From Smart Metering to Smart City Infrastructure

Could the AMI Become the Backbone of the Smart City?

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Abstract— **The paper presents a study and preliminary field results concerning the use an Advanced Metering Infrastructure (AMI) based on the standard protocol Wireless Metering Bus (WMBus) mode "N" (169MHz), also for smart city services. The paper shows how such an infrastructure is suitable for metering services, but it has some limitations when dealing with services requiring either more bandwidth or more frequent communication.**

Keywords— metering; MBus; urban infrastructure; short range; 169MHz.

I. INTRODUCTION

Smart City services could drive the boost of Internet of Things (IoT) since over 50% of world population lives in cities (>3.3bn), growing to 70% of total world population by 2050 [1]. On the other hand, governments, through regulation [2], pushes for a new and strong sensitivity to sustainability, will ensure the creation of a mass market of IoT application in the "Green Economy" area. Smart Metering and Smart Grid are often mentioned as some of the applications integrated into the Smart City even if the two big worlds of "Smart City" and "Energy" seem to proceed in parallel without strong degree of synergy among them. Even if a strong effort has been made by EU Government in order to encourage standardization for the IoT [3][4], still plenty of communication technologies are available on the market. The choice of the right wireless technology for a specific application service, is not easy since different constraint such as range, datarate, power, latency and cost should be taken into account and a satisfactory tradeoff shall be identified. If the same technology platform should be used for different application services, the choice becomes even more difficult to take.

The paper presents the attempt to use a standard European wireless protocol (WMBus mode "N" [5]), that has been chosen for a smart gas metering massive roll-out in Italy, for managing other typical services of the smart city framework.

In 2008, the Italian Authority for Gas and Electricity prescribed the use of Smart Meters for the gas distribution network (about 21 million meters) [6]. The roll out plan states that 60% of «consumer» gas meters (about 18 million) shall be replaced by 2018 and 100% of «commercial» and «industrial» gas meters by 2024. General Packet Radio Service (GPRS) solutions for «commercial» and «industrial» gas meters has been proposed and is being deployed on the field, while Point to Multipoint solutions based on a European standard short range protocol (WMBus 169 MHz) will be used for «consumer» gas meters. Since the project implies a huge investment (around 4-5 billion Euros) and some studies [7][8][9] showed how the business case is very uncertain, in 2012 the Authority for Energy recommended [10] gas DSO to evaluate the possibility to extend the usage of the gas smart metering network to other services including other metering applications, such as water metering and other smart city applications.

In Section II of the paper an introduction to the WMBus protocol is given. In section III the analysis and results on the protocol from different perspective are given. In section IV a Case Study where the results of the analysis are applied to a specific case, are shown. In section V conclusions and further steps to be taken are mentioned.

II. WIRELESS MBUS MODE "N"

MBus is a European communication protocol that has been specified for metering applications (the "M" of MBus stands for "metering"). Mode "N" has been specified in order to allow communication at higher range than the typical home area situations; in this case a lower frequency (the 75kHz band between 169.400 and 169.475 MHz has been identified). This frequency band has been reserved by European Telecommunication Standardisation Institute (ETSI) EN 300 220-1 [11] for metering applications allowing a maximum Equivalent Isotropically Radiated Power (EIRP) of 500mW (27dBm) with a maximum duty-cycle of 10%.

The standard is developed within the CEN (the European Committee for Standardization) also in response to the EU mandate 441 [2]; the "N" mode has been proposed by France and Italy since in both countries a wireless network based on 169MHz frequency will be adopted for gas metering. The wireless protocol is narrowband and it uses a Gaussian Frequency Shift Keying (GFSK) modulation at different data-rates according to 6 different channels; those channels are spaced by 12.5 kHz and have a bit-rate either of 4.8 kbps (channels 1a, 1b, 3a, 3b) or of 2.4 kbps (channels 2a, 2b). Mode N2g (different channels grouped together to get a higher data-rate) that uses a 4GFSK modulation, has been reserved for "relaying" type of communication nodes. Different service classes are defined within the standard and in the higher class a minimum level of sensitivity -115dBm shall be guaranteed at a Packet Error Rate (PER) < 10^{-2}. The protocol allows power saving and bidirectional communication, made possible by the implementation of two communication mechanisms: Access Timing and Synchronous Transmission. At application level, it is possible to use specific data objects but also tunneling of Device Language Specification (DLMS/COSEM) data objects.

III. ANALYSIS OF A MULTISERVICE NETWORK BASED ON WIRELESS MBUS MODE “N”

The analysis has been made breaking down the problem into many independent sub-problems, which are easier to deal with; for each of the analyzed aspects, a simulation model was created, to provide preliminary and qualitative estimations of the performances achievable by the system (traditional and detailed network simulators such as Network Simulator (NS-2) were not used because of the poor maturity of the WMBus mode “N” specifications at the time the analysis was done). Each model was then merged into a simplified network-like simulator, that through a set of parameters, can be adapted to represent a replica of a real scenario. Feedbacks given by this tool may be useful to evaluate the feasibility of new projects.

A. *Channelisation aspects*

Since WMBus is a narrowband protocol (75kHz in total, 12.5kHz each channel), it is likely that more channels will be used in parallel to increase the amount of data that can be transmitted in particular in a multiservice perspective; WMBus is a Frequency Division Multiplexing (FDM) [5] protocol and hence is affected by Adjacent Channel Interference (ACI). A Simulink model was created to assess the theoretical impact of ACI on the transmission; the effect was obtained introducing an interfere source and increasing the power of this interferer until a significant degradation on the channel adjacent to the interferer one, can be detected. In Fig. 1, the Bit Error Rate *(*BER) for different channels, at different interferer power is shown. The influence of the interferer depends on the used modulation and the 4.8kbps channels seems to be the most sensitive.

In order to confirm the results of the analysis, some measurements were made using commercial transceivers implementing WMBus 169MHz; on average, the noise generated by an undesired GFSK 2.4 kbps signal source on the adjacent channel is 64 dB lower with respect to the power generated on the central frequency of the true transmitting channel. There is a 20dB difference when compared to the theoretical analysis; the difference is caused by the filters used in the commercial transceivers that mitigate the effect of ACI.

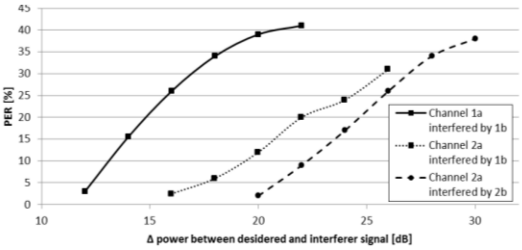

Fig. 1. Simulink ACI analysis.

ACI interference, when continuous, can be compared to a noise floor that limits the sensitivity of the devices; in order to understand what is the minimum power level of the desired signal to obtain a good transmission quality, some additional measures were made. The results showed how the desired signal should have a strength of at least 5-6 dB more than the noise floor caused by the interferer. In summary, to obtain a satisfactory communication when different systems are transmitting in uncoordinated way on different channels, it is important that at the receiver, the difference between the received signal on the serving channel and the one received on an adjacent one is less than ~58 dB.

B. *Energy Consumption*

Energy saving is certainly among the primary objectives in the design of a metering network, since meters are usually not powered by the electricity grid. Therefore, in order to enable remote reading functionalities, it is necessary to install batteries in such devices. With the purpose of minimizing as much as possible the maintaining costs, WMBus has been designed to achieve high energy efficiency. The calculation of the power absorbed by a meter, is a prerequisite to estimate the battery lifespan. Many variables have to be considered in such a computation, coming both from the devices and battery physical characteristics. Considering the usage of real apparatus (already available in the market), some assumptions have to be taken. Let us suppose to equip meters with 19Ah batteries: we must also consider battery self discharge, that leads to decrease its nominal capacity year after year. Consumptions related to metrological functionalities in a meter is normally the smaller part and it depends on the hardware design of the meter; assuming an additional consumption equal to 5 uA (this hypothesis was shared with some meter manufacturers) and degradation equal to 5%/year, it is possible to obtain the graph presented in Fig. 2, which shows battery lifespan as a function of synchronous transmission frequency. Two different Tx-Rx boards differing only for different maximum output power (64mA @ 14 dBm for Device1 and 320mA @ 27 dBm for Device2) are also compared.

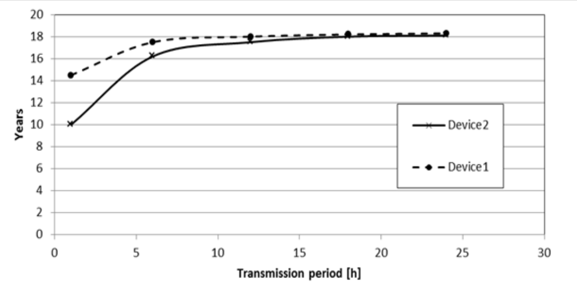

Fig. 2. Meter battery life estimation.

Under the above assumptions, it was possible to estimate that a meter life span could be around 18 years, when the period between subsequent transmissions is 24h. This result is aligned with an assessments made on real devices in [12]. On the other side, comparing the two boards, it can be observed that differences in battery life tend to converge for increasing transmission periods. This kind of behaviour happens because when data sending events are very distant from each other, the only relevant factors that would affect battery duration, are metrological consumptions and capacity degradation.

C. *Radio coverage*

One of the main advantages of the WMBus mode N protocol is the use of a low transmission frequency, which should make it possible to achieve greater Line of Sight (LOS) distances and less sensitivity to attenuation due to obstacles. In a typical scenario, gas meters are installed in concrete niches protected by metal cabinets. The goal is to define some objective parameters that allow to perform, with good approximation, some large scale estimations taking into account those challenging radio propagation aspects.

Although the majority of the meters are placed at ground level, in some cases, devices such as water meters, are located in the basement.

In case of a multiservice network, one data concentrator should be deployed to serve not only gas meters, but different services with their own radio propagation specific issues. In such a case, the radio coverage assured by the data concentrator (i.e., the maximum communication range) should be studied according to the most critical path that could be present between the concentrator and the meters. Some laboratory tests have been conducted in order to estimate the loss due to such obstacles in the LOS.

It has to be noticed that the objective of this analysis, was not to define a new propagation model, but to have a flavor of the performance of this protocol, by tuning available propagation models with some experimental result, since most of the pre-existing models do not fit properly with this context either for the positioning of the "mobile station" or for the adopted bandwidth.

The analysis has taken into account two different positions of the data concentrator, at street level (2m -microcellular) and at mobile station position (30m -macrocellular). Some preliminary and not massive on-field radio coverage test has been conducted, using the two boards already mentioned above (Device1 and Device2). Results coming from experimental test have been compared to some of the already available mathematical models, such as Okumura [13] and Hata [14] (only applicable when transmitting data from an height higher than 30 m).

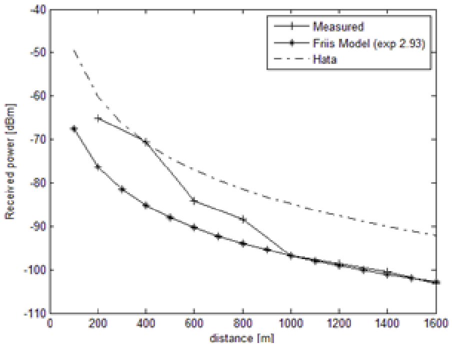

Fig. 3. Measured vs Predicted received power as function of distance in suburban area when Concentrator is installed on a tower

In Fig. 3, it can be noted that Hata does not predict, with an acceptable approximation, the measured radio field, in particular at growing distances. On the other side, Friis model [15], with a modified exponent, seems to model more effectively the real behaviour of the signal. In particular, a value of 3.2 for the exponent, seems to work properly for a *Micro Cellular* positioning of the concentrator in a *Urban* environment and a value of 2.9 for a *Suburban* environment; in case of *Macro Cellular* positioning of the concentrator, the value of the exponent in the Friis formulation to be considered for a *Suburban* environment is 3.0. The analysis was made on data coming from test campaigns on a limited number of sites (no enough data points were collected to tune the exponent in case of *Macro Cellular* in *Urban* Environment), hence further massive test campaigns should be made to validate these preliminary results.

D. Network capacity

Aspects, such as maximum number of users and coexistence between different services, are way more important than data throughput or delays, when analyzing metering networks performance. Given the lack of media access control methods in WMBus, the standard just allows to prevent systematic collision through a cyclic access number that, randomly initialized on each device, allows to slightly vary the time between two subsequent transmissions.

In the most typical scenario, meters have transmission period scattered throughout the day; by approximation, this phenomenon can be seen as a random variable uniformly distributed over 24 hours. A simple Matlab model has been built, capable of simulating the periodic data transmission coming from a set of meters. Communication takes place according to the following rules: first transmission of each meter is made at random time within the day, the next, with periodicity T, are determined using the de-synchronization system implemented by the standard. Sometimes, due to maintenance or control reasons, concentrator may need to transmit some information to meters, in this case a bidirectional exchange of data may occurs. The abbreviation CMD in the graph of Fig. 4 represents the probability that each day, a data exchange between the concentrator and the meter occurs (the hypothesis is that a sequence of 12 message are exchanged, 6 from the meter to the concentrator and 6 is in the reverse path) . For sake of simplicity, collisions do not require retransmissions.

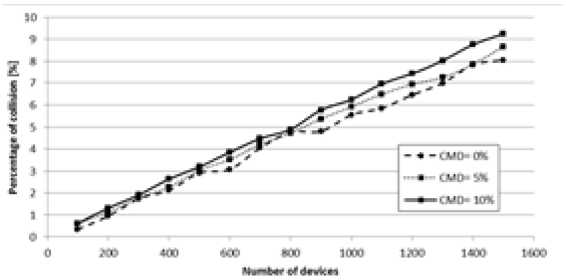

Fig. 4. Percentage of collision in a WMBus network composed by gas (49%), water (23%), heat (7%) and monitoring (21%) meters

Under the above listed hypothesis, the main aspect that influences collision probability is the number of meter in the coverage area of each concentrator. For example, if the maximum acceptable probability error is 5%, no more than 800 devices should be active in the same collision domain. CMD parameter has just a little impact on performance, since collisions are mostly related to the presence of many synchronous messages (due to lack of media access methods).

IV. A CASE STUDY

In order to evaluate how the different network aspects influence each other and to understand what are the network performances of this communication protocol in a multiservice scenario, a model simulating a real network deployment has been created. The model allows the user to configure a set of parameters for each of the drivers that influence the network performances, such as range (e.g., Rx and Tx power and related antenna gains, positioning of the data concentrator, attenuation of obstacles), energy consumption (e.g., type of battery, self-discharging factor, non tx consumptions) and network capacity (e.g., length of data packets, duty cycle, bit-rate, etc.). The parameters can be set and customized for each of the services to be delivered. Due to those different characteristics of each service, the model estimates different “cell” size, according to each service; but when the number of total data concentrator to be deployed for a multiservice network is calculated, the range of the most “difficult” (in terms of radio propagation) service and hence the shortest, is used. On the basis of this range all the other parameters (e.g., collision probability, battery duration, etc.) are estimated.

As an example, in the following list, the results of simulation of a multiservice network (gas, water, heat cost allocators and pollution monitoring) for a small city is shown; the hypothesis is that all the meters are distributed in the city in a uniform way; each of the service have been characterized in terms of propagation aspects, battery and network capacity and in order to reduce the collision probability, 2 different channels have been used. Here the simulation results are presented:

- **Area to be covered:** 20.5 Km^2
- **Data Concentrator (DC) range**: 450m
- **Coverage area of each data concentrator:** 0..64 Km^2
- **Collision Domain**: Ch 2a: 1.20Km^2, Ch 2b: 3.05Km^2
- **# of DC to be deployed**: 32
- **# of meters under each DC**: Ch 2a: 254, Ch 2b: 2983
- **Collision Probability**: Ch 2a: 2.9%, Ch 2b: 7%
- **Battery Duration (years):** Gas: 16 ,Water: 17, Heat: 6, Monitoring: 5

In the case of multiservice, the estimated number of data concentrator is bigger than in the case of gas only network, because heat cost allocator and water meters are even harder than gas to be reached by the radio signal. The probability of transmission errors is critical (up to 7%) even in the case of usage of two different channels. The first outcome of this simulation is that, in order to implement this scenario, either not all the 4 services should use the same network infrastructure, or a more efficient mechanism should be foreseen at physical and MAC layer of the protocol to manage access to the channel and to manage flexible allocation of channels and different data rates.

V. CONCLUSION AND FUTURE WORK

Wireless MBus mode «N» (169MHz) seems to guarantee adequate performance in terms of range when applied to a single metering service with low data rate requirements (e.g., gas, water). The usage of the same communication infrastructure, for additional services, is sustainable only if the additional service does not require high data-rates, if the number of additional sensors is not too big and the sensors do not communicate too frequently. When the number of sensors in the area of the same data concentrator increases from hundreds to thousands, the reliability of the communication decays rapidly. A more flexible management of the physical layer (e.g. carrier sense multiple access with collision avoidance and dynamic management of multiple channels) could limit transmission errors, due to the narrow band of the protocol, only very limited data rate services could co-exist in this network (in this perspective, in recent draft updates of the Italian gas metering standard companion for WMBus, LBT was introduced). In order to guarantee a minimal level of synergy among different services network without limiting too much the range of managed services, a multimode mode network (double frequency band e.g., data concentrators with 868MHz and 169MHz radio) [16] might be a more reasonable tradeoff. Further analysis and test should be done in order to confirm the preliminary results of the study and to evaluate if a scenario where the IoT communication platform can be based on clusters of technologies also exploiting different bandwidths. Those further investigation should also evaluate which bandwidths are the most appropriate for the different kind of services; each cluster of technologies could be based on a specific communication protocol and can provide a set of services (e.g., a cluster based on WMBus 169MHz could enable gas and water metering, insuring longer distance coverage, another cluster based on either 868MHz or 2,4GHz protocols such as ZigBee could enable services that requires more frequent communications, such as parking services) . The different clusters then, could share part of the communication infrastructure in order to reduce costs and to harmonize at least at management level, through a set of standard Application Programming Interface (API), the access to those network clusters.

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