

Viability of WiMax for Smart Grid Distribution Network

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Abstract

Smart Grids require a robust communication network to handle huge amount of data involving different smart devices. Wireless applications become the core of advance meter communication systems. The current advances within this area infer that this type of systems will fulfill the Smart Grid requirements for applications such as Advance Metering Infrastructure, Distribution automation or Demand Response. The objective of this paper is to provide a methodology to characterize and to measure the link quality of a wireless communication system applied to different Smart Grid scenarios.

Index Terms—Smart Grid, WiMax, WAMI.

I. INTRODUCTION

NOWADAYS, the electricity industry is facing several challenges. First it is a significant concern regarding climate changes and a strong effort needs to be done in order to slow down the advance of global climate changes. In addition to this, electric power infrastructure is reaching the limits increasing the network congestion. Furthermore, the electricity demand is continuously growing making the current scenario even worst [1].

A new concept in the area of electric power system known as *Smart Grid* (SG) is becoming very popular which attempts to address these challenges by delivering electricity in a more reliable, efficient and responsible way [2].

This new concept forces the electricity industry to change from centralized, producer-controlled network to one less centralized and more consumer-oriented, in such a way that it is beneficial for both consumers and the grid. It can reduce the need for additional infrastructure while keeping electricity reliable and affordable. In addition, it provides new technology and motivating mechanisms such as real time pricing. Thus, this concept generates important challenges for researchers.

Creating a platform for the SG requires incorporating several critical technologies such as communication, sensing and measurement devices, advance components, new control methods and improving interfaces and decision support tools. All these technologies need to be studied and readapted to this new scenario, that is the main reason why researchers are making an effort to improve and adapt them to the SG area.

Specifically, in the area of communication, researchers suggest several alternatives for communication protocols, physical layers and communication systems that can be used in different scenarios. The SG vision of the electrical system, remarks the importance and benefits of communications to provide information from/to different system locations [3].

In addition, international institutions have been working to establish the needed requirements within this field [4, 5, 6]. Using these specifications as a starting point, different authors have been identified the associated problems and suggested different solutions.

Reference [7] presents alternatives of future researches in the area of SG. Parikh et.al. [8] propose a wireless sensor network for distribution automation, Aravinthan et. al. [9] suggest the utilization of a three layer

wireless communication system and discuss its advantages based on different performance indexes. Gungor et. al. [10] implement a wireless system for a 500 kv substation based on the standard IEEE 802.15 and highlight the potential application of a WSN in SG. Lavery et. al. [11] review different communication system alternatives for distribution networks and compare the features from the different alternatives such as WiMAX, ADSL, 3G and GPRS. De Bruyne [12] provides a measurement and evaluation methodology to analyze the performance of a WiMax system in suburban environments. Different possibilities of communication modules applied to SG are described in [13].

Taking into consideration these previous researches, the aim of this paper is to provide a methodology to characterize and to measure the link quality of WAMI (Wireless Automatic Meter Infrastructure) devices based on WiMAX communication technology. The proposed model and the associated measurement results may become a helpful tool for WiMAX network providers for SG systems, to warranty a requested link quality.

II. TELECOMMUNICATION REQUIREMENTS

Although the International Telecommunication Union (ITU) establishes the standards and regulations related to design and Quality of Service (QoS) used for communication systems, these requirements need to be reviewed and adapted for SG applications. In order to evaluate the performance of a communications system used in SG area, four fundamental measurement requirements can be used as a reference to evaluate wireless communication infrastructure; the network throughput, the communication latency, the geographic coverage area and the traffic profile.

The throughput defines the average rate of successful message delivered over a communication channel from one point to another in bps (bit per second). In wireless systems, the throughput can be defined as the effective information that can be sent or received through a communication channel in the system. In a SG environment, there are different requirements depending on the devices used. For example, for a WAMR system, each Smart Meter will require a minimum rate of 8 Kbps [3].

The communication latency is the measurement index of the time delay that the information experiences from the source to the sink. The latency value for current applications in distribution systems is critical because consumers are expected to change the behaviours based on the information, therefore, the latency requirements will increase. In a SG system in the distribution domain the IEEE 1646 standard can be used as a reference to define the latency, similarly, in the consumer domain, the DOE suggestions can be used.

Another very important and complex factor in wireless systems is the coverage area since these systems are highly dependent on the geographic region, (i.e. highly populated suburban area, industrial or rural). The parameter that highly affects the coverage area is the line of sight (LOS) between the meters of consumers and the control node, affecting the design and planning of the coverage cell and reliability link. Finally, a traffic profile (TF) study must be carried out.

The traffic profile for a typical AMI infrastructure comprising multiple Smart Meters (SM) is used to illustrate how to set the minimum requirements. Table I shows the most relevant aspects of this type of infrastructure[14].

TABLE I: Traffic Profile.

| Traffic Description | Size (Byte) | Arrival Interval | Latency | Direction |
|-----------------------|-------------|------------------|-------------|-----------|
| Interval Data Reading | 480 | 288 per day | Best Effort | Up |

| | | | | |
|----------------------------------------------|-------|------------|-------------|---------|
| Notifications | 64 | 26 per day | 5 second | Up |
| SM Disconnect /Reconnect request | 20 | 1 per day | 2 second | Down |
| SM Disconnect /Reconnect request | 500 | 1 per day | 2 second | Up |
| Meter clock synchronization | 64 | 1 per day | 2 second | Up/Down |
| Meter firmware /patch Upgrade | 50000 | 1 per year | Best Effort | Down |
| Meter firmware /patch Upgrade – Confirmation | 20 | 1 per year | Best Effort | Up |

III. COMMUNICATION TECHNOLOGIES APPLIED TO SG

The communication infrastructure used in a SG system can be based on Wired or Wireless Technologies. Wireless communications has some advantages with respect to the Wired technologies, such as the low-cost and the connection of inaccessible areas. However, the nature of wireless channel usually causes significant attenuation. On the other hand, wired solutions are less susceptible to interference and nowadays, they improved their efficiency. Nevertheless, the deployment costs and implementation are comparative worst than the wireless solution.

Within these two groups of technologies, there are different types of communications standards that runs through a network. The first one is normally applied to customer smart meters sensors and appliances to smart meters, these are the Power Line Communication (PLC), ZigBee, 6LoWPAN or Bluetooth. Many researchers propose ZigBee & PLC as the integral solution for Home Area networks (HAN) [20, 21]. For electrical distribution SG, can be mentioned the ADSL (using the phone wire infrastructure), PLC, Fiber Optic lines (FO), and the third and fourth generation of mobile communications (known as 3G and 4G networks) or WiFi standards.

To select the best solution, during the process of deploying a smart metering infrastructure it is important to consider: the implementation time, the operating costs, the availability of technology, and the deployment scenario (rural / urban or indoor / outdoor, etc.). The choice of technology that qualifies for a particular environment may not be suitable for another environment.

In general, the fourth generation of mobile phone technologies aims to IP convergence, offering high throughputs and low latencies, guaranteeing the best quality service. The most known 4G standards are: WiMAX and LTE (Long Term Evolution).

Although most analysts agree that LTE will prevail over WiMAX in the next few years, however, WiMAX has been adopted by the IEEE as the standard, while the final specification of LTE is not yet available. This is the main reason why this paper focuses on WiMAX solutions.

Table II, summarises the characteristics of the most used technologies in a SG.

TABLE II: Communications technologies used for SG

| Technology | | Frequency [MHz] | Through put | Range | App. |
|------------|----------|----------------------|-------------------|------------|--------------|
| Wired | DSL | ~1 - 6 | 2 - 8 Mbps | 1 - 5 km | AMI, DR |
| | PLC | ~1 - 30 | 2 - 3 Mbps | 1 - 3 km | AMI, DR, HAN |
| | FO | >THz | 1 - 1.3 Gbps | 10 - 20 km | All |
| Wireless | Zigbee | 868, 915 and 2400 | 250 kbps | 30 - 50 m | HAN |
| | GSM | 900-1800 | < 14.4 kbps | 1-10 km | AMI, DR |
| | GPRS | 900-1800 | >170 kbps | 1-10 km | AMI, DR |
| | 3G | 1920-1980; 2110-2170 | 384 kbps - 2 Mbps | 1-10 km | AMI, DR |
| | 4G-LTE | 800, 1800 2600 | >173 Mbps | 1 - 5 km | AMI, DR |
| | 4G WiMAX | 2500, 3500 and 5400 | >70 Mbps | 1 - 5 km | AMI, DR |

IV. VIABILITY OF WIMAX

The communication requirements for the customer domain described in the section II makes most of the available wireless technologies are not appropriate. This is the reason why this paper focuses on the application of WiMAX (Worldwide Interoperability for Microwave Access), which is a new and relevant technology used in telecommunication areas. WiMAX is a wireless broadband technology based on the standard IEEE 802.16 (2004, 2005 and 2009) [16].

This standard is conceived as a metropolitan area network protocol (MAN) which defines the physical communication layer (PHY) and centers the study in the specification of the medium access control (MAC) layer. This layer provides and warranties different quality of service (QoS) depending on the service offered

to the end users. The specifications are valid for speeds up to 70 Mbps and cover areas up to 48 Km [8].

One of the most important characteristics of the WiMax is the adaptive modulation and coding scheme which allows the system to adjust signal modulation or coding depending on the Signal to Noise ratio (SNR) condition of the ratio link, if the SNR increases, then the modulation increases accordingly, allowing bigger capacity of information transportation [9]. Advantages of the WiMax technology are:

- Bigger band width.
- Protocol independency. (IP, Ethernet, ATM)
- Different services such as VoIP, data or video.
- Smart antenna support.
- Authentication and data encryption using 3DES and RSA algorithms.

These technologies have been studied, however its applicability to a customer domain within a SG system has been suggested and theoretical studied but has not yet been extensively tested either using simulations or practical scenarios.

V. WiGRID: SIMULATION SCENARIO

Although the IEEE 802.16 standard provides the air interface for WiMAX, it does not define the full end-to-end WiMAX network. This is the main reason why the model presented in this paper is based on the model proposed by WiMAX Forum's Network Working Group (NWG) which is used as a reference for WiMAX deployments and to ensure interoperability among various devices and operators.

The architecture proposed is shown in Figure 2, it has three sectors with a coverage area of 120 degree, 7 km of coverage ratio, 90% cell coverage with a reliability factor of 99.9% at each covered location and a vertical polarization, assuming 50 simultaneous users per channel. A Fixed Wireless Access Infrastructure (FWA) with star topology is selected; to emulate the smart meters, this configuration has subscribed stations (SS) and one base station (BS) that collects and controls all communications. The heights of the BS and SSs are 30 m and 6 m, respectively, and each SS uses a directional antenna (beam width = 30°) [8].

For the Air-interface profile, the "Wireless MAN-HUMAN" with Orthogonal Frequency Division Multiplexing (OFDM) and Adaptive Modulation Scheme Coding (AMSC) is selected. The duplexation for the uplink (from SS to BS) and the downlink (from BS to SS) is performed in time (TDD) using free frequency bands in 5.8 GHz. Different QoS and transmission speeds are simulated based on the SNR. The customers access to the system is based on TDMA. The time frame is select between 10 ms and 20 ms (50% used for the up-link and 50% used for the downlink). Finally, there are 4 different modulations scheme (BPSK, QPSK, 16QAM and 64QAM), with 2 different rate for the convolutional coding (1/2 or 3/4).

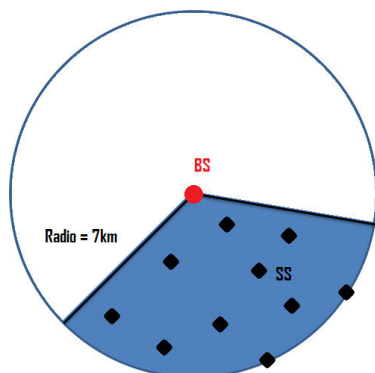


Fig 2: WiMax architecture.

Unlike 802.11a/b/g technologies, 802.16 support a very precise control over provisioning of network traffic flows that guaranteed a specific QoS. The allocation of transmission opportunities for both downlink and uplink traffic flows is invested in the base station. The standard distinguishes four different scheduling types of traffic flows:

- Unsolicited grant service (UGS); it is primarily intended for Constant-Bit-Rate (CBR) services, which means that achieving low latency and low jitter is very important. At the same time, low percentage of packet drops is possible.
- Real-time polling service (RTPS); which is designed to support real-time service flows that generate variable size data packets on a periodic basis (like video streaming).
- Non real-time polling service (nRTPS); it is intended to support non-real-time service flows that require variable size data packets, and a minimum data rate, such as FTP or HTTP protocol.
- Best effort (BE) service is designed to support data streams that do not require minimum guaranteed rate, and could be handled on best available basis. In this paper, BE service is assumed.

Next section provides an explanation of the proposed measurement procedure.

VI. MEASUREMENT METHODOLOGY

Based on the telecommunication requirements set in Section II, different simulation studies are performed. Four different analyses are carried out: link level simulation, resource allocation, capacity estimation and latency analysis.

A. Link-Level Simulations

First, link level simulations are implemented to model the behaviour of a single link over short time scales. It involves the modelling of the PHY and MAC layers, and the main objective of these models is to determine the response of the single link under different radio conditions.

For link-level simulations applied to SG networks, one of the most important issues is to model the multipath channel due to different scenarios in suburban environments. The Stanford University Interim (SUI) proposed six different models for wireless channels, and they are also the ones suggested by the WiMAX Forum [17]. For the simulation carried out in this paper, the channel between each pair (BS and SS) is modeled using the SUI-3 model, since it considers suburban scenarios with a relatively small line of sight.

The simulations are implemented using Matlab ®. Figures 3-6 show the simulation results; they show the evolution of the bit error rate (BER) as a function of the signal to noise ratio (SNR) using different type of modulation schemes. The simulation results are compared to the theoretical results which are used as a reference. Two different coding rates have been used in the simulation; 1/2 and 3/4. The model presented in this paper is based on the model described in [18].

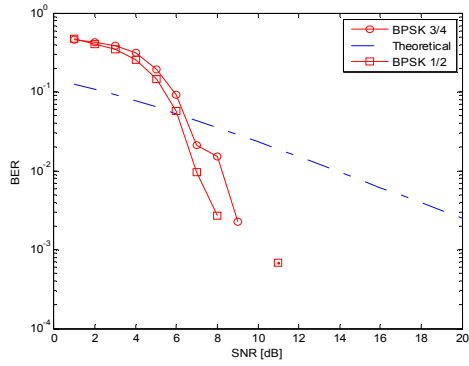


Fig.3: BER comparison, BPSK modulation scheme.

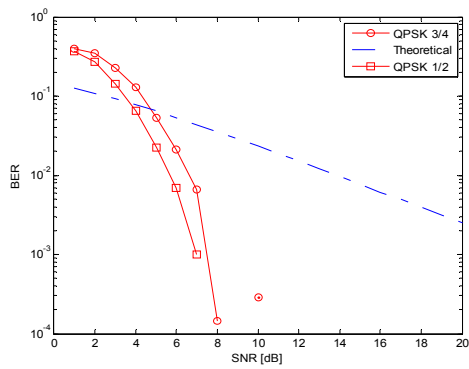


Fig 4: BER comparison using different encodings (QPSK).

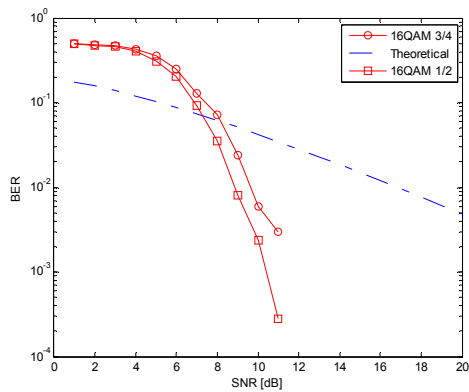


Fig. 5: BER comparison, 16QAM modulation scheme.

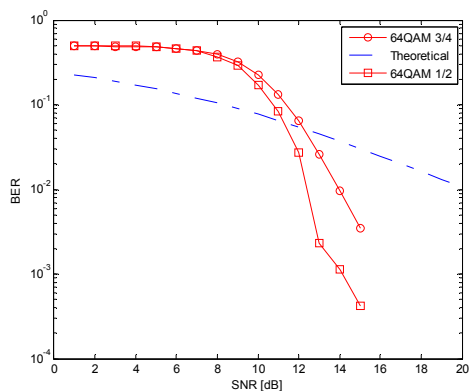


Fig. 6: BER comparison, 64QAM modulation scheme.

From these results, it can be inferred that for a BER = 10⁻³, there is a SNR reduction by changing the coding rate from 3/4 to 1/2. This reduction allows relaxing the communication SNR requirements (improving coverage) at the expense of reducing the throughput of the communication.

Another relevant quality measure for a WiMAX communications in a WAMI is the block error rate (BLER) that refers to the probability that at least one bit is in error in a block of L bits. Mathematically it is defined as follows:

$$BLER = 1 - (1 - BER)^L \quad (1)$$

Where L is the block length (64 bits in the analyzed cases) and the minimum BER is set to 10⁻³.

The spectral-efficiency curves can be used to evaluate the performance of a WiMAX link with respect to the Shannon capacity (SH) and to determine the link adaptation threshold for the AMSC. Mathematically the normalized SH can be expressed as follows:

$$SH_N = \log_2 (1 + SNR) \quad (2)$$

On the basis of the simulation results (Fig. 3-6), the normalized spectral- efficiency (SEF) is calculated as:

$$SEF = (1 - BLER) * r * \log_2(M) \quad (3)$$

Where M is the modulation index (2 for BPSK, 4 for QPSK, 16 or 64 for QAM) and r is the coding rate (1/2 or 3/4).

Figures 7 and 8 show the spectral efficiencies for each modulation and coding rate. The Shannon capacity curve is used as a reference, since this is the theoretical limit, and closer results to this curve means better efficiency. Tables IV and V resume the SNR and spectral efficiency needed for each type of modulation and for both coding rates in order to have the system working at its maximum efficiency. It can be inferred from the results that using the coding rate of 3/4 is more efficient. Results for BPSK are not shown in the tables since they present a very low efficiency, nevertheless it is important to remark that even though this modulation is robust and immune to channel noise is for this reason used to tune both the system synchronization and channel estimation.

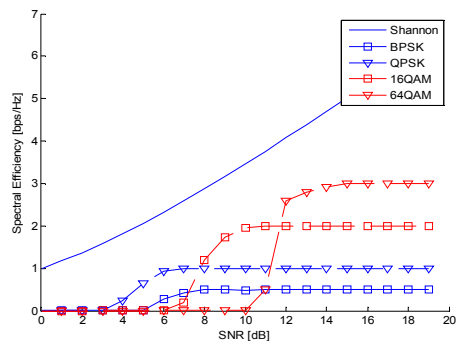
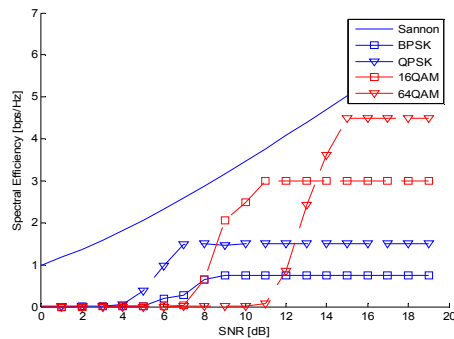


Fig. 7: Spectral efficiency, r=1/2.

TABLE IV: SNR and Spectral Efficiency with $r=1/2$

| Modulation | SNR [dB] | Eficiencia [bps/Hz] |
|------------|----------|---------------------|
| QPSK | 7 | 1 |
| 16QAM | 11 | 2 |
| 64QAM | 15 | 3 |

Fig. 8: Spectral efficiency, $r = 3/4$.TABLE V: SNR and Spectral Efficiency with $r=3/4$

| Modulation | SNR [dB] | Eficiencia [bps/Hz] |
|------------|----------|---------------------|
| QPSK | 8 | 1.5 |
| 16QAM | 11 | 3 |
| 64QAM | 15 | 4.5 |

These conclusions are used as the starting point for the estimation of the communication capacity which is described in section “C”.

B. Resource allocation

In a WiMAX network, the base station (BS) is responsible to take the majority of the decisions concerning the operation of the system. BS is responsible to establish logical connections with the Subscriber Stations (SSs) and to carry out an efficient resource allocation of spectrum and time use in the frame.

Resource allocation in the IEEE 802.16 network is divided into two different tasks:

- Scheduler (planner): to select the transmission order of traffic packets over the network, based on one or more priority policies. It is the primary responsibility for QoS implementation criteria.
- Mapper: once the instruction to send the packages by the scheduler is done, packets must be mapped in a bi-dimensional array. The dimensions of the matrix are determined by the frequency spectrum availability (sub-channels) and the transmission frame duration. Packets that cannot be mapped are returned to the planner.

For uplink traffic (SSs to BS), the mapping algorithm is defined in the standard. However, in the downlink sense (BS to SSs), mapper is left open to allow manufacturers implementation differentiatio.

Both mapping, Up-Link (UL-MAP) and Down-Link (DL-MAP), are very important for the capacity study presented in the next subsection, it is important to remarl that both mapping govern the media access for multiple users.

C. Capacity Estimation

A typical communication system for a customer domain involves the measurement of voltage and current signals. However, within a SG schema, it is expected that besides these data, additional information will be communicated, for example phase angle, sequence domain signals, or real-time pricing related signals. Moreover, communication protocol information such as node address, data error information, packet and message routing will be needed. These additional data increases the required bit rate. This section presents a detailed analysis of the communication throughput for a WiMax system and discusses the condition where it meets the SG needed requirements.

Considering the OFDM symbol time shown in Figure 9, the number of symbols that can be transmitted in the PHY layer for a given BW is determined.

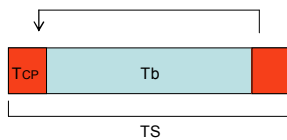


Fig 9: OFDM Symbol Time.

Mathematically, the times described in the figure can be represented as follows:

$$T_b = \frac{1}{n * \frac{BW}{N_{fft}}}$$

$$T_s = T_b + T_{cp} \quad (4)$$

$$T_s = T_b + CP * T_b$$

$$T_s = (1 + CP) * \frac{1}{n * \frac{BW}{N_{fft}}}$$

$$S_{PHY} = \frac{1}{T_s}$$

Where n is the sampling factor, N_{fft} is the total number of sub carriers, T_b is the useful symbol time, T_{cp} is the cyclic prefix duration, CP the cyclic prefix, BW the band width, T_s is the symbol time and S_{phy} the physical throughput.

Using these results, the maximum capacity C_{PHY} can be obtained:

$$C_{PHY} = B * S_{PHY} [bps] \quad (5)$$

Following the IEEE 802.16 standard, for a typical OFDM symbol, the total number of subcarriers is equal to 256 (N_{fft}) where only 192 subcarriers are used for useful data transmission (N_{data}). Table VI describes these parameters for different BW values.

TABLE VI: BW parameters.

| Parameters | Value |
|------------|--------------------------------------|
| NFFT | 256 |
| N used | 200 |
| n | 8/7 if BW is multiple of 1,75MHz |
| | 86/75 if BW is multiple of 1,5MHz |
| | 144/125 if BW is multiple of 1,25MHz |
| | 316/275 if BW is multiple of 2,75MHz |
| | 57/50 if BW is multiple of 2MHz |
| | 8/7 otherwise |
| CP | 1/4, 1/8, 1/16, 1/32 |

For example, for a BW = 10 MHz, n = 144/125, and CP = 0,25 then, $S_{PHY} = 36000$ symbols, the number of bits per symbol (B) that can be communicated in the PHY layer can be calculated as follows:

$$B = N_{data} * BP * CR \quad [bits / symbol] \quad (6)$$

Where BP represents the bits per carrier and CR the coding rates. Table VII gives the bits per symbols that are transmitted in the PHY layer as for different selected Carriers, BP and CR values.

TABLE VII : Bit per symbol transmission.

| Modulation | Bits/Carrier | Coding rate | Bits/Symbol |
|------------|--------------|-------------|-------------|
| BPSK | 1 | 1/2 | 96 |
| QPSK | 2 | 1/2 | 192 |
| QPSK | 2 | 3/4 | 288 |
| 16QAM | 4 | 1/2 | 384 |
| 16QAM | 4 | 3/4 | 576 |
| 64QAM | 6 | 1/2 | 576 |
| 64QAM | 6 | 3/4 | 864 |

Additional times need to be added due to the overhead symbols needed to transmit the information in the MAC layer. These times are related to the header symbols which are function of the number of users and the maximum distance introduced in the MAC layer are calculated. The main headers that need to be considered are; Up-Link header (UL) , Down-Link header (DL), the Frame Control Header (FCH), According to the standard IEEE 802.16, in term of OFDM, UL need two symbols, DL and FHC only one. Moreover, times related to the broadcast messages are also added. The broadcast messages are related to the downlink (DL-

MAP) and uplink (UL-MAP) maps. In this study, the Modulation and Coding scheme (MCS) selected for both the uplink and downlink maps is the modulation known as BPSK $\frac{1}{2}$ since is one of the most robust one. The size of the message can be estimated as follows:

$$MAP = \frac{(x + IE * usr)}{N_b} \quad (7)$$

Where MAP is the message size for DL or UP maps (DL_MAP, UL_MAP), usr is the number of user simultaneously handled in a frame, IE the number of bits needed by the information element (32 and 48 for the DL and UL maps respectively), N_b is the number of bits needed for the OFDM symbol modulation, in this case is 96 since a BPSK scheme is used, and x is the frame overhead (64 and 56 for the DL and UL respectively).

In addition, the step times from source to sink (RTG) and from sink to source (TTG) are added. This time depends on the user distances, and can not be greater than 100µseg:

$$TTG = RTH = \frac{\min\left\{\frac{D_{max}}{3 \times 10^8}, 100 \mu sec\right\}}{T_{sofdm}} \quad (8)$$

Based on these calculation times, the total header time can be obtained for both the down and up links respectively:

$$\begin{aligned} S_{hdl} &= S_{pdl} + S_{fch} + DL_MAP + UL_MAP + TTG \\ S_{hul} &= S_{breq} + S_{RNG} + S_{pul} + nss + RTG \end{aligned} \quad (9)$$

Where S_{pdl} is the preamble needed for channel estimation, SFCH is the symbol reserved for Frame Checking; S_{breq} is the reserve number of symbols for the BW request, S_{RNG} the number of symbols for the initial ranging, S_{pul} number of symbols to identify each user and nss the total number of SSs served in the current frame (active SSs). The total number of symbols in the MAC layer is:

$$S_{hMAC} = S_{hul} + S_{hdl} \quad (10)$$

Finally the throughput can be calculated based on the number of symbols transmitted in the PHY and MAC layers:

$$C_{MAC} = B * \left(\frac{239}{255}\right) * (S_{PHY} - S_{hMAC}) [bps] \quad (11)$$

Where the factor 239/255 is taken from the Reed Solomon Coding Channel (RS-CC).

Throughput is a function of number of user, maximum distance from each SSs to the base, and the additional bits (overhead) needed to built a WiMAX frame. Increasing the number of users, the DL_MAP, the UL_MAP and the broadcast messages increase.

Table VIII shows the calculated throughputs for each modulation scheme with 10 MHz of bandwidth, 50 concurrent users, and frames of 20 ms.

TABLE VIII: Throughputs results.

| Modulation | CR | SNR[dB] | CPHY [Mbps] | CMAC [Mbps] |
|------------|-----|----------|-------------|-------------|
| BPSK | 1/2 | 8 | 3.456 | 2.790 |
| QPSK | 1/2 | 8 | 6.912 | 5.580 |
| QPSK | 3/4 | 7 | 10.368 | 8.370 |
| 16QAM | 1/2 | 11 | 13.824 | 11.171 |
| 16QAM | 3/4 | 11 | 20.736 | 16.741 |
| 64QAM | 3/4 | 15 | 31.104 | 25.112 |

From the results, it can be concluded that there is a significant throughput reduction from PHY layer to MAC layer. In general, if a SNR of at least 15 dB can be guaranteed, the network system can serve up to 50 users simultaneously (usr/sec.) at a speed rate of 502 Kbps, which is over the requirement mentioned in Section II. Considering a pooling to all smart meters, an up-link and down-link rate of 1/2, (502 kbps * 1/2 = 251 kbps for the up-link, 502kbps * 1/2 = 251 kbps for the down-link), and an AMI device as the one illustrated in Table I, the information per smart meter is $480 \times 8 = 3.84$ kbits only to read the meter, then, the rest of the throughput can be used for other applications.

If more restricted requirements are needed, then the criteria mentioned in [19] can be used, where a smart meter generating a packet of 125 bytes per second is chosen. Considering that the pooling time performed by the BS is every 5 minutes (240 second each), then the traffic accumulated by the smart meter is $125 \times 8 \times 240 = 240$ kbps, which is smaller than the established up/downlink traffic flows of 251 kbps. Finally, the total number of meters can be determined: $240 \text{ sec.} \times 50 \text{ (usr/sec)} = 12,000 \text{ (usr)}$ which means that 12,000 meters can be managed for this particular scenario. Next section discusses the communication latency.

D. Latency

In general, the latency is not critical in this type of systems (WAMI), even though the objective of this section is to establish a design criterion in order to minimize the latency and as a consequence, to make the system more efficient. A latency effect due to propagation is assumed negligible.

Due to the nature of this type of systems, the only way to reduce the latency is to employ minimum duration frames. This reduction mechanism has serious implications:

- Throughput decreases if the frame duration reduces.
- Frame duration impacts the user access. For short duration frames, some users may need to wait until next frame to transmit the data, increasing the communication latency.

The minimum round trip time is set as three times the frame time, for the simulations, two time frames are simulated, a short time frame (10 ms) and a long time frame (20ms). The calculations are based on the ones obtained in subsection B. From these results, the short frame has 89 symbols and the large frame 714 (relationship between the total time frame and symbol time). The frame was equally assigned, 50% to the downlink subframe and 50% to the uplink subframe. It is considered that each user transmits more than 2 symbols. The overhead is considered and set a maximum value of 24 symbols $((64 + 70 \times 32)/96)$ for the short time frame, and 50 symbols $(64 + 146 \times 32)/96)$ for the long time frame. To simulate the downlink, a maximum number of users is set as 70 for the short time frame and 146 for the long time frame. The temporal margin is fixed as 340 useg. Figure 10 shows the simulation results for both time frames scenarios.

It can be deduced from the results that the latency increases with the user numbers linearly for the short time frame, although for the large time frame, the latency remains constant up to 150 users. The proposed model is simple and comparable to previous experimental results. Figure 10 illustrates the comparison between two different time frames (10ms and 20 ms).

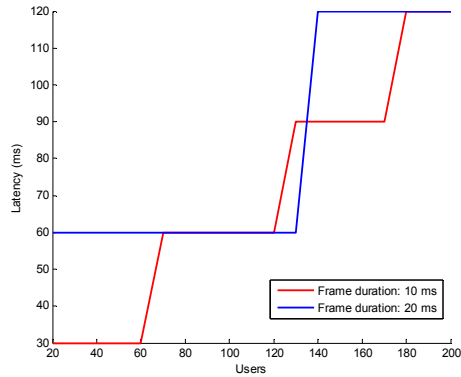


Fig. 10: Latency comparison.

Analyzing the results shown in Figure 10, four different working areas can be identified:

- From 20 to 70 users, the time frame is 10ms.
- From 70 to 140 similar latency is obtained, then, any time frame can be selected, however, it is always better to use large duration time frames.
- From 140 to 146 users, the critical zone, and the large time frame must be used.
- From 140 to 200 users a shorter time frame is recommended.

VII. CONCLUSION

Smart Grids rely on the information and communication technologies to ensure reliability and safety of transmission and distribution networks. WiMAX fulfills the need for a secure wide area broadband communication network used for distribution and substation automation; this is difficult to achieve using other communication networks. WiMAX supports real-time two-way broadband communications between the utility's operations center and the consumer's meter.

This paper proposes a methodology to characterize and measure the link quality in a WAMI (Wireless Automatic Meter Infrastructure) using WiMAX. Results illustrate the potential benefit of various PHY features such as multiantenna techniques, or subchannelization. Specifically, it studies the AMSC that allows WiMAX AMI systems adjust the signal modulation and the coding scheme based on the SNR condition of the radio link that ensure the communication.

Finally, results demonstrate the WiMAX potential to manage 12000 measurement devices per sector, becoming a valid, fast, an economic communication alternative for a new Smart Grid.

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