Integrating Intelligent Transportation Systems Devices using Power Line Communication

Cledson A. Sakurai, Claudio L. Marte, Leopoldo R. Yoshioka and Caio F. Fontana.

Abstract**—** The goal of intelligent transportation system (ITS) is to improve urban mobility in relation to safety , usability , mobility , quality and productivity through the use of information and communication technology and one of the main problems is to ensure that which elements of ITS such as cars, buses, sensors, actuators, lights, among others are exchanging data with them, due to the size of this environment, the infrastructure of communication between the transportation management system (TMS) and ITS components and between ITS components are extremely important in this context, this work proposes the use of communication technologies considered for the smart grid , which is the Power Line Communication (PLC) system, which consists of data communication through the grid network that is available in urban centers , and can even share with the smart grid network. Another characteristic between ITS and Smart Grid is that the booth environment will exchange small data packages, so it is possible to use narrow band technologies. In this paper was considered the evaluation of two initiatives on narrow band PLC, PRIME and G3, which have similar physical layer, and the PRIME privileges the high data rates during favourable conditions and G3 provides better performance on unfavourable conditions. The both projects can be used as a communication data channel for communication between TMS and ITS elements, because this communication requests a low bit rate.

Keywords**—**ITS, Integration, PLC, devices.

I. Problem Description

IN nowadays the intelligent transport systems is very important to manage and monitor the problems caused by traffic jams, accidents and incidents in the world and the use of information technologies to simulate and make a real-time control permit to minimize these problems.

The congestion has been increasing as a result of urbanization and effective changes in population density, so the traffic jams reduce the use of transport infrastructure and increase travel times, air pollution and fuel consumption. The ITS includes several management systems as: traffic light management system, track and trance systems, panel with messages, speed cameras and so on.

These management systems needs to communicate with the sensor and actuators networks installed in the city, in order to obtain the real information of each local, so an effective communication system to exchange data between TMS and ITS elements is necessary.

For data communication several technologies are available as: pair of wire, dedicated line, radio frequency, mobile and others, but the maintenance and deployment cost often prevents the ITS projects. In this context and considering another monitoring system, called Smart Grid, the paper present an alternative solution to enable the communication for ITS.

The smart grid is based on intensive use of information and communications technology (ICT) to monitor and control the power electric network, which will allow the network management with more efficiency. The smart grid permits the convergence between the generation, transmission and distribution infrastructure with data communication and processing infrastructure.

This convergence of technologies requires the necessity to use new methods of control, automation and optimization of electrical system at distributed electrical infrastructure. The main characteristics of smart grid are: [1, 2]

- The ability to detect, analyse, respond and restore network outages;
- The ability to include the consumer behaviour in operation of network;
- The capacity to resist physical and cyber-attacks;
- The capacity to provide energy with the quality expected by consumer;
- The capacity to integrate the energy generated by any sources in many dimensions and technology;
- The capacity to attend any demand requested by consumer;
- The ability to reduce the environmental impact of production system electricity, reducing losses and using sources with low environmental impact, including micro generation.

The smart grid is composed of generation, transmission, distribution and consumer, as shown on fig. 1 and to enable the smart grid concept is necessary to consider several concepts, as:

- Automatic Metering: The equipment for automated data collection and transmission of electric network to a centralized data processing, allows analysing the electrical energy demand in real time and, therefore, acting directly on the network infrastructure in order to optimize the power consumption or correction of any detected issues;
- Pricing: The availability of bi-directional communication between utilities and consumers allows for the introduction of a system of dynamic pricing. In this system, the price of electricity varies throughout the day as a way of encouraging policies to boost the profile of demand and thus reducing the

total cost of expansion and operation of electrical system;

- Centralized and Distributed Generation: The centralized generation is the conventional way of electric power generation. It consists on medium or large generating plants. Actually is used a distributed generation composed of small power generation plants closed to the load. The main issue of smart grid derives from the introduction of energy sources with different characteristics at the same infrastructure. These new situation requires the development of intelligent techniques in order, to accommodate their features seasonal and intermittent chain energy optimization of the system.

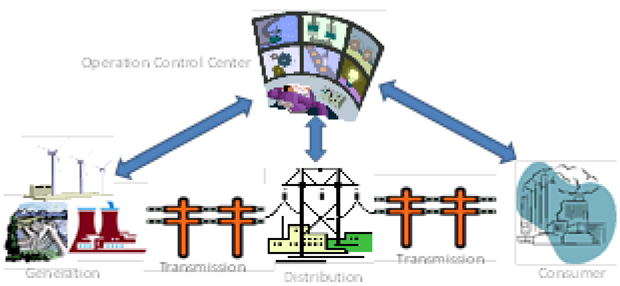

Fig.1 Overview of Smart Grid Components

- Transmission: The transmission System is responsible for connecting the various power generators and connects to consumers through the distribution system. Systematic failures in the transmission may result in dismissal of part or all of the electrical system. Transmission systems are supervised and controlled through the SCADA system, which measures processing scans analogue quantities (voltage, power flow, etc.), and states of switches and circuit breakers (open / closed), with sampling rates of the order 2-10 seconds. [1] [7] [8]. The technological advances in the areas of sensors, devices measurement and digital communications are allowing a volume of high quality information on the conditions of operation from electric system, thus allowing :
  - Real-time monitoring of operating conditions of transmission lines, transformers, among others, allowing more efficient use of such equipment to avoid failures that could compromise the integrity of the Transmission System;
  - Intelligent electronic controls that allow for reconfiguration and adjustments for the best use of the electric system and also to remedy any shortcomings;
  - Substation Automation through integration of systems monitoring, control and protection of substations using standard protocols for data transfer via communication networks.
- Distribution Systems: In distribution systems is being used the electronic measurement equipment, which enables real time reading of consumer demand, detection and isolation of faults or restoration and reconfiguration of services.
- Consumer: The Smart Grid allows monitoring of consumer demand by sending data on how to use the grid for it, besides the possibility of small generation capable of producing energy for own consumption and even sell to the utility.

II. Smart Grid

The Smart Grid is very similar to the necessary infrastructure for ITS, because in both cases there is a centralized management system that needs to communicate bi-directionally with the elements that are in the street through a data communication line. In this context, considering that the energy service providers have their power line distribution installed in the city and also its need to receive data in its entirety, the enterprise responsible for the monitoring of transport could use the same infrastructure communication through the PLC, reducing communication costs of their ITS. This paper focuses on evaluation of data communication technology that is common for the Smart Grid and ITS.

III. Communication Technologies

The following communications technologies can be used in Smart Grid and could be used to ITS:

- Dedicated Line or Dedicated wired data networks can be designed to comply all requirements, however the implementation costs depends directly on the distance between locations.
- Radio Frequency (RF) is the technology based on the communication of data over radio waves, where the frequencies used worldwide are controlled by the ITU (International Telecommunication Union) and ANATEL (National Agency of Telecommunication) in Brazil. The frequency spectrum is divided into tracks where each track has a well-defined characteristics, the free track frequencies are the ranges of 2.4 GHz and 915 MHz. The scope of an RF communication may vary depending on the signal strength of the transmitter module and has a low cost compared to other technologies. However, the issue of accreditation and certification of the radios by the regulatory agency may be an problem. The radio could be a point-to-point or point-to-multipoint (mesh topology). At point-to-multipoint is possible to make broadcast communication between various locals and it is possible to achieve a large coverage area with an emphasis on low power operation.

- GSM (Global System for Mobile Communications) or GPRS (General Packet Radio Service) is an alternative due to installation cost and coverage area, however there is a strong operator dependent services. The GSM is a mobile technology that is be used in over 200 countries and more than one billion of people. At GSM the signal and the voice channels are digital, then the data communication is available. The method used by GSM frequencies is to manage a combination of two technologies: TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access). The bit rate on GSM is around 9.6 Kbit/s, so there is a limited bandwidth. The GPRS is a technology that increases the rate of data transfer in GSM infrastructure. This allows the transport of packet data, so it provides a higher transfer rate (56 to 114 Kbit/s) than previous technologies, because it uses circuit switching. The GPRS has as main advantage the huge infrastructure of the telephone network operator, but has disadvantages such as cost and small and inconsistent coverage in rural areas. [4];
- PLC (Power Line Communication) is a communication system that uses the power line distribution cable to transport telecommunications services, so it allows data communication over the grid at low, medium and high voltage, with the advantage of use existing physical resources.

The Figure 2 summarize each communications technologies characteristics.

Technology	Advantage	Disadvantage
Dedicated Line	• Independent; • Permanent connection; • Large bandwidth.	• High implementation Cost
GSM	• Easy to handle; • Low modem cost; • 9,6 Kbps.	• Operator dependent services; • No influence in case of problems; • Reachability; • No permanent connection; • Limited bandwidth.
GPRS	• Easy to handle • Low modem costs • Permanent connection • Cost effective tariffs • 56-114 Kbps	• Operator dependent services; • No influence in case of problems; • Reachability; • No permanent connection; • Limited bandwidth
Broadband PLC	• Independent; • High reachability • Permanent Conection • High frequency • High bit rate	• Higher technical effort • Noise; • Bridge; • Interference.
Narrowband PLC	• Independent; • High reachability • Permanent Conection • Low frequency • Low bit rate	• Higher technical effort • Noise; • Interference.

Fig.2 Communication Technologies

IV. Power Line Communication

The Power Line Communication (PLC) is a technology that uses the power live distribution cable, then for communication using PLC, each user must have a PLC modem. Due to the transformers some signal are blocked, so it is necessary a bridge to cross it. Some applications use PLC on frequencies below 60Hz, allowing the signals to pass through transformers, but these signals transmit data at low speeds. The factors responsible for low capacity of data communication are changes in impedance, high levels of noise caused by switching the signs and inductors. This degradation in the communication rate caused by noises often restricts the applicability of the technology. Other issues still need better solutions such as electromagnetic compatibility, lack of standardization and better regulatory policies.

At PLC technology to provide data communications via broadband to power utility stations some elements may be needed as blocking elements to be cancelled in the interference problems hubs and RF repeaters to increase the signal levels.

The broadband PLC is a communication system to provide broadband services (voice, data, multimedia, video, etc.) cabling using high voltage electric system that belongs to the existing electric utilities. The scope of the PLC is the provision of broadband services using one or more power cables in the distribution network, while simultaneously electricity is provided. The RF signal is modulated at the first point with the data signal and inserted into the distribution network, which serves as a communication channel. At second point, the RF signal is recovered from the power grid with a modulated signal demodulator for recovering the original data signal. The data is sent from the second to the first point in a similar way, only changing the frequency band. The broadband service is full-duplex, simultaneous two-way communication, between two locations.

The narrow bandwidth PLC does not require changes in the distribution network and no additional equipment for packaging distribution transformer. The communication is not affected by equipment or abnormal conditions that may exist in the electric distribution network, such as capacitor banks, transactions for underground electric lines, voltage dips and harmonics. There are no blind spots for the system, which could be caused by phenomena of standing waves generated by the extension of electric power supply or on its configuration.

Due to the characteristic of each system, the present paper will analyses performance of narrow bandwidth PLC to monitoring services of ITS.

This paper consider the use of Narrow Band PLC in Intelligent Transport System, as a a communication channel between the ITS elements and the TMS, for both are considering the topology shown in Figure 3.

To evaluate the scenario, the present paper consider the following initiatives:

- PRIME (PoweRline Intelligent Metering Evolution) is focused on the development of a new open, public and non-proprietary telecommunications solution which will support not only smart metering functionalities but also the progress towards the smart grid. The PRIME has specified a PLC that uses a OFDM (orthogonal frequency-division multiplexing), open and non-proprietary with focus on interoperability among equipment and systems from different manufacturers.

- G3 PLC is focused on the definition of an open standard for smart grid implementation. The G3 PLC is a standards-based power line communications specification promoting interoperability in smart grid implementations.

Booth projects using the OFDM to modulate the signal in narrowband PLC. The OFDM signal is characterized by the sum of several sub- orthogonal carriers, with the data of each sub-carrier being independently modulated using some form of QAM or PSK. This signal baseband is used to modulate a main carrier, used to communication via radio frequency. The advantages of using OFDM are many, including high efficiency spectral immunity against multipath and noise filtering simple.

Combining OFDM with error correction techniques, adaptive equalization and reconfigurable modulation, I t has the following properties: [12]

- Resistance to optical dispersion;
- Resistance slowly changing phase distortion and fading;
- Resistance against multipath using guard interval;
- Resistance against frequency response null and frequency interference constant;
- Resistance against burst noise.

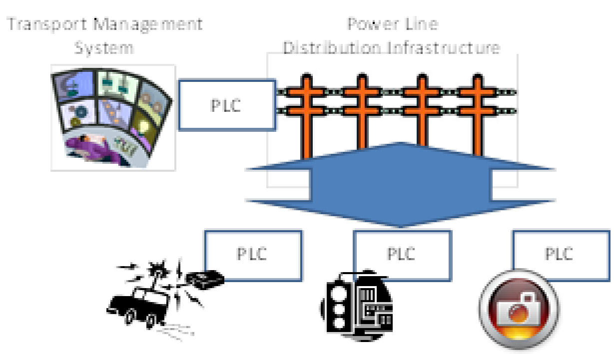

Fig. 3 Scenario

The parameters of each project is presented on figure 4, the structures and choices of coding parameters used in G3 and PRIME have unique features and merits can be synthesized and optimized to produce a single coding structure that can yield high performance with low complexity in a variety of conditions noise.

PRIME provides high rate data communication through the use of un-coded mode, since the G3 privileges the issue of robustness by supplementation of the convolutional code with a Reed Solomon (RS) outer code defined and uses repetition rate code 1 / 4 convolutional end code in output.

Moreover PRIME supports interleaving on the entire package of physical layer in only one symbol in 2.048 ms. The G3 does the intercalation of the whole package of physical layer, up to 252 taking symbols in each 640 micro seconds.

The structures of coding and parameterization used in G3 and PRIME have unique characteristics and merits, and can be synthesized and optimized to produce a single coding structure that can yield high performance with low complexity in a variety of noise conditions.

Although, the activities for exclusive monitoring of ITS there is no need high bandwidth communication capacity, and it is necessary that quality of services of data communication and / or allow the network performance meet the requirements of real time.

The narrowband interference occurs mainly in low voltage distribution due to narrowband communications systems and television receivers screen refresh rate. This paper considers the use of narrowband PLC at low voltage as presented on Fig. 2.

At PRIME and G3 PLC the different noise levels and impedances on the same network can create a good communication level in one direction and a worst communication level in opposite direction, so it is necessary to evaluate each direction separately.

Parameter	PRIME	G3
Nominal sample Frequency	250 KHz	400 KHz
FFT Length	512	256
Modulation	Frequency-Differential	Time-Differential
Type of Modulation	DBPSK DQPSK D8PSK	DBPSK DQPSK
Channel Interleaving	One symbol (2,048 ms)	Across symbols over the whole packet up to 256 symbols, each with 640 ms.

Fig. 4 Narrwoband PLC comparisson

The magnitude of transfer function could be verified through the transmission of block with constant magnitude on neighbouring frequency bands, so the receiver detects these like OFDM symbols and performs a FFT (fast Fourier transform), as presented on figure 3. [6]

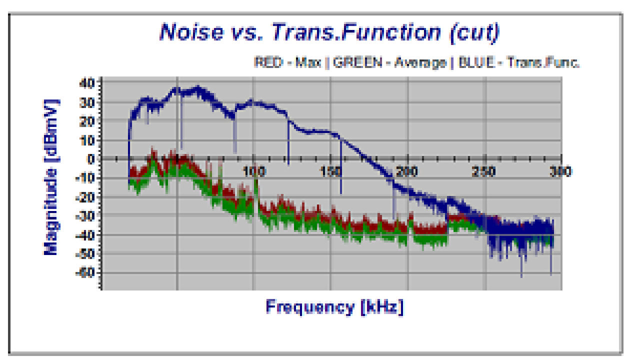

Fig. 5 Noise versus Transfer Function [6]

The SNR (signal-noise relation) is an important criteria for evaluation of data communication, so it is necessary to analyses the signal in frequency and time domain intensive communications tests on different frequencies, considering several bandwidths and type of modulation are performed in each situation.

The results permit to compare PRIME and G3, considering: [6]

- Number of received synchronization;
- Number of correct packets;
- Maximum and average value of the gain selected by AGC (Automatic Gain Control) during the synchronization.

The energy distribution environment is extremely complex because it depends on several elements that are meeting the network as resistance wiring, transformers, repeaters, among others.

So it is difficult to predict the behaviour of data communication through PLC, which can be worsened with the amount of nodes that exist in the distribution line.

V. Evaluation

This paper evaluate the PLC narrowband as means of transmitting data between the sensors and the ITS systems on medium voltage lines (13.8 kV), which concludes that the transmission is feasible because the medium voltage lines interference and the noise is low, moreover, as the application of monitoring does not require high sustained transfer rate, this allows the PLC to operate with greater simplicity.

For that, this work considered the evaluation of PRIME and G3 PLC, which have similar physical layer, and the PRIME privileges the high data rates during favorable conditions and G3 PLC provides better performance on unfavorable conditions. Both projects can be used as a transmission data channel for communication between sensors and ITS systems, due to the low bit rate required.

The initial tests started with two modems composed of F28069 controller board and AFE031 board to wire PLC, both of Texas Instruments. These modems come shipped with PRIME as the communication protocol between the PLCs, with the following characteristics:

- Operating frequency in the range 40-90 kHz (CENELEC A)
- Data rates from 21 kbps to 128 kbps
- Transmission made with OFDM (Orthogonal frequency-division multiplexing) and FEC (forward error correction)
- Modulation phase shift (DBPSK/DQPSK/D8PSK)
- Automatic Gain Control (AGC)
- Support for layers PRIME PHY, MAC, and IEC61334 -4-32 LLC
- Ports with USB and RS-232 for control and as host for data transmission

The initial tests performed in the laboratory analyzed the behavior of different scenarios in modem connection settings for the equipment and modulation, gain and different packet size.

The scenarios analyzed in this report are:

- Direct cable 100m: Both modems were connected to each other via a cable of 100 meters and were not connected to any power network, and the only electrical signal through the wire is the signal generated by the PLC.
- Connection through the electrical grid of laboratory: this scenario the communication between the modems was made linking them in electrical grid of 110 volts present in the laboratory. They were ligated in two places near the same phase.

In order to verify and analyze the operation of the modem to the different situations was used PLC application Quality Monitor, used to change the modem settings when using PRIME. The settings are varied to check the behavior of the PLC are:

- Modulation: There are 3 different modulations to the modem using PRIME: DBPSK, DQPSK, D8PSK
- FEC (Forward Error Correction): FEC adds redundancy to the transmitted signal to reduce errors in transmission.
- Transmitter Gain: the gain of transmission can changed and there are 8 different levels ranging from 3db gain among themselves.
- Receiver Gain and AGC (Automatic Gain Control): The receiver can be set to use automatic gain control that adjusts the gain of the receiver to present less variation and better output signal. Furthermore it is possible to adjust the receiver gain manually to choosing among eight levels ranging from 6dB to each other.
- Curve Data: The program allows you to pass three different kinds of data packet, and they fixed a byte, a ramp that ranges from 0 to 255 and the standard of certification data PRIME consisting of two sentences (PRIME IS A WONDERFUL IS TECHNOLOGYPRIME A WONDERFUL TECHNOLOGY) with no space between them.
- Size PPDU (Physical Layer Protocol Data Unit): This size varies from 1 to 765 bytes when the FEC is disabled and 1 to 377 bytes when the FEC is enabled.

In both scenarios the modems were configured to transmit data with a slope of 125 bytes and PPDU with AGC on. The reason for the size of the PPDU was chosen due to the behavior of the BER curve X PPDU that indicated only for very small values of PPDU that effectively changed the rate. As in actual cases of continuous transmission of the PPDU value tends to be near the maximum value was used a small value not presenting the same values for BER PPDU that in cases of large.

For direct connection with 100 meters of cable, initially was analyzed the operation of the modem conditions of scenario 1 above, where the modems were connected directly to each other with a 100m cable between them just where he passed the signal generated by the PLC. In this situation was expected that in whatever chosen modulation even without the FEC activated, the signal data transmission errors not present and also the SNR would be low, as there were no external interference and impedance of the wire was too low to affect the transmitted signal.

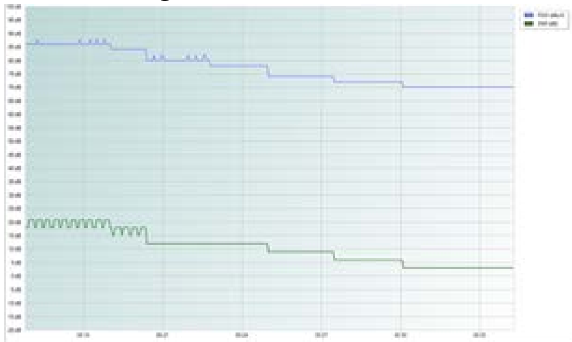

Fig. 6: SNR versus RSSI

The figures 6 and 7 show the signal to noise ratio and the error rate for the six variations of modulation.

Both the SNR as BER varies due to the gain variation of transmission is done during transmission, where the moments in which it can be noticed varies by more abrupt variations in curves.

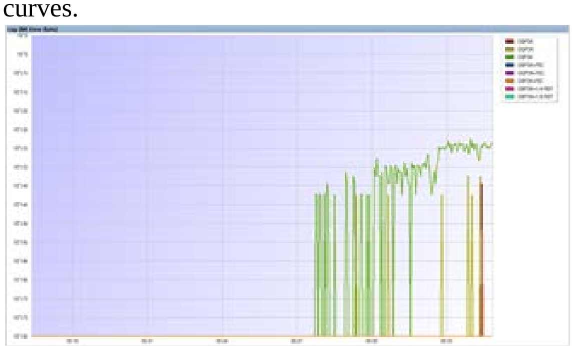

Fig. 7: Bit error rate with several modifications

As expected, the above figures show that even for values slightly below the maximum gain of the transmitting PLC showed high reliability even with zero error rate for the three modulations even without the FEC. It can only observe non-zero values of bit error rate with earnings below MOL (Maximum Output Level) -15dB when the FEC is not enabled, and when using the FEC transmission shows no error even for low SNR. Using then a gain of transmitting up to 9dB below the maximum reliability can be guaranteed at a maximum transmission velociadade 128kbps with the modulation D8PSK without using FEC.

VI. CONCLUSION

This paper evaluated the possibility of using the PLC narrowband as means of transmitting data between the TMS and ITS elements, which concludes that the data communication is feasible because the distribution lines interference and the noise is low, moreover, as the application of monitoring does not require high sustained transfer rate, this allows the PLC to operate with greater simplicity.

For this conclusion, the paper considered the evaluation of PRIME and G3, which have similar physical layer, and the PRIME privileges the high data rates during favourable conditions and G3 provides better performance on unfavourable conditions. The both projects can be used as a communication data channel for communication between TMS and ITS elements, because this communication requests a low bit rate.

The PRIME was evaluated with success in the laboratory, so the project will evaluate the performance by installing equipment in the field, which will hold the interconnection between SEGP and OCC. In this experiment will be assessed the quality of services parameters and performance of PLC technology under real conditions of use.

The next steps in the project is to implement a pilot project using the PLC narrowband as data communication line between the Traffic light management Systems and Real-time traffic light in a big city in Brazil, in order to verify the behaviour of the communication infrastructure in a real

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