SMART GRID DEPLOYMENT PLANNING: CASE STUDY COVERING A BRAZILIAN FEEDER IN AUTOMATION PROCESS

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ABSTRACT

A Smart Grid is able to process information of producers and consumers of energy using data aggregators and smart meters. This paper proposes a system which assists in the positioning of these devices in order to provide coverage and good communication links. With the proposed system, users can create, remove, and move meters and aggregators over a map. The system allows users to verify in real time which meters are covered and the quality of the established wireless links. The quality of these links is based on the user's selected options, such as the wireless technology used, the transmission power and the scenario in which the devices are deployed. The system also allows users to use RF-Mesh technology and automatically generate an initial planning which is obtained based on a well-known optimization problem, the Set Covering Problem.

INTRODUCTION

Smart Grids [1] are the evolution of the current electrical networks and allow data communication among consumers, distributors, transmitters and electrical power producers. This communication allows energy companies to use information sent by consumers to optimize the generation, transmission and energy distribution. In order to operate, however, Smart Grids require the installation of smart meters at the subscribers' homes and of data aggregator points (DAPs) in the distribution network. In this work we consider street electrical poles as potential DAP deployment positions. These devices are equipped with communication interfaces and are part of the advanced metering infrastructure (AMI) [2]. In a Smart Grid, each residence contains a smart meter responsible for storing detailed information about its electrical power consumption. Data collected by these meters are periodically transmitted to one or more DAPs, typically via wireless communication. The DAPs transmit the collected data from the neighbourhood to the power distribution company via long-distance communication technologies. There is no standard on which technology should be used for communication between meter-aggregator and aggregator-provider. For the first, short distance communication standards such as IEEE 802.15.4 and IEEE 802.11 can be used. For the second, longer range technologies such as GPRS, 3G cellular network, LTE, 4G or the IEEE 802.16 (WiMAX) are recommended.

Planning the positions of DAPs is one of the greatest challenges for an AMI deployment. In a Smart Grid, each residence has a meter. The manual analysis of the best DAPs positions is costly and hard to execute in practice, especially in high density neighbourhoods. Planning an entire city, for example, involves considering millions of meters, one for each residence. This work proposes a system named Smart-Planner (SP), which allows users to plan a short-range communication network for the AMI. With the SP, the user can automatically obtain an initial solution that contains the minimum number of DAPs necessary to cover the maximum number of meters in a given area. This initial solution may be used as a base for the user's planning, avoiding the need to create and place each DAP separately. The user can interactively place, replace and move DAPs in real time, verifying whether the meters are covered and the quality of the link between them. Furthermore, the SP allows users to choose the devices communication technology (IEEE 802.11 and ZigBee), their radio transmission power and the scenario (urban, suburban and rural) on which the network is deployed.

SMART-PLANNER ARCHITECURE

The SP interface is developed using the JavaScript, HTML and CSS. The map and devices geographic coordinates are obtained from the Google Maps JavaScript API Version 3. Users can access the Smart-Planner via a web browser, which communicates with a server responsible for the data processing. The server operations are implemented in C++. The Smart-Planner is divided in two distinct categories: its functionalities and its operations. Figure 1 illustrates this architecture and shows the Smart-Planner functionalities and operations.

The Smart-Planner's operations are sub-divided in graphical and data processing operations. Graphical operations involve displaying the map, all objects (meters, DAPs and poles) and GPRS/3G/4G signal strength heatmap. Data processing operations are the core of the system and are performed in the server as shown in Figure 1. These operations involve the calculation of communication links (with and without RF-Mesh) and solving the Set Covering Problem generating the automatic planning.

signal strength in each DAP is represented as a percentage above it indicating its efficiency to communicate with the central facility. The region signal strength is displayed by a heatmap and can be obtained with site survey techniques. The red color indicates areas with higher intensity while blue indicates lower intensity. Figure 2 exhibits a small neighborhood in the Smart-Planner. All objects can be created, moved and removed via the Smart-Planner's interface or added via a XML input file to avoid the need to manually place them.

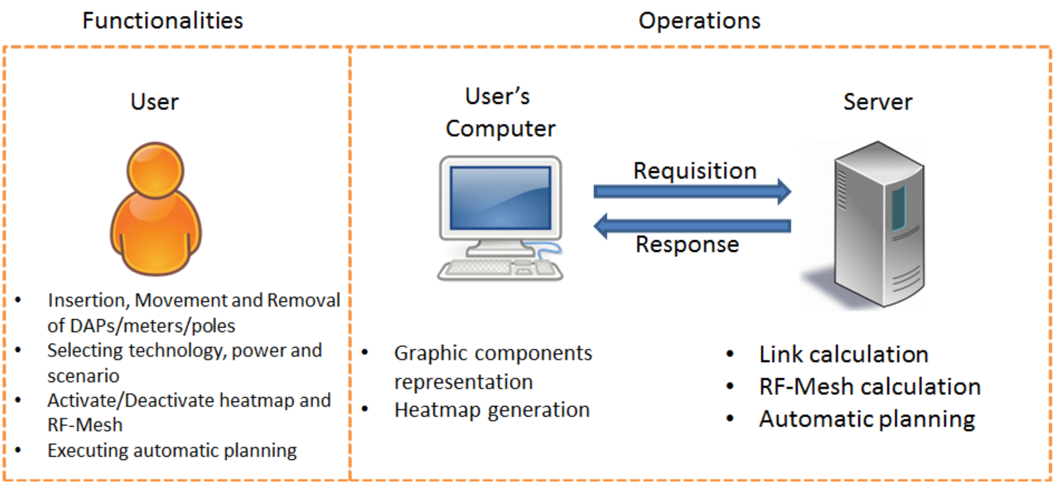

Figure 1 – The Smart-Planner architecture.

Graphical operations are processed in the user's computer while the data processing operations are executed on the server.

SMART-PLANNER OPERATIONS

Graphic components representation

There are three distinct objects in the Smart-Planner system: smart meters, DAPs and electrical poles. Poles indicate possible positions to install a DAP and are used during the automatic planning. Communication links are represented by lines between devices. The line color indicates the quality of the link. The packet successful delivery rate indicates the existence of a link. This rate is calculated according to a model explained in Section "Link calculation". If this rate is higher than 90%, the link exists.

We assume links above 90% are out of the quality range we need to AMI operates. Blue lines indicate the successful delivery rate is between 90% and 95%, yellow between 95% and 98% and green higher than 98%. When the user finishes the positioning of a DAP or a meter, the Smart-Planner recalculates the links on the network. Thus, users are able to observe which links have been removed and which have been created. The GPRS/3G/4G

Link calculation

The link quality between two devices is based on the Successful Delivery Rate (SDR). SDR is computed according to the chosen technology, the transmission power and the operation scenario. More specifically, SDR is obtained from the bit error rate (BER). The BER, in its turn, is obtained from the spectral density of the noise and energy per bit. The noise spectral density can be estimated for each scenario or, for better accuracy, measured in the receiver proximity.

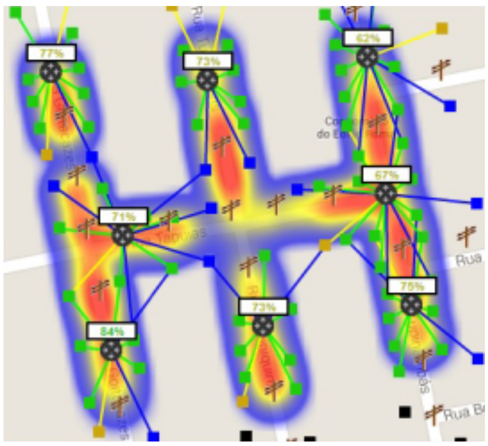

Figure 2 – An example of neighborhood in the Smart-Planner.

The energy per bit of the signal is representative of the level of signal power at the receiver. The signal strength at the receiver is equal to the power of the transmitter signal subtracted from the link attenuation. For simplicity, losses on cabling and connectors are considered to be compensated by the low directivity gain of the antennas. The path loss is calculated according to the operation frequency, the antenna heights, the distance between them and the specific scenario. The Smart-Planner allows the choice of three types of scenario: Urban, Suburban and Rural, as recommended by the ITU-R SM. 2028-1 [3]. Users can choose the technology among IEEE 802.11a, IEEE 802.11g, and IEEE 802.15.4 (ZigBee). Power choices range from 0 to 20 dBm for IEEE 802.11 and -3 to 0 dBm for IEEE 802.15.4, typical values for commercial devices of these technologies.

Several propagation models were studied. H such as Okumura-Hata [4, 5], Hata COST 231 [6], the Walfisch-Ikegami [7] and Extended Hata SRD [8]. The first two models are applicable only at distances that exceeds 1 km, the third model requires many parameters that are difficult to obtain in practice such as streets average width, separation of buildings etc. The model chosen was the Extended Hata SRD that is suitable for long distances and for short range devices (up to 100 m).

Heatmap generation

The heatmap indicates regions covered by GPRS/3G/4G signal used for the communication between DAPs and the central facility. A DAP is capable of transmitting its data to this facility according to the signal quality where it's placed. In Smart-Planner, this quality is represented by the percentage above each DAP. The heatmap consists of a series of geographic coordinates, each one associated with a value that indicates the signal quality. These data are obtained from a site survey performed on the neighborhood in which a Smart Grid network may be deployed. How to obtain these data is out of the scope of this work. We assume this information is given to the Smart-Planner via a XML file. From these data, the Google Maps API can generate the heatmap. The main objective of the heatmap is to visually indicate regions with higher and lower signal intensity. Users can turn the heatmap on and off by clicking a button.

RF-Mesh Calculation

The Smart-Planner allows users to plan a neighbourhood with RF-Mesh (Radio Frequency mesh technology) [9]. In mesh networks, each meter is able to cooperate with the data distribution, i.e., a meter is able to forward data of other meters to an aggregator. Thus, the network coverage increases without the need to add new DAPs. The calculation of RF-Mesh connections in Smart-Planner is quite simple. Each meter is connected to the nearest meter that already has a link to an aggregator. The maximum number of hops to the aggregator is configurable. All links of the RF-Mesh connections are represented by dashed lines and their colors follow the same criteria of a regular link. Figure 3 shows a neighborhood using the RF-Mesh.

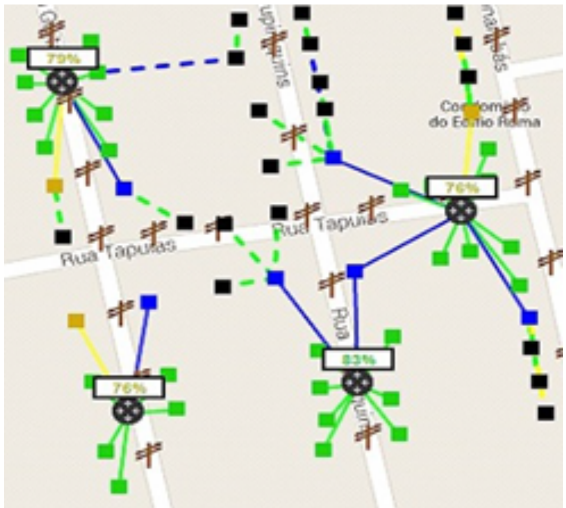

Figure 3 – An Example of Planning of a neighborhood using RF-Mesh technology.

Automatic Planning

Given a set of electric poles and meters, the Smart-Planner can automatically calculate the number of DAPs and its positions in order to maximize the number of meters covered using the least quantity of DAPs needed. The meter coverage problem is modelled as optimization problem known as Unique Cost Set Covering Problem [10]. The automatic planning can also employ the RF-Mesh technology. The current version of the Smart-Planner does not consider the heatmap information in order to solve the problem.

FUNCTIONALITIES

The Smart-Planner's interface functionalities are described below.

Insertion, Movement and Removal of DAPs/meters/poles: The insertion and removal of objects is performed with simple mouse clicks. To insert a new object (meter, DAP or pole) the user selects it from the options tab. The mouse cursor changes according to the object selected, visually indicating which action the mouse click will perform. When the user clicks on a given position, an object of the selected type will be placed on that position. If the object is either a meter or a DAP, at the moment of its placement the system automatically recalculates communication links. To remove an object, users must first click the erase button. In the same way as the insertion, the cursor is changed to indicate the action. While the erase option is activated, a click upon any object will have it removed. To move existing objects, users must simply click the object and hold the button while dragging it to the new position to finally release it. If users wish only to visualize the map, they should select the view mode, which will not create nor remove any objects clicked. Figure 4 illustrates the option tab and the cursor for each option.

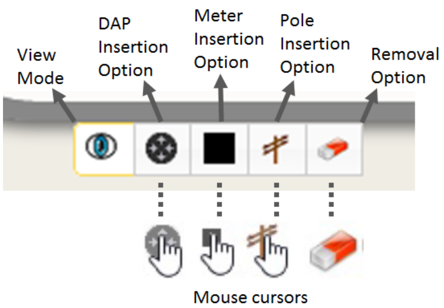

Figure 4 – An Example of Planning of a neighborhood using RF-Mesh technology.

Selecting technology, power and scenario: To choose the scenario and technology, users must simply click on the button next to its related option. When clicked, the interface shows the options to select. The scenario may vary from Urban, Suburban and Rural, and the technology can be selected from IEEE 802.11a, IEEE 802.11g, and ZigBee. Users can change the device's signal power in dBm by using an interface slider. Whenever one of these options is changed, the Smart-Planner automatically recalculates the current communication links. The selection options are represented by Figure 5.

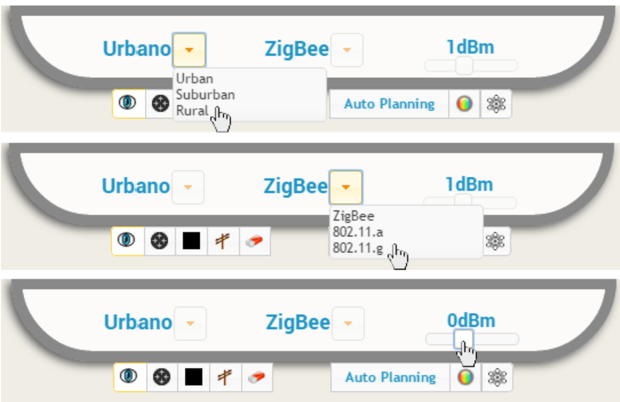

Figure 5 – Scenario, technology and signal power selection.

Activate/Deactivate heatmap and RF-Mesh: These options can be activated or deactivated with a single click. The heatmap activation/deactivation simply turns on or off its visualization. When users choose to use the RF-Mesh, however, the server must recalculate the links on the network. The same happens if the user turns RF-Mesh off.

Executing automatic planning: With a simple click on the automatic planning button, the interface sends the positions of all the meters and poles to the server. The server returns a set of poles on which a DAP must be placed. The interface automatically place DAPs on these positions and the links are recalculated.

CASE STUDY

The automatic planning functionality was tested for the region of the Agronômica feeder in the city of Florianópolis/Brazil containing approximately 29,000 meters and 12,000 electric poles. This region is shown in Figure 6. The electrical poles positions were obtained from CELESC Power Distribution Company [11]. Green circles represent smart meters and poles are not shown for visual clarity.

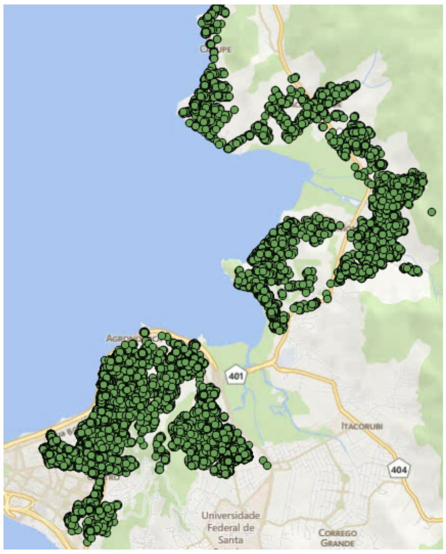

Figure 6 – Target Smart Grid deployment site in Florianópolis (Agronômica Feeder).

	RF-Mesh Disabled		
Scenario	Urban	Suburban	Rural
Number of DAPs	3026	2308	979
Avg. Number of meters per DAP	9.6	12.6	29.6
	RF-Mesh Enabled (maximum of 4 hops)		
Scenario	Urban	Suburban	Rural
Number of DAPs	1782	1074	307
Avg. Number of meters per DAP	16.3	27.0	94.5

Table 1 – Automatic planning results.

Table 1 shows the number of DAPs obtained from the automatic planning necessary to cover this region with and without RF-Mesh technology for urban, suburban and rural scenarios. Since the Extended Hata SRD propagation model implementation is still under development, the maximum reach of a DAP used in this test was based on the work of Gupta [12] considering that the DAP transmits with 20dBm power using BPSK modulation at 6Mbps. The maximum ranges for urban, suburban and rural scenarios obtained are 18 m, 25 m and 48 m respectively.

The use of RF-Mesh clearly has a great impact on the number of DAPs needed, the results show that for the rural scenario this number decreased approximately 3.2 times. However, the lesser the number of DAPs, the higher the load (average number of meters per DAP) in each DAP. Though the network traffic in a Smart Grid is low, having a DAP covering exclusively a high number of meters might be a problem, especially if this DAP fails. Future versions of the automatic planning will consider the average load in each DAP and will add redundancies so that meters have more than one DAP to send data.

CONCLUSION

The Smart-Planner system is an efficient solution to plan a Smart Grid on a neighbourhood reducing the cost and avoiding the imprecision of manual deployment. This system allows users to manipulate the position and technology of DAPs and smart meters while verifying its connectivity in real time. The connectivity is determined by a propagation loss model for a varying set of scenarios, technologies and signal strengths. Additionally, the Smart-Planner offers the option of automatic planning, responsible for positioning the minimum number of DAPs needed in order to cover the maximum number of meters in a given area. The system also supports RF-Mesh communication. Preliminary tests have shown that considerably large regions can be automatically planned with the system and that RF-Mesh technology is capable of greatly reducing the number of DAPs necessary to do it. A video showing the use of the Smart-Planner was prized in the 2014 IEEE SmartGrid Comm Student Video Competition [13] and it is available at the following link: https://www.youtube.com/watch?v=SV379E-FZDw.

ACKNOWLEDGEMENTS

This work is supported in part by CNPq, CAPES, FAPERJ, TBE/ANEEL and CELESC/ANEEL.

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