A Real Time Co Simulation Platform for Smart Grid Communication Protocols Performance Analysis

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Abstract: - This paper provides a comparison between three different communication protocols, in order to highlight the best solution in data transmission for electric vehicle charging stations. In order to succeed the above comparison two different simulation platforms were joined and adopted. First of all, two wired and one wireless communication protocols are selected. For wired interface and data transmission, the ATM (Asynchronous Transfer Mode) and MPLS (Multiprotocol Label Switching) protocols were used. The first is a widespread protocol used in many applications for several decades (since the late 1980s), while the second is a newer technology that appeared at the beginning of the new millennium (in 2001 the key standards of the model proposed by the IETF work group was published) and is gaining increasing support. Similar to the wired networking, a well-known protocol for wireless networking, which proves to be reliable under any test, is compared. This is IEEE 802.16e-2005 or Mobile WiMAX (Worldwide Interoperability for Microwave Access). Mobile WiMAX (originally based on 802.16e-2005) is the revision that was deployed in many countries and is the basis for future revisions such as 802.16m-2011. The technology was designed in its entirety to offer wireless communication in metropolitan networks and to provide competitive services to the existing wired network technologies.

Key-Words: - Data Transmission applications, Wired Communications, Wireless transmission, Charging stations, Co-simulation, Performance Analysis.

1 Introduction

According to the latest data, during 2014, approximately 1.236 billion vehicles were circulated worldwide, of which 907 million were passenger and 329 million were professional vehicles [1]. The majority of these vehicles are run by internal combustion engines, i.e. gasoline or diesel engines, releasing on a daily basis large amounts of substances harmful to human health and the environment. These effects are evident both locally and globally. The measures taken through the installation of highly efficient filters to block the main pollutants cannot provide a permanent solution to the problem of environmental pollution. The decisions taken by the leaders of European countries for environmental protection, with the aim of implementation by 2020 [2], increase the EU's energy security – reducing dependence on imported energy and contributing to achieving a European energy union.

The present paper is divided into four sections. In the first section the selected protocols are described and analyzed. The second section provides the co-simulation study based on the interface of the communication simulation program named Riverbed Modeler with Matlab software, which is used for the energy system simulation in order to obtain power system data, like voltage, current, power, etc. The interface between the two programs was realized through MEX Interface [3]. Simulation results, achieved by using the co-simulation model for specific scenario, are extracted and analyzed in Section 4. In Section 5 the article was finalized by giving conclusion remarks.

2. Communication protocols

2.1. ATM

For many years, the term ATM [4], is prominent in telecommunications. Many large telecommunication companies use this standard for broadband ISDN. ATM belongs to the family of telecommunications standards that introduced the concepts of packet hopping, frame broadcast and the switched high-speed data service. Both ATM and STM (used in telephone networks for data and voice packets transfer over long distances) are based on similar technologies. The ATM uses cells, i.e. frames of fixed size and shape. The transport model which describes the ATM network consists of three main layers: the physical layer, the ATM layer and the ATM adaptation layer (Figure 1). The ATM layer relates to the end to end movement of cells and contributes to the routing of algorithms and protocols between the ATM switching devices. Routing decisions are based on the Virtual Circuit Identifiers (VCIs) and Virtual Path Identifiers (VPIs). Due to the small size of an ATM cell, the high transmission speed of the connections and the nodes switching speed, the ATM provides minimal latencies. The adaptation layer in ATM networks (AAL - ATM Adaptation Layer) is completely different from the TCP (Transmission Control Protocol).

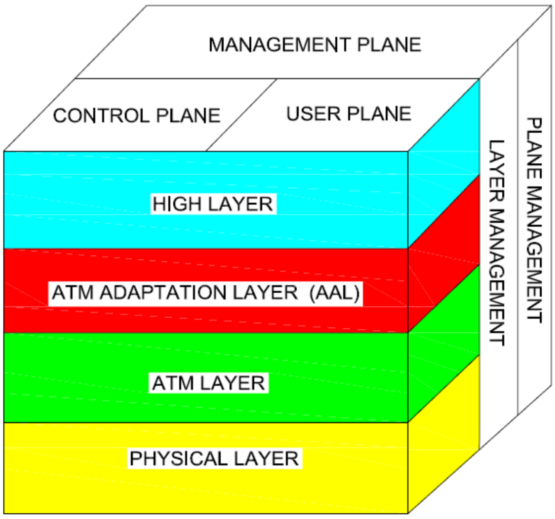

Fig. 1: ATM architecture layers

2.2. MPLS

MPLS is an emerging technology that offers high performance packet management and forwarding with concurrent network control. Its operation mechanism enables quicker service due to the usage of small tags on each packet instead of the long addresses appearing on conventional IP networks. As there is no use of long IP addresses, there is no need for complex searches in the routing table. MPLS does not aim to replace the conventional IP networks, but to adding some features for improved network performance, as it combines the advantages of IP routing with the simplicity of label changing. The forwarding decisions are performed based on labels which combine to create a label switching path (LSP) in the MPLS network. It should be noted that packet forwarding based on the data of the incoming label presents the reverse logic from that applicable to the forwarding of traffic on a pre-routed environment with matrices. Considering that the devices do not control anything other than the incoming label and forward packets according to it, any device able to control and change the incoming label can be used in the MPLS network [5]. The MPLS packet header size is 32bit. It consists of four sections as shown in Figure 2. The first part in the series occupies 20 bits and the value received by the tag of the package (label value). The next three bits concern the experimental field (EXP) and is currently used to determine CoS (Class of service). It can be used more generally to determine the quality of service features required by the package.

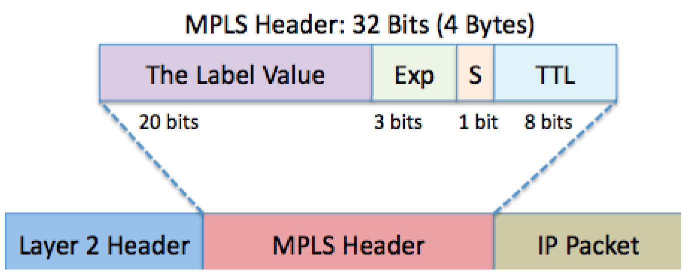

Fig. 2: MPLS Header structrure

2.3 Mobile WiMAX

WiMAX is a technology that operates in the RF band and provides wireless broadband access as foreseen by the IEEE 802.16 standard. Theoretically, it can support data transmission even at distances of 50 km at transmission speeds of up to 70Mbps. WiMAX networks are used to transmit data over broadband connections. Fixed WiMAX networks serve subscribers with terminals located at a fixed position, while Mobile WiMAX networks are capable of handling mobile users. The networks with fixed users are easier to provision and design compared to networks that serve mobile users for whose it is not easy to foresee their possible movements in order to be analyzed accurately [6],[7]. The WiMAX technology operates at frequencies from 2 to 66 Gigahertz (GHz). This operating range is divided into two frequency sub-areas, one with 2 to 11 GHz and another with frequencies 10 to 66 GHz. The lower frequency band supports links out of sight (NLOS), while on sight links (LOS) are supported in the upper frequency band.

The services and protocols specified in IEEE standard 802 covered by the two lower layers (Data Link and physical) of the OSI model of seven layers. The data link layer is divided into two sublevels called Logical Link Control layer (LLC) and media access control layer (MAC). The MAC layer is divided into three sub-layers (Figure 4), the sub-layer Convergence Specific Services (CS) which supports conversion of the external data network, the public MAC section (CPS), in which basic functions of the level performed, and the Security sub-layer, which provides opportunity authentication and secure exchange of encryption keys and codewords. For PHY layer there are several features that vary depending on the width of the frequency and type of application [8],[9].

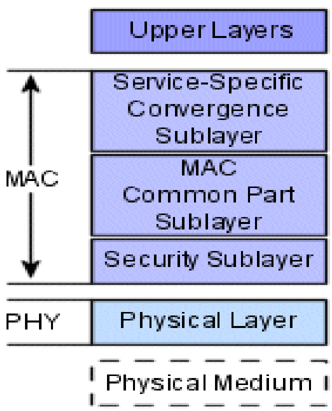

Fig. 4: WIMAX layer structrure

3. Co-Simulation Study

The increasing complexity of modern power system operation requires the simulation of various interacting systems, in order to achieve a realistic analysis of the system operating conditions. For this reason, various software packages have been developed, each of which focuses in modeling of a particular system [10],[11]. In order to study how the whole system operates, i.e. the interaction among all systems, it is most likely to end up using more than one computer software. For example, the study of the operation of a power network interconnecting various nodes of different components, like PV, EV, batteries, houses, etc together with the way each node interacts with others by exchanging messages, constitutes a design and simulation example of a system, which needs to use more than one software package.

In this study the known telecommunication networks simulation package, Riverbed Modeler [12, 13] is used. This program, through the very good hierarchical design provided, allows the simulation of telecommunications networks, using data from physical devices, or obtained by other simulation programs and computer packages, such as Matlab [14], or by running simulations with predefined parameters.

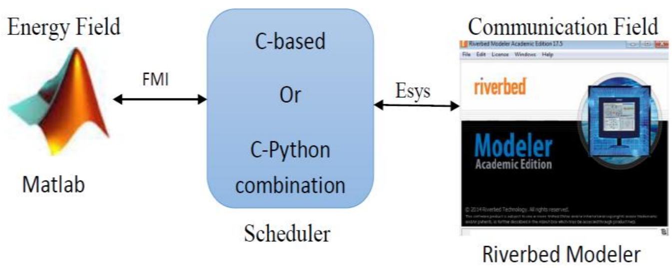

Fig. 5: Matlab-Riverbed Co-Simulation

As shown in Figure 5, Matlab computation package has been used to design and simulate the energy system, while Riverbed Modeler has been used for the implementation of the communication system. To interface Modeler with Matlab and their data exchange, MEX API, offered by Matlab was used. The data flow diagram has a circular form. The procedure entry point is in the scheduler program, which is able to start a co-simulation ether with or without user input parameters, such as the simulation steps to be followed or the number and the names of the nodes of which the functionality is studied. The scheduler calls a Matlab script or a Simulink model, containing the topology and parameters of the energy system, by using MEX (matlab external) AP interface. Once the simulation for the selected nodes is completed, all data of interest are sent back to the master program (scheduler), using one of MEX interface.

After this task is completed, the schedule program checks the value of a Boolean variable, which states whether there is a message sent between internal system nodes.

- In case the variable gets the value "True", scheduler invokes the software package Riverbed Modeler to simulate the topology in the telecommunication field. Upon completion of the simulation in Riverbed Modeler, control returns to the master program and the procedure is fulfilled.
- If the variable value is equal to "False", no simulation needs to take place in the telecommunications field and as a result the procedure for the selected nodes is completed.

The network topology scenario was in a real environment at the National Technical University (NTUA) Campus in Zografou, Athens [Figure 6] and examined three parking lots. The comparison among the three protocols assumes an ability to serve a network of 500 electric vehicle charging stations, which transmit power data (instantaneous voltage, current and power) to a database installed at the buildings of the Electrical Engineering School at the NTUA.

Considering the large number of vehicles, the vehicles are divided in parking areas, which are the subnets shown in Figure 7. In all cases, the selected application was database access (light) in the simulation software, so as to equally test the data transmission ability of all stations using all three different technologies compared. Each charging station sends data over a period between 20 and 110 seconds, while the time between two different data transmission requests follows an exponential distribution with a mean value of 30 seconds.

In continuation, time duration parameter of the network data transmission was examined. More specific the scenario tested, comprises 5 nodes and 100 nodes respectively and the WiMAX technology.

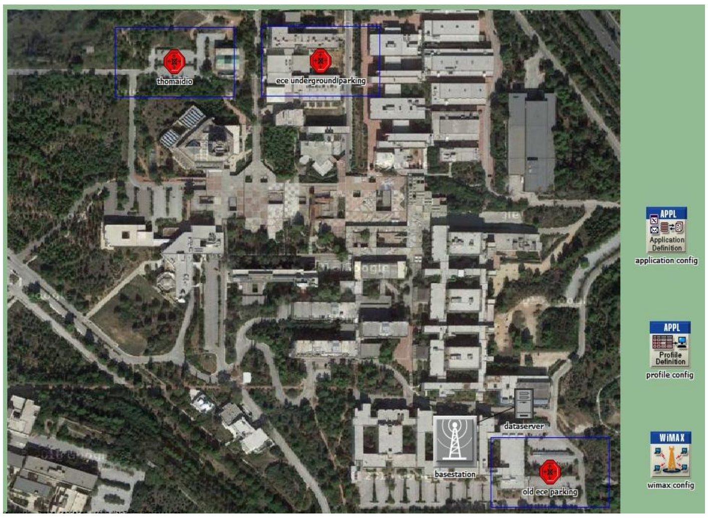

Fig. 6: WiMAX network topology

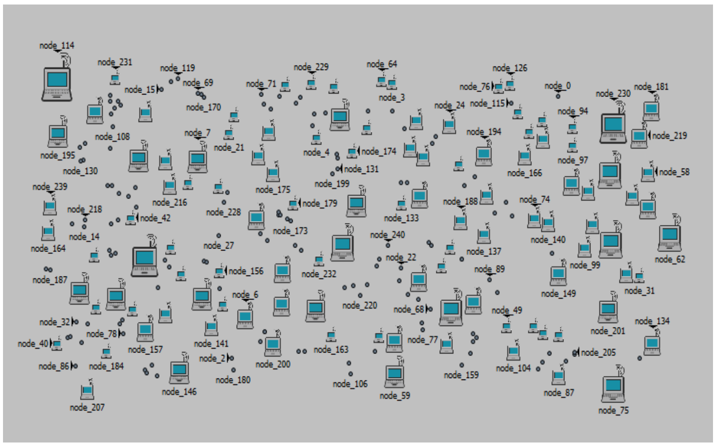

Fig. 7: Subnet topology for wireless network

4. Simulation results

The simulation of the three communication protocols was done for a period of 10 minutes, as a sample of the network operation load during a random ten-minute period of the day. Charging of the vehicles is performed at a random time, following a uniform distribution.

Due to the fact that information can be transmitted both from the charging stations to the database, and vice-versa, parameter Database Queries/Total transactions was set at 50%. That is, for each entry in the database there is a corresponding piece of information transmitted from the database to the charging station. It was selected to display all graphic items related to the data transmitted by the charging stations in order to be entered in the database (database Entry).

Initially, the average time between the transmission of a data packet to the database and the confirmation package that reaches the charging station was compared [Figure 8]. It is evident that wireless protocols lag compared to the wired ones, as they require more time to transmit data up to the reception of a response. In particular, WiMAX [15], [16] presents a satisfactory performance with times up to 0.5sec. Wired protocols, MPLS [17],[18] and ATM achieve the same fastest time among the three protocols examined, which is expected, considering that data transmission is performed through a fixed and interference-free path.

Further, the capability for the reception and transmission of data packets to and from the database on a per second basis is compared [Figures 9 and 10, respectively]. Same with the response time, the wired technologies present better performance, supporting better data transmission and reception in the order of 3.5 Kbytes per second. WiMAX protocol supports data volume transmission and reception in the order of 2.5 Kbytes per second.

Regarding the results of the graphs related to the delay (DB Entry response time) in data reception from the database, the delay of transmission (WiMAX Delay) and the volume of the transmitted information (WiMAX Load), for the scenarios 5 and 100 charging stations respectively, are presented.

As shown in Figures 11, 12 and 13, despite the large increase in the volume of the transmitted information in the 100-nodes network, there is no increase in transmission delay. The only significant change relates to the response time of the database during information registration.

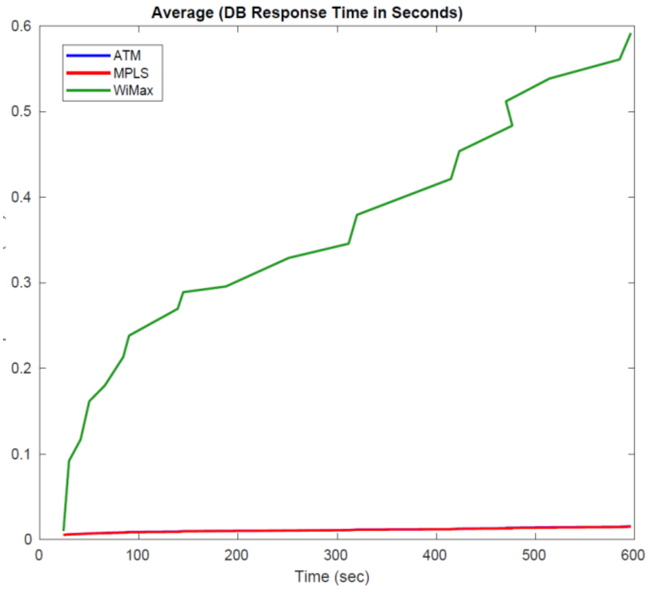

Fig. 8: Database Entry Response Time (sec)

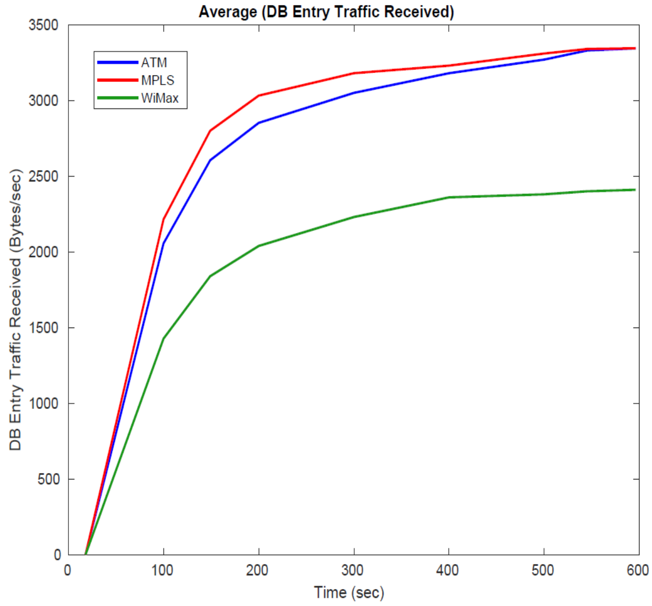

Fig. 9: Database Entry Traffic Received (bytes/sec)

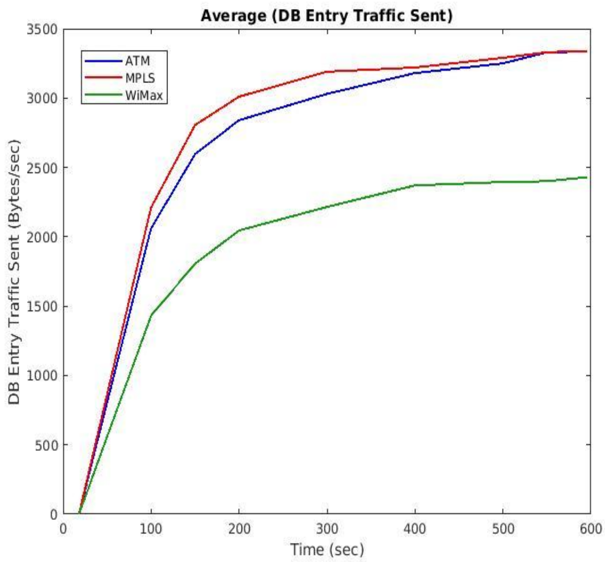

Fig. 10: Database Entry Traffic sent (bytes/sec)

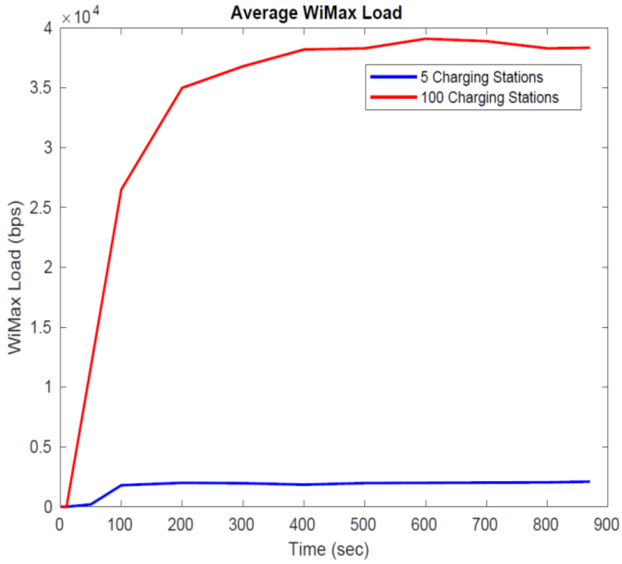

Fig.12: Wimax load (bps)

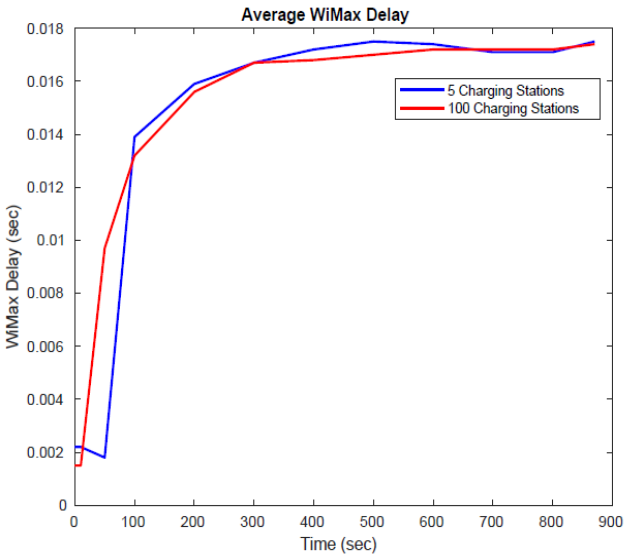

Fig.11: Wimax Delay (sec)

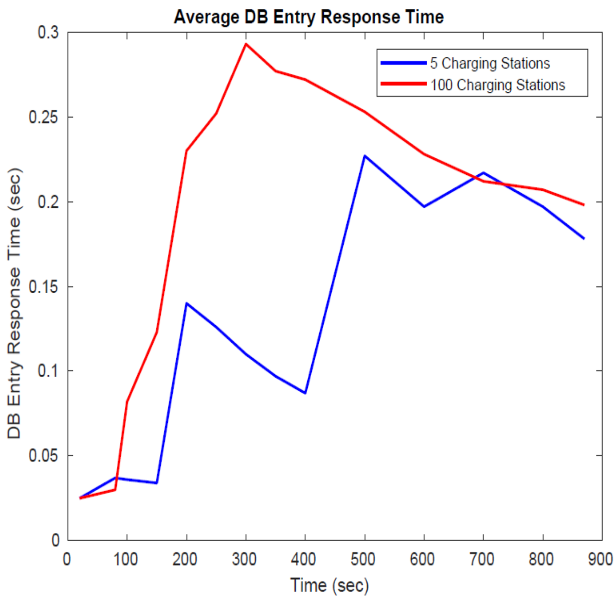

Fig.13: Database Entry Response Time (sec)

5. Conclusions

This paper examines different issues, aiming to broaden the knowledge in the telecommunications networking technologies in electric vehicle transmission data. Three different types of networks protocols were simulated, during which data transmitted in real time between charging stations and the database of the installed network in the Municipality of Zografou, Attica. The entirety of the simulations were performed using Riverbed Modeler and Matlab programs, while parameters comparison, such as the delay and the volume of information transmitted per second, were tested. The results are very encouraging for WiMAX technology, which is constantly gaining the trust of engineers through its performances. Considering that currently WiGRID [19] technology is also available, a further improvement of the performance of this protocol is expected in the electric vehicle charging applications. Furthermore, the easy scalability of existing infrastructure and low-cost installation of new ones, are yet more advantages of WiMAX protocol.

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