ENERGY CONSUMPTION ANALYSIS OF WIRELESS ACCESS TECHNOLOGIES FOR V2G COMMUNICATIONS

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Abstract

Vehicle-to-Grid (V2G) technology can be used to interconnect electric or plug in hybrid vehicles with the power grid by either delivering electricity and level peak demands or by throttling their charging rate. Two types of wireless communications are required to a V2G system. The communications between the Aggregator, an intermediate entity, and the Control Center which will be realized through IEEE *802.16-2004 (802.16d)* and between Aggregator and the Electric Vehicles which will be realized through vehicular communications (IEEE 802.11p). In this paper the two wireless communication protocols, needed for the V2G system to operate, are presented and evaluated, taking into consideration the energy consumption.

1. INTRODUCTION

V2G concept is based on the fact that most vehicles are parked an average of 95 percent of their time, so their batteries could be used to let electricity flow from the vehicles to the power lines and back. The introduction of V2G concept has been the subject of several publications [1], [2]. Electric vehicles can be connected to the electric network either in the residences of their holders, either in public spaces such as underground parking stations, airports, commercial centers etc., participating this way in power market and more specifically, depending their contract, to the peak power, ancillary services and regulation power market.

IEEE 802.16-2004 (802.16d) WiMAX [3] allows for an efficient use of bandwidth in a wide frequency range and can be used as a last mile solution for broadband internet access. IEEE 802.11p standard is being considered as a promising wireless technology for enhancing transportation safety and provides safety related services like collision avoidance and emergency breaking.

The main contribution from this paper is the energy consumption analysis and evaluation of IEEE 802.11p for the communication between the Aggregator and the EVs. and WiMAX for the communication link between Control Center to Aggregator.

2. V2G ARCHITECTURE DESIGN

The V2G concept operates when a vehicle is parked, plugged in to the electricity grid and accesses a broadband connection. The V2G wireless communications architecture is shown in Fig. 1.

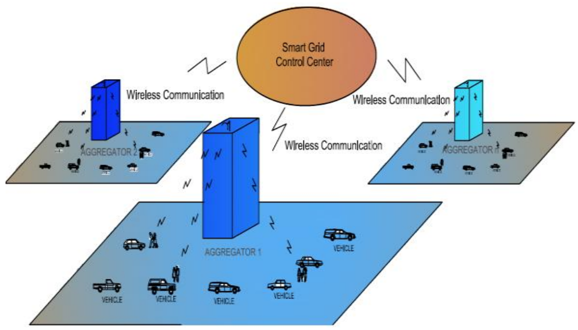

Figure 1. V2G Wireless Communication Architecture

The real time information is exchanged among the Control Centre, the Aggregator and vehicles, and the security requirements consist of source authentication, message integrity, replay attack resistance, and privacy protection. The V2G communication have the crucial requirements of fast authentication and encryption/ decryption, high bandwidth, low latency, interoperability, high reliability and accuracy and non-restrictive distance limits [4].

3. WIRELESS PROTOCOLS

The IEEE 802.16 standard was firstly designed to address communications with direct visibility in the frequency band from 10 to 66 GHz. The last revision of this specification is better known as IEEE 802.16-2004. The WiMAX standard defines the air interface for the IEEE 802.16-2004 specification working in the frequency band 2-11 GHz. IEEE

802.11p standard is being considered as a promising wireless technology for enhancing transportation safety and provides safety related services like collision avoidance and emergency breaking. At first this includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz.

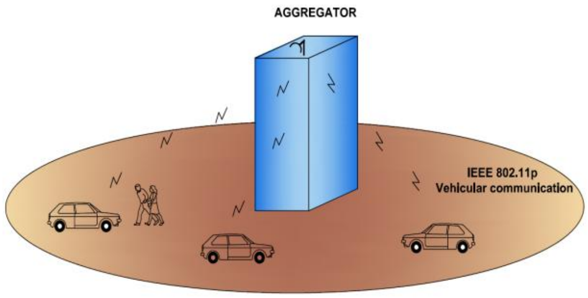

Figure 2. V2G IEEE 802.11p Communication scheme

4. ENERGY CONSUMPTION

The global Information and Communication Technology (ICT) industry is a fast growing contributor to the world wide greenhouse gas emissions, currently it has a footprint of about 2%. More importantly, this number is expected to grow drastically in the coming years. According authors at [5] the energy consumption of terminals is negligible with respect to the energy consumptions of the networks. Consequently, this study is focused on the base stations since the terminals in vehicular communications are placed in vehicles and powered from their batteries.

The power consumption of the entire base station in Watt will be:

$$P_{el} = n_{sector} \cdot \left(P_{EL/AMP} + P_{EL/TRANS} + P_{EL/PROC} + P_{EL/RECT}\right) + P_{EL/MICRO} + P_{EL/AIRCO} \quad (1)$$

with n_{sector} the number of sectors in the cell, $P_{EL/AMP}$ the power consumption of the power amplifier, $P_{EL/TRANS}$ the power consumption of the transceiver responsible for receiving and sending of signals to the terminals stations), $P_{EL/PROC}$ the power consumption of the digital signal processing responsible for system processing and coding, $P_{EL/RECT}$ the power consumption of the rectifier, $P_{EL/MICRO}$ the power consumption of the microwave link responsible for communication with the backhaul network, $P_{EL/AIRCO}$ the power consumption of the air conditioning.

The values of the WiMAX and IEEE 80211.p base station equipment can be found in Table 1. These values are retrieved from data sheets of various manufacturers of network equipment.

Table 1. Power consumption for the equipment of the base station

Equipment	IEEE 802.16d	IEEE 802.11p
Power Amplifier	100 W	80 W
Transceiver	100 W	45 W
Digital signal processing	380 W	300 W
Rectifier	80 W	80 W
Microwave link	90 W	70 W
Air conditioning	600 W	400 W

4.1. Range calculation

The next step for the determination of energy consumption of the wireless access technologies is to set up a link budget in order to relate the power consumption with the maximum wireless range of the base station. A link budget is the accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. Firstly, there is a need to calculate the maximum path loss PL_{max} (in dB) to which a transmitted signal can be subjected while still being detectable at the receiver. To determine the maximum path loss (PL_{max}) the parameters of [3],[6] were taken under consideration. Once the maximum path loss PL_{max} is known, the range in metres by using a path loss model can be determined

Firstly, a path loss PL_{med} function for WIMAX Erceg C model and in continuation for 802.11p model is given. For a given close-in reference distance d_0, the median path loss (PL in dB) is given by the following equation

$$PL_{MED} = A + 10\gamma \log_{10}\frac{d}{d_0} + s \quad \text{for } d>d_0 \quad (2)$$

where A = $20\log_{10}(4\pi d_0/\lambda)$, ($\lambda$ is being the wavelength in m), γ is the path-loss exponent with $\gamma = (a - b h_b + c/h_b)$ for h_b between 10m and 80m (h_b is the height of the base station in m), d_0 = 100m and a, b, c are constants dependent on the terrain category. The path loss model with the correction terms would be

$$PL_{mod} = PL + \Delta PL_f + \Delta PL_h \quad (3)$$

where PL is the path loss given in (2), ΔPL_f (in dB) is the frequency correction term given by

$$\Delta PL_f = 6 \log_{10} (f/2000) \quad (4)$$

where f is the frequency in MHz, and ΔPL_h (in dB) is the receive antenna height correction term given by

$$\Delta PL_h = -10.8 \log_{10}(h/2) \quad (5)$$

for Categories A and B

$$\Delta PL_h = -20 \log_{10}(h/2) \quad (6)$$

for Category C, where h is the receiver antenna height between 2m and 10m. For the 801.11p, we examine the case where the vehicle has no eye contact with the Aggregator's antenna, for example when the EVs are parked in underground parking stations. The log-distance path loss model is employed and the equation is:

$$PL_{MED} = PL_0 + 10\gamma \log \frac{d}{d_0} + X_g \quad (7)$$

where PL_{MED} is the total path loss measured in Decibel (dB), PL_0 is the path loss at the reference distance d_0, d is the length of the path, d_0 is the reference distance, usually 1 km, γ is the path loss exponent, X_g is the normal random variable with zero mean, reflecting the attenuation caused by flat fading. In case of no fading, this variable is 0. In case of only shadow fading or slow fading, this random variable may have Gaussian distribution with standard deviation in dB, resulting in log-normal distribution of the received power in Watt.

5. RESULTS

This section provides computation results in order to evaluate power consumption with range dependence of the two wireless communication protocols in the V2G environment. In the most simple situation, the base station uses only one antenna for transmission and the mobile station uses only one antenna for receiving. The number of sectors was set to two Regarding the communication link between the Aggregator and the Control Center, we used the Erceg C model with the middle category (Category B). The operating frequency was set at 3.5 GHz with ¼ cycle prefix, 3.5 MHz channel bandwidth, transmitter antenna height is 30m and we considered 10m antenna height for receiver. The shadowing margin which depends on the standard deviation of the path loss model was found 12 dB. For the link between the Aggregator and the EVs the operating frequency was set to 5.9 GHz with 400 ns RMS delay spread. Figure 3 shows the power consumption of the base station (P_{el}) needed from the electricity grid (in Watt) as a function of the range R (in metres) for the 802.16d and 802.11p technologies respectively. The power consumption of Wimax is higher than the 802.11p because of the different power consumption of the equipment and the different range of the base station.

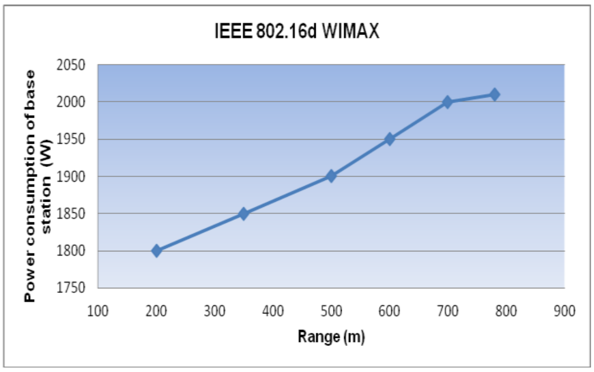

Figure 3. Power consumption vs Range for Wimax

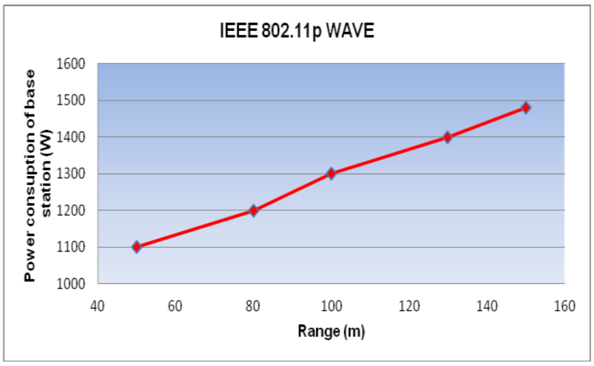

Figure 4. Power consumption vs Range for IEEE 802.11p

6. CONCLUSIONS

This article presents the power consumption evaluation of two different wireless communication protocols enabling the Control Center-to-Aggregator and the Aggregator-to-Evs communication respectively. As a first step in the evaluation Fixed WIMAX was explored for communication between Control Center-to- Aggregator at 3.5 GHz. Erceg C model was used to describe the path loss attenuation. As a second step, 802.11p standard was tested in N-LOS paths representing parked vehicles in underground stations. Log-distance path loss model was used to describe the path loss attenuation. Our results have shown that the power consumption is related to the coverage of their base stations and at the maximum range is higher than the power consumption at the minimum range.

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