MD-5 HMAC	16-bit CRC	16-bit CRC	32-bit CRC	3-bit CRC with 1/2 Convolution	3-bit CRC with 1/2 Convolution	ANSI-41,SS7
Max Number of Cell Nodes	1	more than 65000	8	32	7cells/cluster 9,12,13!*	7cells/cluster 9,12,13!*	1-7cells
Node Acqui-sition Time	100ms	30ms	3s	2s	Depends On GOS	Depends On GOS	Depends On GOS
Node Wake-up Time	100ms	15ms	3s	1s	NA	NA	NA
Network Topology	Point to Multipoint; multipoint tomultipoint	Star, Mesh, cluster-tree	Star, Piconet, Scatter-net	Star Topology	multipoint to multipoint	multipoint to multipoint	multipoint to multipoint
Power Categorized	High Power Technology	Low Power Technology	Low Power Technology	Medium Power Technology	High Power Technology	High Power Technology	High Power Technology
Power Consumption	100mW-10W 20- 40dBm	3.16μW -1mW -25 to 0dBm	1-10mW 0-10dBm	31.6-100mW 15-20dBm	0.5-2W 27-33dBm	0.5-2W 27-33 dBm	600mW 27.78dBm

HAS: Home Automation System, HAN: Home Area Network, AMI: Advanced Metering Infrastructure, CDMA: Code-Division Multiple Access, TDMA: Time-Division Multiple Access, MAN: Metropolitan Area Network, LR-WPAN: Low-Rate Wireless Personal Area Network, WLAN: Wireless Local Area Network, CSMA-CA: Carrier Sense Multiple Access-Collision Avoidance, OFDMA: Orthogonal Frequency

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Devision Multiple Access, SOFDMA: Scalable-OFDMA, DSSS: Direct Sequence Spread Spectrum
FHSS: Frequency Hopping Spread Spectrum, TDD: Time-Division Duplexing, FDD: Frequency-Division Duplexing, AMC: Adaptive Modulation Coding, QPSK: Quadrature Phase-Shift Keying, QAM: Quadrature Amplitude Modulation,O-QPSK: Offset-Quadrature Phase Shift Keying, GFSK: Gaussian Frequency Shift Keying, CCK: Complementary Code Keying,GMSK: Gaussian Mask-Shift Keying AES: Advanced Encryption Standard, DES: Data Encryption Standard, EAP: Extensible Authentication Protocol,RC4: Rivest Cipher4 WEP: Wired Equivalent Privacy, WAP: Wireless Application Protocol, IPSec: Internet Protocol Security,CMAC: Cipher Based Medium Access Control, MD-5: Message Digest-5 Algorithm, HMAC: Hash Message Authentication Code, CRC: Cyclic Redundancy Check ANSI-41:IS-41CellularCommunicationProtocol,SS7:SignalingSystemno.7,GOS:GradeOfService
Asterics: *Line of Sight (LOS),**Non Line of Sight(NLOS),!!Logical Channels, !*Standard Number of cells in Cluster