Heterogeneous Wireless Communications Employment in Smart Grids Home Area Network

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ABSTRACT. This paper presents new communication solutions to smart grids in the home area network based on the existent wireless facilities. Different types of wireless systems: cellular networks and WLAN are analyzed. The large number of available frequency bands, for these systems, point to a fractal multiband antenna solution. A Sierpinski gasket antenna has been designed for cellular systems (GSM 900, DCS 1800 and UMTS) and a Minkowski island to both cellular networks and WLAN communications. The system was thereafter implemented and tested using SMS messages to support communications between the EV and the infrastructure. This allows the V2G concept implementation by means of a more efficient energy management technique implementation on the smart grid.

KEYWORDS. Home Area Network; Wireless Systems; Fractal Antennas; V2G communication.

1. INTRODUCTION

Smart grids intend to improve the efficiency, reliability, and sustainability of the production and distribution of electrical energy, using the consumers and suppliers activity information [1]. Wireless technologies are promising candidates to perform that crucial, last mile, exchange of information because they inherently provide terminal mobility, low installation cost, rapid deployment and extended coverage over traditional wired solutions. The accessibility to multiple radio access technologies standards such as: 2G/3G cellular networks; IEEE 802.11 a/b/g wireless LAN, WiMAX and ZigBee based on IEEE 802.15.4 provides the mentioned benefits and redundancy over wired technologies.

Among the loads present at home the electrical vehicle (EV) is perhaps the most promising candidate to optimize the residential energy consumption due to the involved power values and to its potential bidirectional transmission of electricity feature. The EV batteries could be seen as an energy storage unit that can return energy back to the grid when parked, accomplishing the vehicle to grid (V2G) concept. Consequently, the accurate identification, on a given area, of the vehicle’s: location, parking status, and mainly its storage capability can be used to design an energy efficiency strategy. When parked at home the EVs must use the available networks to promote communication with the smart grid fulfilling certain particular requirements. It is recognized that Home Area Network (HAN) communications service requirements comprise relatively low data rate (<1 Mbps); high reliability, low latency, low power consumption, secure communication and a medium range coverage area [2].

The remainder of this paper is organized as follows. Section 2, describes the radio interface of the most important cellular systems used nowadays, namely the GSM, EDGE, GPRS and UMTS systems. The mentioned description also includes the wireless systems Wi-Fi and WiMAX based on the IEEE 802.11 and IEEE 802.16 protocols respectively. In section 3, two different types of fractal antennas with a multiband behavior, Sierpinski gasket monopole and the Minkowski island are designed, simulated and implemented. Finally, section 4 explains the SMS service usage to support the information exchange between the EV and the infrastructure. It is also explained the implemented data communication system, based on AT commands, that is employed to send and receive information. The used hardware includes the mentioned microstrip fractal antennas, a GSM/GPRS modem and an ATmega328 microcontroller.
2. WIRELESS COMMUNICATION SYSTEMS

Wireless communications systems are natural candidates to be used in smart grids and particularly in the Home Area Network. The lack of wirings enables the equipment mobility, offers low-cost solutions and provides flexibility in the communications network configuration, aspects that are of particular value. Among the multiple wireless technologies that were examined, particular attention has been given to the mobile cellular systems (e.g. GSM and UMTS) and to the wireless networks such as WiFi and WiMAX.

2.1. Global System for Mobile Communications (GSM) Cellular System

Cellular systems topology consists of multiple overlapping cells that provide coverage, obtained from relative low power transmitters located on base stations BS’s. Global System for Mobile communications (GSM) is a second generation (2G) based on digital technology, circuit switched mode, designed and optimized to support full duplex voice service.

GSM frequency bands or frequency ranges are the cellular frequencies designated worldwide by the International Telecommunication Union (ITU) for the operation of GSM mobile phones. In Europe GSM/GPRS most frequently used frequencies are the 900 MHz and the 1800 MHz bands. However according with 3GPP TS 45.005 (ETSI 05.05) there are fourteen licensed frequency bands defined to this system [3]. The available spectrum is divided into radio carriers each one having a bandwidth of 200 kHz. One or more carrier frequencies are then assigned to each BS. Each of these carrier frequencies is then divided in time, using a Time Division Multiple Access (TDMA) scheme, into eight distinct time slots, which will be used to support speech and data channels. One time slot is used for transmission by the mobile and one for reception. They are separated in time so that the mobile unit does not receive and transmit at the same time as represented in Figure 1.

2.1.1 Enhanced Data Rates for GSM Evolution (EDGE) and General Packet Radio Service (GPRS)

Enhanced Data for GSM Evolution (EDGE) is an evolution of GSM that provides third generation (3G) capabilities in the existing frequency bands. EDGE enables services like web browsing, email, multimedia, and video conferencing to be accessible from its mobile terminals.

The GSM standard provides data services with bit rates up to 14.4 kbps for circuit switched data and up to 22.8 kbps for packet data, per time slot. Thus, higher bit rates can be only be achieved with multislot operation. The General Packet Radio Service (GPRS) provide data rate up to 171.2 kbps accordingly with the used coding scheme that depends on: the radio link quality, the number of other users sharing the service concurrently and the user negotiated QoS [4 - 5]. Both GSM and GPRS systems are based on the Gaussian Minimum Shift Keying (GMSK) modulation technique that has a spectral efficiency of 1.3541 bps/Hz, which correspond to an aggregate data rate per carrier of 270.833 kbps.

Thus, the core of the EDGE concept includes the introduction of a new modulation scheme 8-PSK, that allows data to be sent at speeds up to 384 kbps [5]. This increase in data rate is obtained from the usage of the 8-PSK modulation technique that has a 3 bit per symbol efficiency. Note that the symbol rate for both modulations is 270.8(3) ksymb/s, leading to gross bit rates per time slot of 22.8 kbps and 59.2 kbps for GMSK and 8-PSK.
2.2. Universal Mobile Telecommunications System (UMTS)

The UMTS is a third generation (3G) mobile cellular technology designed to provide mobile personal communications (with anyone, anywhere and anytime) with transmission rates up to 2 Mbps according to the environments of use, support universal roaming and offer wideband multimedia services. The UMTS system is based on a set of basic requirements that includes: a high spectral efficiency, a large traffic capacity, the support of various services and applications, indoor and outdoor coverage, the use of small, light, low price and high autonomy terminals, high quality service, and the establishment of secure communications. The system provides a broad range of services to a large number of users. The services provided by the system include the telephony voice service, new multimedia and Internet services, which should be available from a variety of radio terminals and platforms.

2.3. IEEE 802.11 protocol Wi-Fi

A Wireless Local Area Network (Wireless LAN) is a wireless communication system that allows notebooks, computers, PDAs and tablets PC to access and share data, internet access or other network resources in the same way as for wired networks. Its main advantages comprise terminal mobility, short term usage, speed of deployment and scalability. There are also some disadvantages such as power consumption, low safety levels and operating frequencies that differ from country to country.

The IEEE 802.11 protocol, also referred as “Wi-Fi” (Wireless Fidelity), is a network access technology that provides connectivity between wireless stations know as Access Points (AP) and wired networking infrastructures. There are several versions of IEEE 802.11, which include:

- 802.11b - is the older version, transmits in the 2.4 GHz band and supports transmission rate of 11 Mbps and uses Complementary Code Keying (CCK) encoding.
- 802.11g - also transmits in the 2.4 GHz band, but supports maximum speeds of 54 Mbps, the usage of Orthogonal Frequency Division Multiplexing (OFDM) increases the efficiency.
- 802.11a - same as 802.11g, but it works in the 5 GHz band.

2.4. Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is broadband wireless access (BWA), technology based on IEEE 802.16 standard created with the aim of providing wireless access to the Internet with the following characteristics: large geographical coverage area, huge number of simultaneous users accessing the network, high transmission rate and is low cost. It fits a wide range of applications and environments: data, voice and multimedia fixed and mobile, licensed and unlicensed. The WiMAX standard specified a frequency range of 10-66 GHz with a theoretical maximum bandwidth of 120 Mbps and maximum transmission range of 50 km [6]. It was designed to bring end-user wireless Internet without the expense and inconvenience of wiring or the distance limitations of Digital Subscriber Line (DSL).

WiMAX is supported by the WiMAX Forum, which has as its primary mission to ensure compatibility and interoperability between devices based on the IEEE 802.16 and is mainly composed of chipsets equipment manufacturers. The WiMAX Forum is the equivalent of the WiFi Alliance, responsible for the great development and success of the Wi-Fi throughout the world.

3. FRACTAL MULTIBAND ANTENNAS

As mentioned before different wireless systems technologies have been proposed in the scope of the HAN smart grids communications. As the systems work in different frequency bands, WLAN systems and Bluetooth work on the 2.4 GHz Industrial, Scientific and Medical (ISM) band (e.g. IEEE 802.11 b/g; IEEE 802.15.4, etc.) in conjunction with the release of the 5.2 GHz ISM band, (e.g. IEEE 802.11 a/n) is therefore necessary that the antennas present a multiband and behavior, in order to maintain backward compatibility. Several methods for obtaining multi-band and/or wideband antenna characteristics have been developed. Fractal geometry is a very good solution for this problem resulting also in antennas with wider bandwidth and smaller dimensions. Fractal structures are known by their self-similar and scaling properties and fractional dimension [7].
In terms of implementation microstrip antenna presents many advantages such as light weight, small volume and low fabrication cost. However, they present also some disadvantages, where the most limiting are: a narrow bandwidth (for patches); low efficiency and gain; radiation from feed and junction and low power handling capacity. Among the fractal shapes used for antennas: the von Koch curve, the Minkowski curve, the fractal tree, the Sierpinski (gasket and carpet) fractals and the Cantor set are the most usual [8].

3.1. Sierpinski gasket

The Sierpinski gasket (also called Sierpinski triangle) was selected for a fractal antenna in this work since it is similar to the triangular or bow-tie antennas, which already present a broadband behavior relatively to the rectangular patches. The Sierpinski gasket is created by subtracting a central inverted triangle from a main triangle shape (Figure 2; \( n = 0 \)). In each iteration the middle triangle(s) are removed from the antenna, preserving three (first iteration) or nine (second iteration) equally sized triangles, which are one-half or one-fourth the height of the original triangle (zero iteration) [8].

\[
f_r = k \cdot \frac{c}{h} \cdot \cos\left(\frac{\alpha}{2}\right) \cdot \delta^n \quad \text{with} \quad \delta = \frac{h_n}{h_{n+1}}
\]

From (1), it can be observed that the height of each sub-gasket will determine the resonant frequencies of the antenna. In this case four different bands are obtained from the height values of the sub-gaskets \( (h_1 = 77.7 \text{ mm}; \ h_2 = 39.3 \text{ mm}; \ h_3 = 20.6 \text{ mm} \text{ and } h_4 = 11.1 \text{ mm}) \). From the dimensions presented on Figure 3 it can be conclude that the flare angle is equal to 53° (the triangle is not equilateral). The \( k \) constant is dependent of the considered dielectric substrate type and thickness, in this work a \( k \) equal to 0.152 was considered.

The proposed triangular Sierpinski gasket conductor structure was printed over a thin dielectric substrate FR4 that was placed vertically over a square conductor ground plane. In this work it was considerer a 10 x 10cm square, in future implementations such ground plane can be obtained from the EV hood.

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Figure 2. Sierpinski gasket fractal antenna iterative construction method.

Figure 3. Sierpinski gasket antenna dimensions.

Figure 4. Current distribution: Sierpinski gasket antenna @900 MHz.
For the Sierpinski gasket antenna presented in Figure 3, simulations have been carried out using Ansoft Designer software to evaluate the exploitable frequency bands (VSWR < 2) and the radiation pattern. The observed resonant frequencies retrieved from Figure 5 were (870 MHz; 1880 MHz and 3730 MHz)

![Figure 5. Sierpinski gasket antenna VSWR.](image)

![Figure 6. Sierpinski antenna radiation pattern 3D.](image)

### 3.2. Minkowski island

The Minkowski island fractal is obtained using the recursive process depicted in Figure 7 [9]. The initial shape, zero order of the Minkowski island fractal (M0), is a square. The first order Minkowski island fractal (M1) is created by displacing the middle third part of each side by a portion less than 1/3 of the original side length. Applying the same procedure on (M1), the Minkowski island fractal of second iteration (M2) is obtained. Minkowski fractal antennas present both a broadband and multiband behavior. As more contours and iterations of the fractal are added, the coupling between the wires becomes more complex and different segments of the wire resonate at different frequencies.

![Figure 7. Minkowski Island fractal antenna iterative construction method.](image)

![Figure 8. Minkowski island antenna dimensions.](image)

![Figure 9. Current distribution (2.4 GHz): Minkowski island antenna.](image)

From the retrieved simulation presented in Figure 10 it can be observed that the 2nd order Minkowski island antenna fractal presents a multiband performance having four exploitable bands around 850 MHz, 1520 MHz, 1830 MHz and 2450 MHz (up to 4 GHz). Moreover, the 2432-2467 MHz band presents the VSWR values lower than 1.4 dB.
In order to construct the proposed fractal antennas it was used the FR4 board. This material has a frequency of operation (until 10 GHz) and a low price, suitable to this initial phase of development. Figure 12 presents the implemented Sierpinski gasket monopole antenna and Figure 13 the Minkowski island fractal antenna.

4. V2G COMMUNICATIONS BASED ON SMS

In the scope of this paper, efforts have been made in the V2G communications implementation. The used onboard unit consists of a microprocessor, a GPS module a GSM/GPRS module with a SIM card. The implemented test bed includes the LinkSprite GSM/GPRS module named SM5100B, a miniature single-side board, quad-band GSM 850/EGSM 900/DCS 1800/PCS 1900.

4.1 V2G Communication Required Information

The considered information includes the following fields [10]:

- Vehicle/onboard unit identification; (using SIM module ID)
- Vehicle location; (using GPS and the GSM Cell ID)
- Vehicle speed; (using GPS)
- Charging station(s) location; (GPS)
- Driving destination;
- Driving cycle history; (supported on a high rate communication e.g. IEEE 802.11.b/g)
- Power demand profile;
- Power supplied or charged by the sources;
- Battery SoC (State of Charge);
- Charging/discharging time and current data;
- Power electronics module parameters.
4.2 The Short Message Service (SMS)

Nowadays, the SMS is one of the most successful telecommunication services in terms of the number of users and cost-effectiveness. SMS is supported by cellular networks such as the GSM and UMTS. Initially the SMS specifications have been carried out in the ETSI scope and comprised the service definition, the network architecture, protocols and functionalities. Later an innovative concept, the Third Generation Partnership Project (3GPP), was created in order to define a radio access technology for the future generation cellular system that was intended global. The success obtained from the GSM system and its evolutions, that include the GPRS and EDGE, had lead to the preservation of the GSM has part of the future system’s core.

The SMS provides transfer of short text messages, in a connectionless mode, supported by the cellular networks radio resources. SMS offers a mean of sending messages, up to 160 characters (7 bit coding), to and from a mobile phone, fax machine, and/or IP address [11]. SMS is a store and forward service that uses a Short Message Service Center (SMSC), to relay the messages from sender to the appropriate recipient. The cellular network, checks if the originating MS (MO SMS) is allowed to use the short message service, by querying the Home Location Register (HLR) database. If the mobile is allowed to send the message, then MSC routes the short text message to the SMSC which must then direct it to the appropriate mobile device. The SMSC sends a SMS Request to the HLR in order to find the destination. The HLR responds to the query by sending the serving MSCs address of the terminating MS. The message in a Short Message Delivery Point-to-Point format is transferred from the SMSC to the serving system. Once the location of the receiver MS is found, the MSC further queries its Visitor Location Register (VLR) database, the system pages the recipient device, if it responds, the short message is delivered by the serving cell BSS. The final step in this protocol is the verification that the message was properly received [12].

4.3 The Implemented Data Communication System

The implemented solution in this paper uses the well known AT commands in order to configure the message format, send a message and read, write and delete SMS messages. The 3GPP TS 27.005, (ETSI 07.05) [13] specifies AT commands and interface protocols for control of SMS functions within a typical mobile cellular unit (e.g. SM5100B modem), from a remote terminal via an asynchronous interface.

In order to send SMS messages (V2G information), it is necessary to place a valid SIM card on an external socket of the SM5100B modem that is directly connected with the Arduino Uno (Figure 14). The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins, 6 analog inputs a 16 MHz crystal oscillator and a USB connection. The serial communication between the Arduino Uno board and the SM5100B modem is established using TTL serial data.

After that it is necessary to verify if the modem is waiting for a Personal Identification Number (PIN) using for example the AT command "AT+CPIN?". In order to overcome this step is advisable to disable the PIN usage before place the SIM card on the modem. In order to operate in text mode it is necessary to set the cellular modem for that purpose using the command “AT+CMGF”. To send a SMS message, the microprocessor should write the following command: AT+CMGS="+35196xxxxxxx" <ENTER>. If the modem responds positively the message text can be inserted reporting the available EV information (section 3.1) following a proprietary protocol. The message is sent when the <CTRL><Z> is inserted.
In addition, it is necessary to configure the communication link in the opposite direction (grid to the vehicle). The EV receives information and/or commands supported also in SMS. Thus, is necessary to know how the newly arrived SMS messages should be handled by the modem. The command AT +CNMI is used to specify that the newly arrived SMS messages forward directly to the serial port disabling that way its storage in the SIM card. The information available in the serial port is handled by the micro processor that decodes the messages and/or commands and performs the required actions.

5. CONCLUSIONS

This paper presents a technical solution that enables communication between an EV and the infrastructure. In order to implement such system, initially it was identified the relevant information to be sent and/or received by the EV. The SMS supported by the cellular communications systems was selected for this purpose. However, given the high number of available frequency bands for those cellular services multiband antennas were required. Two types of microstrip fractal antennas a Sierpinski gasket and a Minkowski island have been studied and implemented. From the simulation and experimentally results it can be verified that the Sierpinski presents VSWR acceptable values, around the 0.9 GHz, 1.8 GHz and 3.7 GHz bands. The EV location, speed, destination and parking status in conjunction with the batteries SoC are used to forecast the vehicle capacity to provide energy to the grid. When parked the EV also furnish important statistics such as the driving cycle history and the power demand profile using a Wi-Fi wireless network. The presented solution allows the V2G concept implementation by means of a more efficient energy management technique implementation on the smart grid.

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REFERENCES


