First Step Towards a Smart Grid Communication Architecture for the Brazilian Federal District

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Abstract: Most electrical grids worldwide employed are outdated, and this includes the electrical grid of the Brazilian Federal District (DF). In order to cope with new technological requirements that arise from an increasingly automated devices of power and communication systems, the concept of smart grid has spread. Smart grids involve completely integrated systems allowing better control of data as well as the improvement of energy efficiency. This work proposes a Smart Grid Communication Network (SGCN) in the context of the DF, in Brazil. Firstly, the present work gathers demographic and electric power meters information from the electrical grid of the Brazilian Federal District (DF). In order to cope with new technological requirements that arise from an increasingly automated devices of power and communication systems, the concept of smart grid has spread. Smart grids involve completely integrated systems allowing better control of data as well as the improvement of energy efficiency. This work proposes a Smart Grid Communication Network (SGCN) in the context of the DF, in Brazil. Firstly, the present work gathers demographic and electric power meters information from the DF region. Afterwards, the data capacity requirements are calculated based on the joint information. Finally, suitable communication technologies for each subnetwork of the SGCN are suggested. This work is a first step towards the implementation of a SGCN on the DF.

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1. INTRODUCTION

The world’s perception of electrical energy has changed significantly over the last decades. Climate changes and greenhouse gases have become a significant problem and balancing energy supply and demand is more complex than ever. In addition, the utilization of renewable energy sources comes with barriers when we consider our current electrical grid. In this context, the concept of smart grid comes into scene to fit these aspects.

Current electrical grids operate as broadcast grids according to Fang et al. (2012). Therefore, the energy is generated in different sites and manners, as from nuclear to hydroelectric power plants, being in sequel transmitted to the consumers, i.e. houses and industries. Since energy storage is generally expensive and inefficient, it is necessary to control the amount of energy generated in a way that it is totally consumed. This task has become more complex than ever and, as a consequence of the high instantaneous levels of electric power demand achieved, has resulted into black-out in certain regions.

Another drawback in our current electrical grid is the lack of support, appropriateness and use of renewable energy sources, since the energy is continuously provided. Considering the necessity of employing increasing amounts of power by means of renewable resources and the inadequacy of the current grids to cope with intermittent generators, improvements on the structure of the current power grids are required.

In order to adjust in real-time the energy supply and consumption, the electric grid should be monitored. By monitoring the network, near-real-time energy pricing and consumption information can be provided. Hence, smart grids imply into improving the system reliability, reducing the ecological impact and improving operational and electrical efficiencies of the grid as shown in Flynn (2009).

Since smart grids allow the full integration and connection of the whole system, a relevant part of their conception comes from the use of communication technologies and the development of a smart grid communication network (SGCN). The basic idea of the SGCN is to create a network connecting the consumers and the utility company. According to Wollenberg and Amin (2005), from a refinement of the National Institute of Standards and Technology (NIST) Smart Grid System Architecture, the basic elements of the SGCN can be outlined. More detailed
information about the structure of a SGCN can be found in NIST (2009).

For energy management applications, a communication network must provide some essential qualities, such as high reliability and availability, high coverage and distances, security, low delays, among others as shown in M. A. Hammoudeh (2012). On the other hand, the different types of information being carried have distinct requirements and delay tolerances. T. Otani (2010) presents tables that summarize the communications requirements of information coming to and from customer’s gateway.

Each network carries different volumes of information and within different ranges. Therefore, they present different communication technologies. In the context of the Brazilian Federal District (DF), we are going to focus on three of these subnetworks, namely Neighborhood Area Network (NAN), Field Area Network (FAN) and Wide Area Network (WAN).

The rest of this work is organized as follows. In Section 2, we analyze the demographics and the data capacity requirements for the DF. In Section 3, we propose a SGCN based on the requirements defined on the previous Section and on cases of other SGCN already implemented in different cities. Finally, in Section 4, conclusions are drawn.

2. DEMOGRAPHICS AND DATA CAPACITY REQUIREMENTS FOR THE DF

In this section, we primarily analyze and categorize the regions that compose the DF and, afterwards, from this perspective, we calculate the required data capacity for the SGCN architecture.

As described by Moura (2009), the administrative regions on DF can be classified into four categories, namely, dense urban, urban, suburban, and rural. The dense urban regions have a population density greater than 2500 inhabitants per km², while urban regions, the population density ranges between 800 and 2500. The population density of a suburban region varies between 100 and 800 inhabitants per km², while for rural regions, this value is up to 100 inhabitants per km².

Table 1 provides information about the number of electric power consumption meters (EPCM) in each demographic category, according to the local electric power company, in portuguese, Companhia Energética de Brasília (CEB), and the IBGE Census 2010. Note that the vast majority of the consumers still use the conventional mechanical energy meters.

| Region           | Pop. Density (inhabit./km²) | # EPCM | EPCM per km² |
|------------------|-----------------------------|--------|--------------|
| Dense Urban      | 4528                        | 398 779| 1842         |
| Urban            | 1594                        | 414 954| 643          |
| Suburban         | 316                         | 175 909| 126          |
| Rural            | 51                          | 72 924 | 21           |
| Global           | 444                         | 1 068 616| 184        |

Table 1. Population density and amount of EPCM in each region on DF

Based on Table 1, we can estimate the amount of data capacity required by each of the four demographic categories on DF.

The Smart Grid Networks Deployment Modeling Framework, developed by the OpenSG Networks Working Group, and the Wireless Modeling Engine, developed by SGIP PAP02 NIST (2015a), merged to form the Smart Grid Framework and Wireless Modeling Tool (SGFWMT) NIST (2015b). This tool consists of a spreadsheet that uses demographic information, such as demographic area requirements and the quantity of EPCM, to estimate the data volume requirement for a certain region. The SGFWMT is a tool to provide initial estimates of network base station requirements to fit coverage, data volume, and latency requirements in a wide range of deployment venues.

The information in Table 1 is used as the input for the SGFWMT, which then calculates the average data throughput as shown in Table 2, where UL stands for Uplink and DL for Downlink, both in kbps/km². Based on the data capacity requirements, the communication technologies for each network and subnetwork can be chosen as shown in Section 3. Table 2 shows the average data throughput, as a data density in kbps/km² for each demographic category.

|                | Dense Urban | Urban | Suburban | Rural |
|----------------|-------------|-------|----------|-------|
| Avg. Baseload  | 0.9720      | 4.7506| 1.3572   | 0.3153|
| Requirements   | DL           | UL    | DL       | UL    |
| UL             | 0.0905      | 2.4599| 0.4439   | 0.0267|
| Avg. Highload  | 16.3183     | 11.2804| 12.0384  | 1.7832|
| Requirements   | DL           | UL    | DL       | UL    |
| UL             | 36.0084     | 34.4577| 22.3997  | 5.3917|

The average baseload requirements and the average highload requirements are, respectively, the minimum and maximum network traffic loads. They are fundamental parameters and are considered in order to propose SGCN with appropriate technologies. More details regarding the baseload and highload can be found in Gray (2015).

3. PROPOSED SMART GRID COMMUNICATION NETWORK

Based on the required data capacity for the DF and on the available infrastructure, we propose a SGCN architecture for the DF in this section.

As shown along this section and illustrated in Figure 1, the proposed SGCN for the DF is based on a fiber-optic WAN backbone and a private wireless broadband network, including a WiMAX FAN combined with a 900 MHz wireless mesh NAN. The 900 MHz wireless mesh network collects all the smart EPCM data from the consumers in a neighborhood. The WiMAX base stations, which are installed near the transmission lines as depicted in Figure 1, then, establish the connection between the information coming from the NAN and the fiber-optic backbone. Finally, the fiber-optic backbone delivers all the collected information to the utility company, i.e. CEB.

For the wireless part of the SGCN architecture, we propose to use private wireless networks, since, as shown in Grid-
Com Tropos (2012) and Utilities Telecom Council (2009), there are five main advantages of owning and operating a SGCN, namely, high availability, low latency, high control, high quality of service (QoS), and low cost control. Given the proposed SGCN architecture in Figure 1 and the adoption of the private wireless broadband, we propose the communication technologies for each subnetwork addressed in this work. In Subsections 3.1, 3.2 and 3.3, the WAN, FAN and NAN for the SGCN on DF are, respectively, addressed.

### 3.1 Wide Area Network (WAN)

The electrical substations play a crucial role in the electric power system and they also support the SGCN in a smart grid. Aiming the near-real-time monitoring and control in a smart grid, extensive transmission and distribution substation automation needs to take place in order to add deeper levels of automation and intelligence to the power system grid. Examples of the changes to the current substations on DF include the replacement of conventional Voltage Transformers (VTs), Current Transformers (CTs) and Remote Terminal Units (RTUs) by microprocessor-based intelligent electronic devices (IEDs), secondary equipments (e.g. relays and bay controllers) and the use of a distribution management system for the enhanced monitoring and control of the grid according to M. Thottan et al. (2014).

The traffic from nearby endpoints and local traffic may be aggregated at a cluster router (CR) located in the substation. Therefore, we recommend the design of a SGCN with the substations of the power grid utility interconnected with a fiber-optic backbone.

The fiber-optic provides 155 Mbps - 2.5 Gbps maximum theoretical data rate and coverage area up to 60 km with Passive Optical Network (PON) technology, 40 Gbps maximum theoretical data rate and coverage area up to 60 km with Wavelength Division Multiplexing (WDM) technology, and 10 Gbps maximum theoretical data rate and coverage area up to 60 km with Synchronous Optical Networking (SONET) technology in Rahman et al. (2014).

Since fiber-optic cables are immune to electromagnetic interference Ezeh (2013), CEB already has some fiber cables installed on the DF. Therefore, the next step is the interconnection of the automated substations. Figure 2 shows the map of the DF with its electric substations interconnected with the fiber-optic cables.

### 3.2 Field Area Network (FAN)

In contrast to the wirelines, wireless technology provides the best alternative for the implementation of a smart grid network. Wireless technology is cost-effective, quick to deploy, and is compatible with the existing utility infrastructure. The use of WiMAX is suitable to implement the backhaul FAN connection to the utility fiber-optic infrastructure.

WiMAX is a wireless broadband technology capable of delivering voice, video, and data over the microwave RF spectrum based on the standard IEEE 802.16 (2015). WiMAX is designed to operate in the licensed band (2.5 to 2.65 GHz and 3.4 to 3.6 GHz) and in the unlicensed band.
(5.725 to 5.850 GHz), with channel bandwidth integer multiple of 1.25 MHz, 1.5 MHz and 1.75 MHz with a maximum of 20MHz. WiMAX supports the circuit mode time-division multiplexing (TDM) and frequency-division multiplexing (FDM).

The advantages of the WiMAX technology include the protocol independence (IP, Ethernet, ATM), different services (such as VoIP, data or video), peak data rates of 75 Mbps for fixed connections and up to 15 Mbps for mobile connections and area coverage up 50 km Jenkins et al. (2015). An alternative to the WiMAX technology is the LTE technology, as indicated by C. Rodine (2011). LTE cellular networks adequately meet the smart grid communication requirements, as demonstrated by laboratories Ericson (2013). Note that in this work we adopt the WiMAX due to the previous reasons along this subsection.

Moura (2009) estimates the number of base radio stations for a WiMAX implementation on the DF for data, voice and video services. Such services require higher bandwidth when compared to the smart grid applications included in this paper. Based on the fact that the amount of base stations required in Moura (2009) is found as a function of the coverage area, the number of base stations found is also applicable to our work. Therefore, based on Moura (2009) and on the estimates of the Smart Grid Framework and Wireless Modeling Tool NIST (2015b), Table 3 summarizes the number of base stations needed to implement the smart grid on the DF.

Table 3. Number of Base Stations for the FAN

| Demographic Region | Area (km²) | # Base Stations |
|--------------------|------------|-----------------|
| Dense urban        | 210        | 72              |
| Urban              | 645        | 49              |
| Suburban           | 1383       | 24              |
| Rural              | 3551       | 22              |
| Total              | 5789       | 167             |

Note that the local electric utility company (CEB) installs one base station at each electrical substation to be the gateway to the fiber-optic backbone. Moreover, for cost reduction, the WiMAX base station antennas should be installed on the same structure of other telecommunication companies base station (site share) to provide coverage to the rest of the service area. Figure 3 depicts the locations of the base stations from one telecommunication companies on the DF, which may be used to install the base station antennas required in the SGCN.

3.3 Neighborhood Area Network (NAN)

One of the most important features of the smart grid is the use of smart meters. The smart meters provide near-real-time information regarding energy consumption. This information may help modify the costumer’s behavior and make it easier for the network operator to manage the peak demand.

Two factors support the recommendation to deploy a 900 MHz wireless mesh network in the DF. First, frequencies below 1 GHz are more suitable to building penetration in urban centers according to Gray (2015). Second, the high density of tree foliage at the DF diminishes the penetration and reach of multi-GHz communication.

For the implementation of the wireless mesh network, this work recommends the 900 MHz ZigBee technology, mainly due to its simplicity, mobility, robustness, easy network implementation, low band-width requirements and low cost of deployment. Furthermore, ZigBee works within an unlicensed spectrum band and is based for IEEE 802.15.4 protocol Lu and Gungor (2009). ZigBee is ideal for smart grid applications, such as load control and reduction, demand response, real-time pricing programs, real-time system monitoring and advanced metering support as shown in Peizhong et al. (2011), Gezer and Burati (2011).

Regarding the theoretical data rate of 250 kbps and considering the coverage range of the Zigbee technology ranging up to 100 meters (Zigbee) and up to 1600 meters (Zigbee Pro) Rahman et al. (2014), it is reasonable to set 2 or 3 devices as Data Aggregation Points (Smart Meter Regional Collector) per square kilometer.

Even though the 900 MHz ZigBee technology is the one suggested in this work, other technologies are also suitable for the NAN implementation. For instance, the EN13757 M-Bus family has become standard in the European markets according to A. Sikora et al. (2014). The wireless M-Bus technologies are focused on communication and clustering of the information coming from gas, water, heat and energy meters. On the other hand, ZigBee is ideal for implementing low-power, low-cost and short-range wireless mesh networks.

The communication technologies here chosen are justified by the amount of data that flows through each network, as calculated in Section 2, and by looking at other SGCN architecture cases from other cities. Some of them are the InovCity project, in São Paulo Ecil Energia (2013), the San Diego Smart Grid University of San Diego (2006) and the Smart Grid Applications in Palo Alto EnerNex Corporation (2011).

For instance, the InovCity project Ecil Energia (2013) installed 15,400 electrical meters using Brazilian technology. Moreover, InovCity considered a backbone with WiMAX and a wireless mesh network with ZigBee. The San Diego Smart Grid presents no specific communication technologies, and provides an analysis of costs and technical feasibility of different technologies. Therefore, University of San Diego (2006) is a relevant resource that presents a portfolio with different communication technologies that would be suitable to implement a SGCN. The Smart Grid Applications in Palo Alto, by EnerNex Corporation (2011), features a 900 MHz mesh NAN and a WiFi WAN. The NAN is a double band 2.4 GHz and 5.8 GHz implemented with IEEE 802.11n standard.

Note that the already proposed SGCN, such as the ones discussed previously, provided valuable insights for the SGCN of the DF in this work. Afterwards those insights were adapted to fit the specific needs and characteristics of the DF, such as the population, the already available infrastructure and the region’s geography, for example.

4. CONCLUSION

The concept of smart grid has motivated a significant amount of research effort in accommodating new domains and players with new paradigms in the electric power
industry. The electric power industry and companies must move forward to the modernization of the grid and bring the system to the digital era.

The results arising from this work aim to stimulate discussion within stakeholders, i.e. CEB, the local state government, in portuguese, Governo do Distrito Federal (GDF) and the local citizens, who would also be the primary beneficiaries. Future works may create a smart grid simulator considering different layers, such as the communications, the electric and the economic layers. The simulator should emulate the behavior of a working smart grid and, with that tool in hands, one might propose an optimal architecture in the context of the DF.

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Fig. 3. Current base stations of the telecommunication companies for the FAN.