Modeling and Comprehensive Analysis of WiMAX Protocol for Grid Control Center to Aggregator Communication in Vehicle-to-Grid (V2G)

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Abstract- V2G has become a reality with development in power grid and advancements in vehicle technology. The electric vehicles (EV) will gradually replace the existing vehicles due to growing oil demand and environment concerns. The EVs can be integrated to the grid for power transaction and can contribute power to the grid. The Grid Control Center (GCC) to aggregator communication is very crucial in V2G operation in order to meet the load demand. The fixed WiMAX (Worldwide Interoperability for Microwave Access) protocol is proposed for GCC to aggregator communication. The applicable path loss models for WiMAX protocol are analysed and compared. The physical layer of WiMAX protocol is modeled in MATLAB/SIMULINK and its performance is investigated.

Keywords— EV, path loss, V2G,WiMAX.

1. Introduction

The EVs will gradually replace the existing vehicles due to growing oil demand and environment concerns. The EV connected to home grid is Vehicle-to-Home (V2H), EV to EV is Vehicle-to-Vehicle (V2V) and group of EVs connected to the grid for power transaction is called V2G[1]. V2G supports the grid in maintaining load demand and help to improve the stability of a power system for a shorter duration of time[2][3]. V2G can be used for peak shaving, valley filling, load leveling and EV battery can supply the reactive power to the grid [4][5]. The group of EVs make sizeable difference when connected to the grid [6]. A conceptual framework of V2G is shown in Fig.1. EVs can be integrated to the grid through charging stations which are connected to Medium Voltage (MV) network and Low Voltage (LV) network. The medium scale distributed generation (DG) can be connected to the MV network and small scale distributed generation can be connected to the LV network. Smart buildings have a parking lot through which EVs can be connected to the grid.

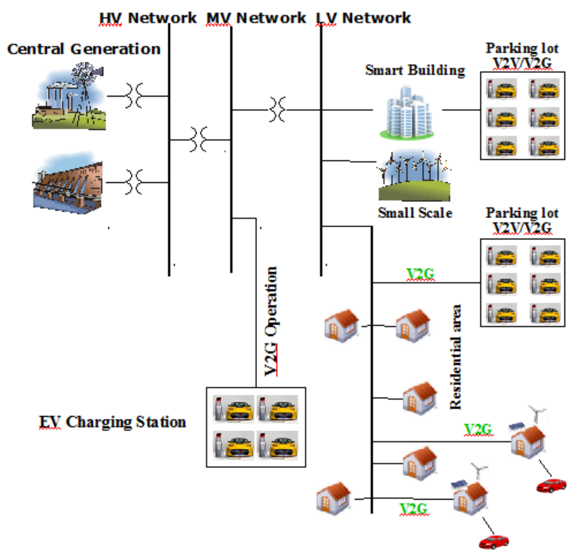

Fig.1. Conceptual framework of V2G.

The wind turbine and photovoltaic (PV) can generate power in smart homes and can pump power back to the grid based on the domestic requirements or allow EV to get its battery charged. The GCC will have the information about the power requirements based on the energy market.

The energy market is categorized in to two types:

- 1. Real Time Markets (instantaneous): can sell or buy power
- 2. Day-ahead Markets (forward): participants may submit bids to buy or sell defined amount of electricity.

The GCC, aggregator and EV are three key elements of V2G communication as shown in Fig.2. These three elements are very important in development of wireless communication infrastructure for V2G environment. GCC will send information about the power requirements to the aggregator and aggregator inturn sends this information to EVs. EV owners after receiving the information from aggregator decide whether to participate in power transaction based on the state of charge (SOC) of battery. The Fig.3. depict EV action based on the SOC of the battery. EV acts as a connected load if SOC is less than 60% and Distributed Resource (DR) if SOC is more than 80% [7]. EV acts as a connected load or DR for SOC between 60-80%.

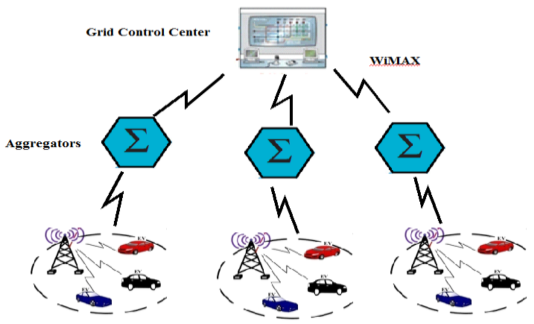

Fig.2. Wireless infrastructure framework of V2G.

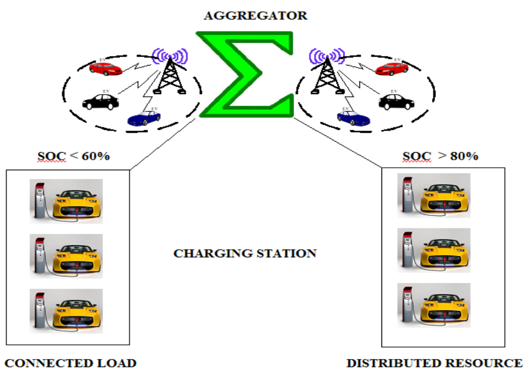

Fig.3. EV action based on SOC of a battery.

The development of wireless communication infrastructure for V2G communication is very essential. The WiMAX protocol is proposed for GCC to aggregator communication in V2G for smart grid application. The supporting path loss models for protocol are analyzed and compared. The physical layer WiMAX protocol is modeled and simulated in MATLAB/SIMULINK.

In the available literature only few papers discuss about the V2G communication. The GCC to aggregator and aggregator to EV communication are discussed in [8][9][10].The Bluetooth protocol for V2G is presented in [11] and V2G communication interfaces are discussed in [12]. HPGP (Home Plug Green PHY) is presented in [13] and secured communication protocol is described in [14]. Unique batch authentication protocol is proposed in [15]. In this paper we have analyzed and compared the path loss models for WiMAX. The physical layer is modeled in MATLAB/SIMULINK and its performance is investigated.

2. Path Loss Models

The difference between the transmitted power and the received power measured in terms of dB is path loss. The propagation models are used to calculate the electrical field strength and to predict the path loss which is very crucial in planning and designing the wireless network. The information in wireless communication system is transmitted from the transmitter to the receiver by the means of electromagnetic waves and in the process of propagation they come across lot of obstacles in the environment which causes the Path Loss[16][17]. The Propagation models are split in to three categories:

- Deterministic model: site specific theoretical
- Empirical models: based on measurements, antenna height, frequency and distance
- Stochastic models: based on series of random variables.

The empirical models are considered for analysis.

2.1. Free Space Path Loss Model

It is the amount of signal strength lost during propagation from transmitter to receiver. The free space path loss is calculated using the following equation[17]:

$$PL_{FSPL} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (1)$$

where, f: frequency in MHz; d:distance in m; Power is usually expressed in decibels (dBm).

2.2. COST 231 Hata Model

The COST 231 model is used in urban areas at higher frequencies ranging from 1500 MHz - 2000 MHz. This models calculates the path loss and contains corrections for three different environments like urban, suburban and rural. Although 3.5GHz frequency range is beyond its frequency range but still it simplicity and correction factors allows to predict path loss in higher frequency ranges[18]. The equation for COST 231 Hata Model is given by:

$$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + \left(44.9 - 6.55\log_{10}(h_b)\right)\log_{10} d + c_m \qquad (2)$$

2.3. Standard University Interim Model

The IEEE 802.16 working group proposed the standards for the frequency below 11GHz containing the channel models developed by Stanford University (SUI) model. The IEEE 802.16 has adopted the Erceg C [19] model as a reference propagation model for WiMAX system evaluation. This model can be applied in three different environments: Type A, B and C terrain regions.

By using this model the total attenuation PLs(d) is given by:

$$PL_s(d) = PL_{s0}(d) + s$$
$$= 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \quad (3)$$

2.4. Hata Okumara Extended Model or ECC 33 Model

This model is most extensively used empirical propagation model based on Okumura Model. An extrapolated method is applied to predict the model for higher frequency greater than 3 GHz. The path loss for this model is given by:

$$PL = A_{fs} + A_{bm} - G_b - G_r \quad (4)$$

where, Afs: Free space attenuation [dB]; Abm Basic medium path loss [dB]; Gb:Tranmitter antenna height gain factor; Gr: Receiver antenna height gain factor.

2.5. COST 231 Walfish-Ikegami Model (W-I) Model

This model is extension of COST 231and is well suitable for flat suburban and urban areas that have uniform building heights. This gives precise path loss.
For LOS condition

$$PL_{LOS} = 42.6 + 26\log(d) + 20\log(f) \quad (5)$$

and for NLOS condition

$$PL_{NLOS} = \begin{cases} L_{FSL} + L_{rts} + L_{msd} & \text{for urban and suburban} \\ L_{FS} & \text{if } L_{rts} + L_{msd} > 0 \end{cases} \quad (6)$$

where,
L_{FSL}: Free space loss; L_{rts}: Roof top to street diffraction; L_{msd}: Multi-screen diffraction loss.

2.6. Ericsson Model

The network planning engineers use software to predict the path loss developed by Ericsson Company Ltd.The path loss for this model is given by:

$$PL = a_0 + a_1.\log_{10}(d) + a_2.\log_{10}(h_b) + a_3.\log_{10}(h_b).\log_{10}(d)$$
$$-3.2\left(\log_{10}(11.75h_r)^2\right) + g(f) \quad (7)$$

3. WiMAX Protocol for GCC to Aggregator Communication

The WiMAX standard defines air interface for IEEE 802.16e for the frequency range of 2-6 GHz [8] and 256-FFT orthogonal frequency division multiplexing (OFDM) Physical layer specification supports up to 50km coverage area and data flow up to 70Mbps. In practice, the coverage area is 5-7 Km and data flow of 7Mbps. An OFDM has three subcarriers i) data subcarrier, ii) pilot subcarrier and iii) null subcarrier.

For the line-of-sight (LOS) transmissions the single carrier air interface is used and for the non- line-of-sight (NLOS) transmission the two OFDM schemes are used. The block diagram of physical layer WiMAX is shown in Fig.4. The WiMAX model has three parts the transmitter, receiver and a communication channel.

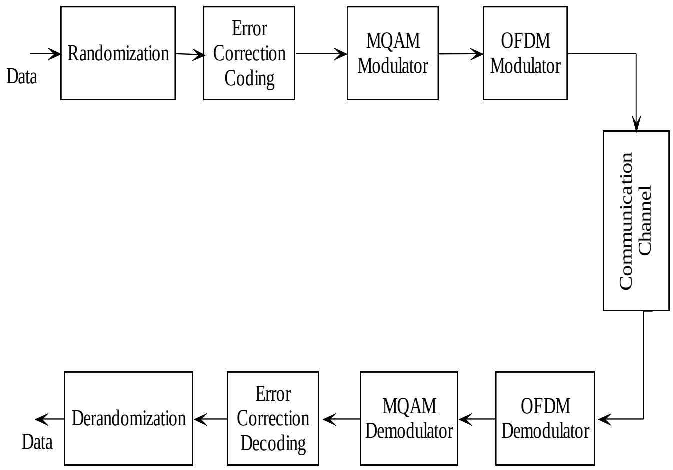

Fig.4. Block diagram of physical layer WiMAX.

The signal is distorted when the information is transmitted via a wireless channel because of multipath. There is a LOS path between a transmitter and receiver and it is not always the same. The other alternative paths are created by signal reflections due to vehicles, buildings, and obstacles (i.e NLOS). The signals travelling along these paths reach the receiver at different times based on the distance travelled along each path.

Previously, the single carrier modulation scheme was used in cellular systems and the delay spread due to multipath caused a symbol to "bleed" in to the subsequent symbol reaching the receiver via direct path and is referred to as inter-symbol interference (ISI) [20], [21]. The effect of multipath distortion in frequency domain is shown in Fig.5.

The time domain equalizers methods are used to compensate the channel distortion. The methods are a) channel inversion and b) rake equalizers are employed to resolve individual path (CDMA systems). Increase in data rate leads to implementation complexities and shortest symbol time. OFDM eliminates inter symbol interference (ISI) caused due to multipath with the help of longer symbol periods and a cyclic prefix. Unlike single carrier system, to achieve higher data rates it does not require increased symbol rates. Cyclic prefix (CP) and FFT period are two components of OFDM symbol. The Fig.6 shows the OFDM symbol period (longer) and cyclic prefix to eliminate the ISI. The WiMAX is based on OFDM technology and helps to tackle the ISI. Disadvantages of OFDM are i) highly sensitive to frequency offset and ii) high peak-to- average power ratio (PAPR).

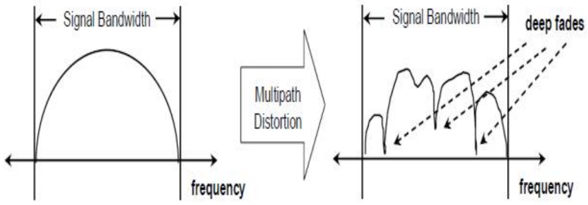

Fig. 5. Frequency selective fading.

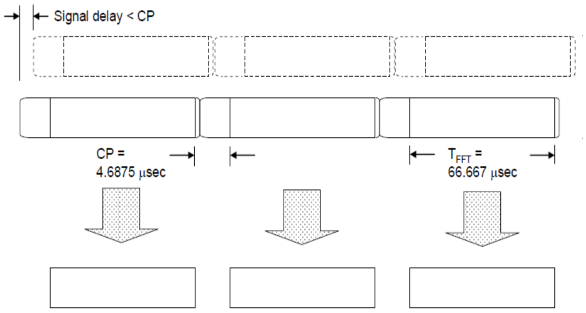

Fig. 6. OFDM symbol period and cyclic prefix.

4. Results and Discussion

GCC to aggregator communication is very crucial in meeting the load demand and contribute power to the grid. The aggregator provides parking and charging slot to EVs for power transaction with the grid. The fixed WiMAX protocol is proposed for GCC to aggregator communication. The simulations were carried out using the parameters as shown in Table I. The metrics prediction error mean (μ) and standard deviation (σ) are used for evaluating the path loss models. The positive value of μ means that a model over estimates path loss value and negative value means a model predicts smaller path loss value than the expected one. In line with this, a small value of σ indicates a good model prediction and large value indicates less accurate model.

Table 1. IEEE 802.16 WiMAX

Parameters	Value
Frequency Band	2GHz-6GHz
OFDM carriers	OFDM: 256 OFDMA: 128, 256, 512, 1024
Modulation	QPSK, 16QAM, 64QAM
Transmission Rate	1Mbps-75Mbps
Duplexing	TDD or FDD
Channel Bandwidth	(1,2,4,8)x1.75MHz (1,4,8,12)x1.25MHz 8.75MHz

The transmitter antenna height considered is 30m and receiver antenna height is 6m/10m.

The receiver antenna height is considered as 6m for urban The transmitter power is 43dBm and the results are shown in Fig.7 and Fig.8. SUI model demonstrates lower path loss of 162dB and 142dB for urban and suburban environments respectively. COST HATA, COST WI and ECC-31demonstrate path loss of 158dB, 162dB and 164dB respectively for Suburban environment. Ericsson model demonstrates comparatively higher path loss of 204 dB for Suburban but it is interesting to note that it exhibits path loss of 160dB which is lower as compared to all other models in case of Urban environment. COST WI and COST HATA exhibits higher path loss of 178 dB and 176dB respectively for Urban environment as compared to other models for 10m antenna height.

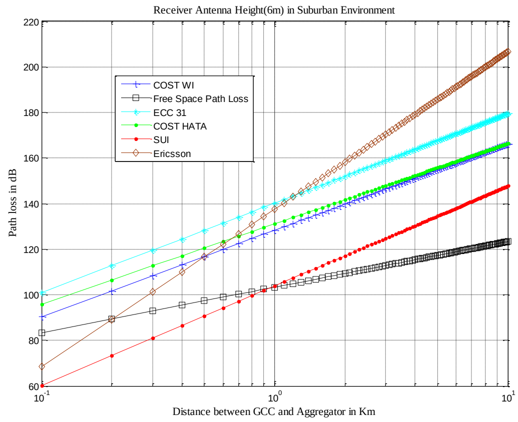

Fig. 7. Path loss for the Suburban environment with 6m receiver antenna height.

With 6m receiver antenna height for Urban environment, the Ericsson model projects path loss of 160dB and ECC 31 exhibits highest path loss of 180dB. The COST WI and COST HATA demonstrate about 178dB. The SUI is moderate and demonstrates 168dB as depicted in Fig.9. For suburban with 6m antenna height the SUI demonstrate the lowest path loss of 148dB and Ericsson demonstrate the highest path loss of 208dB. The COST WI and COST HATA demonstrate the path loss of 165dB as shown in Fig.10.

The physical layer of WiMAX protocol is modeled and simulated in MATLAB/SIMULINK. The bit error rate (BER) v/s signal-to-noise ratio (SNR) graph is plotted and is shown in Fig.11. To achieve the BER of 10^{-2} both BPSK ½ requires 7.5dB, QPSK ½ requires 12dB, QPSK ¾ requires about 15dB, 16QAM ½ requires around 16.5dB. The QPSK ½ and 16 QAM ½ are less prone to errors as compared to other modulation schemes.

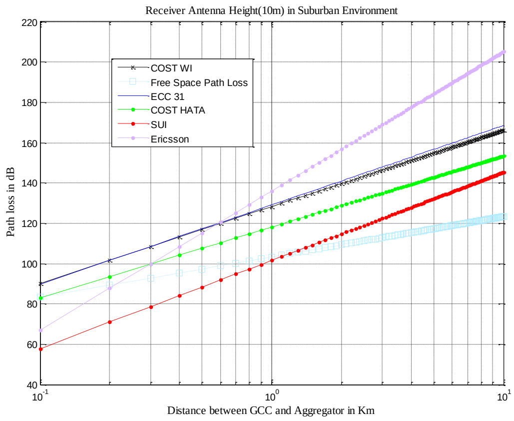

Fig. 8. Path loss for Suburban environment with 10m receiver antenna height.

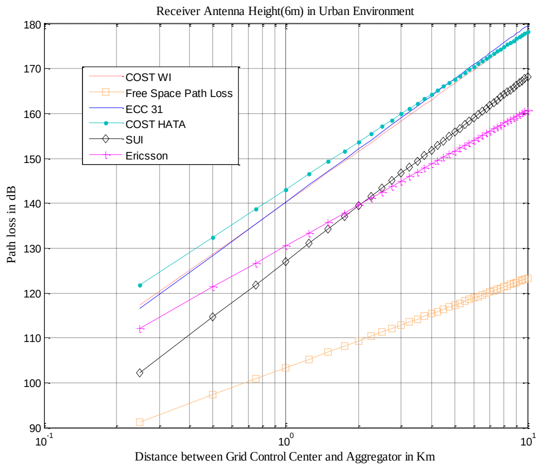

Fig.9. Path loss for the Urban environment with 6m receiver antenna height.

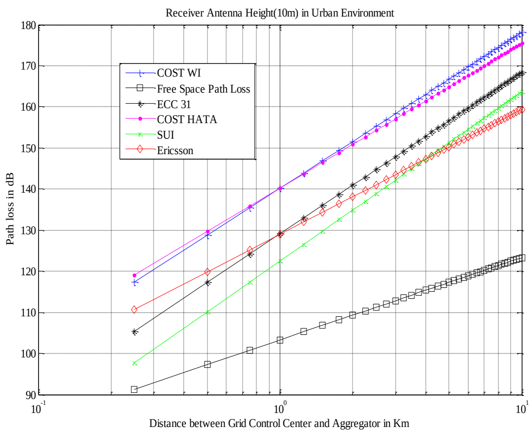

Fig. 10. Path loss for the Urban environment with 10m receiver antenna height.

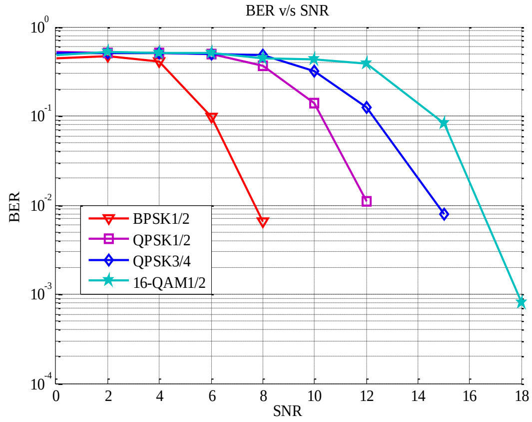

Fig.11. BER v/s SNR.

5. Conclusion

The wireless link is established for GCC to aggregator communication in V2G. The path loss models for WiMAX are analysed, compared and suitable models for Urban/Suburban environment are suggested. The BER v/s SNR curves are plotted in order to investigate the performance of the protocol. The main contribution of this paper is the development of wireless communication infrastructure for GCC to aggregator communication in V2G for Smart Grid application.

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