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Link Quality Estimation for AMI

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***Abstract*—An important application in Smart Grids is the Advanced Metering Infrastructure (AMI). Under AMI, utilities use smart meters and aggregators to collect consumer data that support better-informed and automated decisions. AMIs are typically formed by wireless links, reducing the investments in infrastructure. Although beneficial, the use of wireless raise issues of reliability and coverage, and requires the estimation of the success rate in delivering packages. This paper discusses the application of the Extended Hata-SRD propagation model in urban, suburban and rural scenarios, for IEEE's 802.11g and 802.15.4, to determine the success rate of packets exchanged between meters and aggregators.**

I. Introduction

Smart grids [1] are the evolution of the conventional electrical distribution networks, providing a two-way communication between energy consumers and distributors. Smart Grids technology provides data communication between users and distributors in order to identify problems or new demands, giving feedback to the energy suppliers and distribution chain. However, such communication demands the installation of smart meters at the subscribers' residences and aggregators (DAPs – Data Aggregation Points) in the neighborhood. To reduce costs associated with a wired infrastructure, smart meters use low-cost wireless interfaces to communicate with aggregators, thus forming an Advanced Metering Infrastructure (AMI) [2]. Figure 1 depicts a generic example of an AMI. The meters in each house, represented by black circles, connect to an aggregator, which transmits the data generated by these meters to the power distribution company using a long-range technology. The aggregators, represented by triangles, may be installed on poles, as shown.

In an AMI, each residence is equipped with a smart meter responsible for storing information about the electrical consumption. Data collected by these meters are periodically transmitted to one or more DAPs, through short-range wireless links. DAPs transmit the data collected from the neighborhood to the power distribution company through long-range communication technologies. There is no consensus on which technology should be used for communication between meter and aggregators or between aggregators and the utility company. For the first, standards such as IEEE 802.15.4 and IEEE 802.11g have been considered. For the second, longer-range technologies such as GPRS, 3G, LTE or the IEEE 802.16 are possible choices.

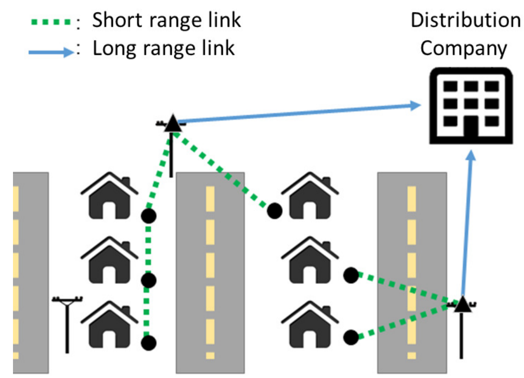

Figure 1. AMI generic example.

This paper focuses on the short-range communication between meters and aggregators and in the selection of an adequate propagation model to use in link budgets calculations. Such model must consider the short distances involved as well as the fact that antennas are placed only a few meters above the ground. The presented analysis is centered on the reliability of the communication using simulated results for each of the three types of scenarios: urban, suburban and rural, as recommended by the ITU-R SM [3].

The rest of this paper is organized as follows. Section II further details our motivation. Section III explains how to calculate the Packet Success Rate (PSR) and presents the estimated communication range for each scenario and technology. In Section IV our conclusions are presented.

II. Motivation

Planning the positions of DAPs is a non-trivial task. The manual analysis of the best positions to install aggregators is complex, costly and may be impractical in regions with high density of residences or buildings. In an office building, for example, tens or hundreds of meters may be installed close to each other, which may be a challenging setup, due to interference and collisions.

An AMI planner tool, such as the one proposed under the Tele-SIRIS project [4], allows the user to select the transmission technology, scenario, transmission power and other metrics. The user may choose between a point-to-multipoint network and a mesh network. The tool is capable of facilitating the user's planning decisions, ensuring planning scalability and speeding up the DAP deployment process.

A central metric to evaluate the placement of DAPs is the Packet Success Rate (PSR). We calculate the PSR as a function of the path loss, the SNR (Signal to Noise Ratio) and the modulation technique, which depends on the used data rate. The motivation of this paper is to show how different scenarios can affect the PSR, compare IEEE 802.15.4 to IEEE 802.11g and provide estimations on the practical expected range of the communication between nodes.

III. PSR ESTIMATION

In order to calculate a link budget, several variables must be taken into account. Transmission power, antenna gains and receiver sensitivity, for example, are obtained from manufacturers' data sheet and are mostly fixed in value. However, a propagation model must also be selected, and this may be a non-trivial task. There is a multitude of propagation models, more or less applicable to AMIs. One important goal of the Tele-Siris project was to select a propagation model that is applicable to the frequencies, range and power expected from smart meters and aggregators. This model must also distinguish the interference experienced under dense urban scenarios and sparse rural scenarios.

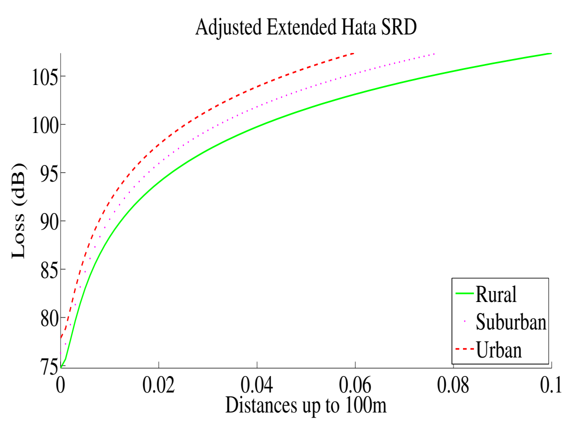

Figure 2. Path loss in three scenarios.

To select a proper propagation model, several options were studied, as Okumura-Hata [5], [6], Hata COST 231[7], the Walfisch-Ikegami [8] and Extended Hata-SRD [9]. The first two models are applicable only at distances that exceed 1 km. The third model requires many parameters, which are difficult to obtain in practice, such as the average width of streets, separation of buildings, etc. The Extended Hata-SRD model was selected because it is suitable for long distances and short-range devices (up to 100 m). Additionally, the Extended Hata-SRD may be parameterized to outdoor only and indoor-outdoor communications.

In Figure 2, we can see the path loss for the urban, suburban and rural scenarios for 2.4 GHz, using an adjusted Extended Hata-SRD model. The use of the term "adjusted" will be better explained later in this Section.

As AMI must provide a reliable service, it is important to define a metric to evaluate the quality between two nodes for each scenario studied in this paper. The selected metric is the Packet Success Rate (PSR), which is the complement of the Packet Error Rate (PER).

One intermediary step in the estimation of the PSR is the estimation of the Bit Error Rate (BER). The BER is a function of several input variables.

$$BER = f(env, tech, power, h_1, h_2, d) \qquad (1)$$

In equation 1, *env* captures the average noise power and the expected attenuation for each scenario, *tech* are the parameters for specific transmission technology, such as the modulation and data rates, *power* represents different transmitting power, h_1 and h_2 are the antennas heights, and the d is the distance between communicating devices.

Algorithm 1 BER Calculation

procedure GET_BER(*env, tech, distance*)
    loss ← getExtendHataSRDadj(*env, tech, distance*)
    $RxPower \leftarrow TxPower - loss$
    $SNR \leftarrow RxPower - getNoise(env)$
    $\gamma_b \leftarrow SNR\ / spectral\_efficiency$
    $BER \leftarrow \alpha Q(\sqrt{\gamma_b})$
    return BER

Algorithm 1 summarizes how the BER is calculated. The variable *loss* is calculated from the adjusted curves depicted in Figure 2 given the scenario and distance. *RxPower* is the power at the receiver, calculated subtracting *loss* from the power of the transmitter. *SNR* (Signal to Noise Ratio) is obtained by subtracting the scenario noise from the power at the receiver (*RxPower*). It is important to notice that this noise varies according to the scenario. Urban scenarios, for example, have a higher value of noise due to its higher concentration of electronic devices. The SNR per bit (γ_b) is calculated by normalizing the *SNR* by the spectral efficiency. The spectral efficiency is described as the amount of useful information that can be transmitted over a given bandwidth during a period of time. Finally, BER is calculated from a Q function, which is defined as the probability that a Standard normal variable (a Gaussian variable with mean 0 and variance 1) is bigger than $\sqrt{\gamma_b}$. The value of α depends on the modulation. For the IEEE 802.11g base rate (6Mbps) the modulation technique is BPSK and α is set to 0.5.

Given the small typical volume of information to be exchanged between aggregators and meters, and to avoid any potential interference, higher rates are not demanded, so the base rates in IEEE 802.11g will be assumed, which tends to increase the chances of success decoding.

After obtaining the BER, we proceed by calculating the Packet Error Rate, as in equation 2, where n is the packet size in bits. The value is powered by n because for a packet to be considered in error it is enough that a single bit is inverted. Therefore, PER, in 3, represents the probability that all n bits are correct.

$$PER = (1 - BER)^n \tag{2}$$

$$PSR = 1 - PER \tag{3}$$

The method for calculating the PSR described in this paper is presented in [4], and uses real coordinates obtained from CELESC (Centrais Elétricas de Santa Catarina).

The results are shown for IEEE 802.11g, and IEEE 802.15.4 (ZigBee). Transmitter power is equals to 20 dBm for IEEE 802.11g and 0 dBm for IEEE 802.15.4, which are typical transmission power values for commercial devices. In both cases, packets of 1500 bytes were assumed. As it is in general impractical to incorporate all features of a real deployment in the simulation, a conservative approach is recommended. That means providing enough fade margin to accommodate for more challenging environments without being too pessimistic (as that would result in using of more DAPs than necessary). This was achieved by adjusting the curves in Figure 3 to add extra dBs in the path loss. Furthermore, recent field tests using IEEE 802.15.4 devices show that wireless links, specifically in smart grids, present high PER and varying link capacity because of numerous interference sources, noise, dynamic topology changes, fading, and obstructions [10]. Therefore, the adjustment to the basic Hata Extended-SRD formula [9] were performed, (so that the model properly suite to our needs). The final obtained PSR for each scenario is presented in Figure 3.

In Figures 3a, 3b and 3c the PSR for IEEE 802.15.4 is presented in three scenarios using power transmission of 0 dBm, antennas placed at 3 m (smart meter) and 5 m (DAP) and data rate of 250 kbps. Figures 3d, 3e and 3f shows the PSR for IEEE 802.11g for the same scenarios, with 20 dBm of power and the base rate of 6 Mbps. In these Figures one clearly sees how the PSR varies greatly from scenario to scenario. The difference is explained by the higher multi-path fading in the suburban, and mainly, in the urban scenario. The multi-path fading happens because a receiver will receive not only the signal that travels directly from the sender (direct signal), but also copies of the signal reflected by objects such as buildings or trees. The reflected copies follow longer paths than the original signal, so the destination node receives the combination of multiple copies of the signal at different time offsets. Multi-path also may lead to intersymbol interference, which degrades signal quality [11].

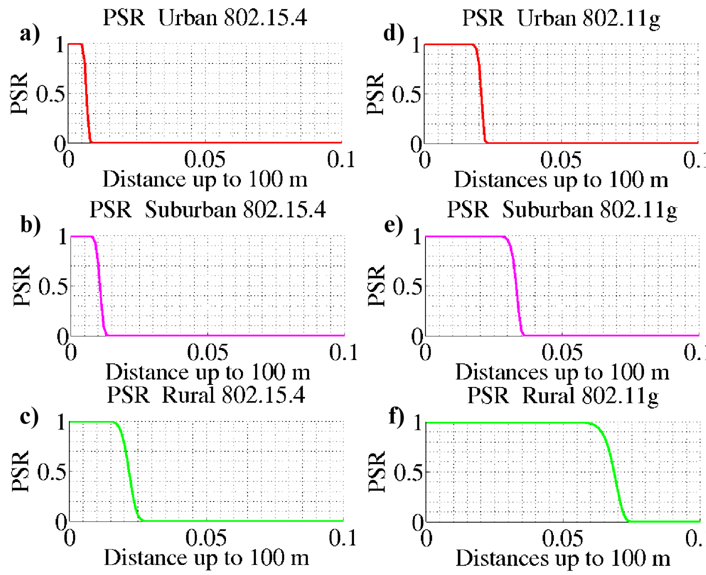

Figure 3. PSR in IEEE 802.11g and 802.15.4.

A direct application of the link budget calculation presented in this paper is shown in Figure 4, which displays a scenario where mesh networking was used in order to extend the coverage of a DAP.

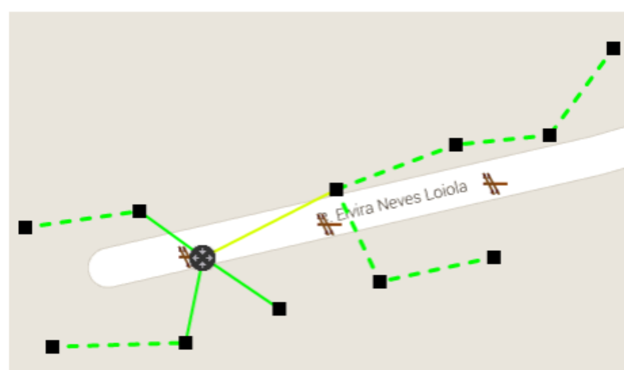

Figure 4. Agreggators and multi hop links to meters example.

Black circles represent the aggregators and squares represent the smart meters. The links between nodes are colored according to the expected PSR. The presented model provides such PSR, which is used for the coloring scheme. The link colors vary gradually from yellow to green, yellow representing a PSR of 90% and pure green representing a lossless link.

The provided algorithms built around the formulas and curves presented make inexpensive use of CPU and permits changing its parameters. It may also be easily changed to accommodate for different data rates.

Table I
PSR in 802.15.4 for 3 scenarios

	PSR Urban	PSR Suburban	PSR Rural
6 m	0.99	1.00	1.00
7 m	**0.81**	1.00	1.00
8 m	0.31	1.00	1.00
9 m	0.02	0.99	1.00
10 m	0.00	0.92	1.00
11 m	0.00	**0.71**	1.00
19 m	0.00	0.00	0.95
20 m	0.00	0.00	**0.88**

When all calculations are put together, it is possible to estimate the distances at which the PSR will be higher than 90%. Tables I and II present the PSR estimation for the urban, suburban and rural scenarios for each transmission technology.

Table II
PSR in 802.11g for 3 scenarios

	PSR Urban	PSR Suburban	PSR Rural
19 m	0.99	1.00	1.00
20 m	0.95	1.00	1.00
21 m	**0.78**	1.00	1.00
31 m	0.00	0.96	1.00
32 m	0.00	**0.90**	1.00
33 m	0.00	0.77	1.00
64 m	0.00	0.00	0.93
65 m	0.00	0.00	**0.90**
66 m	0.00	0.00	0.85

The distances at which the PSR drops below or equals to 90% are boldfaced. For IEEE 802.15.4 this distance occurs beyond 6 m in the urban scenario, 10 m in the suburban scenario and 19 m in rural scenario. For IEEE 802.11g links are considered unfeasible (PSR $< 90\%$) for distances greater than 20 m (urban), greater than 32 m (suburban) and greater than 65 m (rural).

IV. Conclusion

In this paper, we presented a method for calculating the Packet Success Rate of the transmissions between smart grid devices. The method uses the Extended Hata-SRD model, which was selected among many other propagation models. This model was chosen because it fits well to the characteristics of a real AMI scenario: short-range devices (less than 100 m), antennas positioned few meters above the ground, and operating frequencies in the 2.4 GHz band (IEEE 802.15.4 and 802.11g). Using this model we could estimate a maximum distance from which a packet is received with probability greater than 90%, considering transmission power, ambient noise and signal to noise ratio required for successful decoding. This method has been used in AMI planner already implemented in the Tele-Siris project.

The main purposes of the presented model is to find a clear cut-off distance above which DAPs should not be installed, otherwise communication fails. The maximum recommended distance are 7, 10 and 19 m for IEEE 802.15.4 and 21, 32 and 65 m for IEEE 802.11g for urban, suburban and rural scenarios respectively.

As a future work,for further refinements, we plan to extend the adjusted model to other frequency bands and compare with actual measurements in the field .

Acknowledgment

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References

[1] H. Farhangi, “The path of the smart grid,” *Power and Energy Magazine, IEEE*, vol. 8, no. 1, pp. 18–28, 2010.

[2] L. Wenpeng, “Advanced Metering Infrastructure,” *Southern Power System Technology*, vol. 3, no. 2, pp. 6–10, 2009.

[3] CEPT, “Monte-carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems,” *ERC within the CEPT (February 2000)*, 2000.

[4] G. Rolim, C. Sousa, R. C. Carrano, C. V. N. Albuquerque, A. Bettiol, A. Carniato, L. Passos, R. Homma, R. Andrade, and F. Molina, “Smart Grid Deployment Planning : Case Study Covering a Brazilian Feeder in Automation Process (Paper 666), to be published.” Lion: 23rd CIRED - International Conference and Exhibition on Eletricity Distribution, 2015.

[5] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, “Field strength and its variability in VHF and UHF land-mobile radio service,” *Rev. Elec. Commun. Lab*, vol. 16, no. 9, pp. 825–73, 1968.

[6] M. Hatay, “Empirical formula for propagation loss in land mobile radio services,” *IEEE Transactions on Vehicular Technology*, vol. 29, no. 3, pp. 317–325, 1980.

[7] E. Damosso and L. M. Correia, *COST Action 231: Digital Mobile Radio Towards Future Generation Systems: Final Report.* European Commission, 1999.

[8] J. Walfisch and H. L. Bertoni, “A theoretical model of UHF propagation in urban environments,” *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 12, pp. 1788–1796, 1988.

[9] European Comunication Office, “Extended hata srd, extended hata model for short range devices implemented in the seamcat simulator,” 2015.

[10] V. C. Gungor, B. Lu, and G. P. Hancke, “Opportunities and challenges of wireless sensor networks in smart grid,” *IEEE Transactions on Industrial Electronics*, vol. 57, no. 10, pp. 3557–3564, 2010.

[11] D. Aguayo, J. Bicket, S. Biswas, G. Judd, and R. Morris, “Link-level measurements from an 802.11 b mesh network,” in *ACM SIGCOMM Computer Communication Review*, vol. 34, no. 4. ACM, 2004, pp. 121–132.