LTE AND PLC TECHNOLOGIES FOR MV NETWORK SUPERVISION AND AUTOMATION

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ABSTRACT

This paper introduces the main features of the communication infrastructure used in the GRID4EU Demo 4 that will support new security features and control along the Medium Voltage distribution network by the use of LTE wireless technologies and FCC band power line communication using G3-PLC standard.

INTRODUCTION

The growth of DER, like wind farms, photovoltaic and biomass plants, requires an electricity grid infrastructure capable of managing a bidirectional energy flows that involves:

- A strictly connected system composed of generation, distribution and storage elements.
- The capability to smooth out the intermittent performance of renewable energy sources.
- The increase of hosting capacity without electric grid refurbishment.

Although energy storage elements can actively balance energy demand and DER production, "the most cost-effective approach to large scale electricity energy storage is to minimize the need for it" [1]. A new smart grid can be achieved only by an optimization of all grid elements where the resources involved in the energy production and telecontrol system are distributed in a large geographical area.
Some of the possible benefits of distributed telecontrol systems installations are:

- Remote monitoring of network status about grid condition around each primary and secondary substations.
- Reduction of maintenance costs by the use of suitable diagnostic indicators.
- Operational management procedures to reduce dead trunks or grid topological changes.

A communication infrastructure that permits information exchange and commands in a secure and reliable way, combining all disparate source of information will be realized using LTE (supplied by a TelCO provider using a public infrastructure) and PLC (power line communication) technology in the Demo 4 GRID4EU European project (Figure 1). A major innovation of this architecture is primarily linked to an IP-based (IPV4/6) network where IEC-61850 protocol will be used for all messages exchange through the elements in the portion of distribution grid connected to a Primary substation.

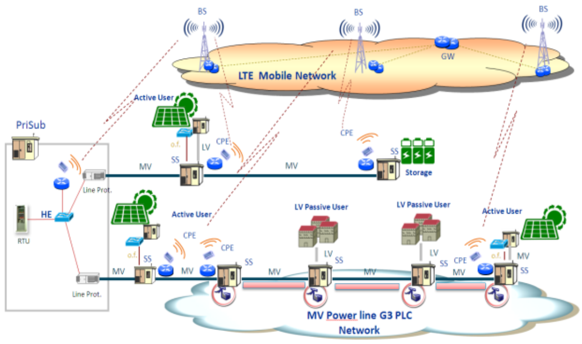

Figure 1 - Communication infrastructure in Demo4 GRID4EU project

The IEC-61850 standard was originally developed for inner Primary substations communication purpose. Nevertheless, It can be used for securely sending MMS, GOOSE and SV messages over wide area network.

LTE WIRELESS TECHNOLOGY FOR MV NETWORK AUTOMATION

The volume of data exchanged and the maximum latency in message delivery for distribution networks control, automatic protections and management has been estimated by two recent European and American reports [2][3]. Both reports created a summary of telecommunication requirements for distribution network automation (Table 1).
The estimated volume of information to be sent through the use of IEC 61850 requires a telecommunication infrastructure capable to exchange data with an adequate value of throughput, latency, jitter and packet loss ratio.
LTE is a new standard for mobile communication that provides an improvement in term of data rate, latency and packet loss in respect to previous 3GPP technologies like UMTS and HSPA. The growth of this technology and the new capabilities that it introduces, makes LTE an attractive perspective for the use in Smart Grid application.

	Transfer rate	Latency	Priority	Reliability	Availability
Inject energy surplus into the grid	1-5 Kb/s	5-60 s	Low	0.1-5%	80-90%
Produce maximum power	1-5 Kb/s	5-60 s	Low	< 0.01%	80-90%
Peak shaving	5-100 Kb/s	200ms-500ms	Medium	0.01-0.1%	90-99.9%
Anti-islanding	1-5 Kb/s	200ms-500ms	High	< 0.01%	99.9%
Voltage and reactive power regulation	5-100 Kb/s	0.5s-5s	High	< 0.01%	99.9%
Support island operation	5-100 Kb/s	200ms-500ms	High	< 0.01%	99.9%
Ensure correct operation of power system	5-100 Kb/s	200ms-500ms	High	< 0.01%	99.9%

Table 1 - Smart Grid Communication Requirements (source[3])

Encapsulation of IEC-61850 in L2TPV3

The use of a public mobile network for the transport of electrical network data and control message requires the need to encrypt the information. IPSEC protocol offers an high level of security with a keyed-hash message authentication code (HMAC) and cryptographic hash function, such SHA-1. The IPSec protocol adopts a Layer 3 tunnel mechanism for IP packet encapsulation in a new encrypted packet with a specific header tunnel (Figure 2). IEC 61850 uses the Manufacturing Message Specification (MMS) mapped to TCP/IP protocol stack to support the transfer of data and control information between substation devices. For time-critical events such as the protection of electrical equipment IEC 61850 uses messages know as Generic Object-Oriented Substation Event (GOOSE) that, in the case of a local Ethernet network, are mapped directly to the Ethernet IEEE 802.1q frame .In order to transport of MMS messages in a secure mode only a IPSEC protocol is required. On the other hand for transmit GOOSE messages over the WAN a Layer 2 tunnel must be employed. For this purpose a L2TPv3 tunnel has been selected (Figure 2).

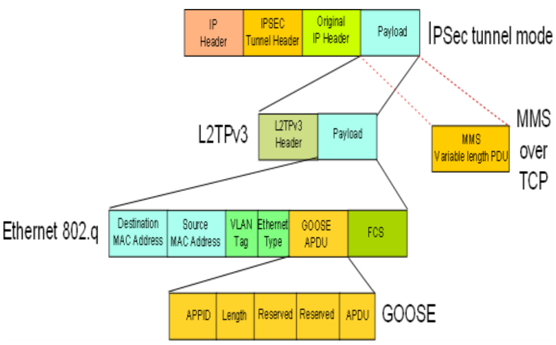

Figure 2 – Goose and MMS packet encapsulation

GOOSE traffic from primary substation to protection relay located into secondary substations requires deterministic and low latency treatment (<200ms). To evaluate these timing requirements, the increase of the header for transport on the LTE network should be evaluated.

The latency analysis in the LTE network can be evaluated by sending different ICMP data length packets so as to calculate round trip time (RTT) and packet loss statistic. Table 2 shows RTT for different data packets length using LTE modem from two Sweden mobile operator.

Length (byte)	Mean (ms)	Std (ms)
50	16.47	13.14
100	18.54	17.87
500	22.33	14.63
1000	29.65	30.86

Table 2 – RTT time for different data packet lengths (source[4])

Grid4EU Demo4 test scenario

Our proposal for GRID4EU demo 4 is to transport information from Primary substation to Secondary substations (Figure 3) using L2TPv3 Tunnel over IPSEC protocol over Wireless LTE network in accordance with the project partner ENEL Distribuzione.

The demonstration site for Demo 4 GRID4EU is located in an Italian rural area and involves 2 primary substation and 100+ secondary substations. The Cisco routers, located in each secondary substations, are connected through the LTE Service Provider network to a main "HUB" located in WAN Enterprise Network (Figure 3). GOOSE frames leaving the Intelligent Electronic Device (IED) should already have their VLAN tag set.

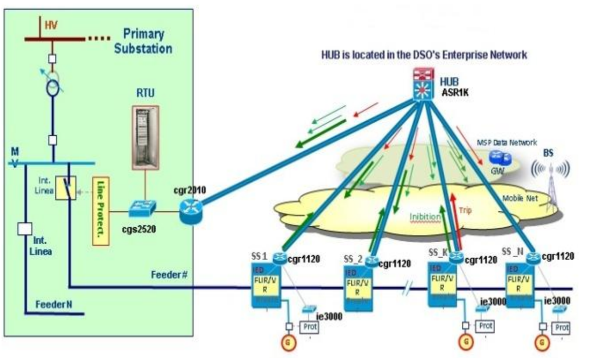

Figure 3 – Architecture of Smart Grid "Extended Substation"

The primary objectives of CISCO activity research in GRID4EU DEMO 4 are:

- Setting the Substations router configurations for the transport of IEC 61850 message.
- LTE latency estimation by the measure of RTT through IP analyzer
- Throughput and latency estimations for IEC61850 message transportations over LTE network.

FCC G3-PLC WIRELINE TECHNOLOGY FOR MV NETWORK AUTOMATION

FCC band G3-PLC standard

It is well known that Cenelec-A band (36 – 90 kHz), used for power line communication system in the low and medium voltage distribution networks is a bottleneck in term of available bandwidth. Moreover it presents a challenging noise level [5]. The PLC noise comprises two main components [6]:

- **Background noise –** composed of coloured noise and narrowband interference caused respectively by residential electronic equipment and external broadcast radio bands.
- **Impulsive Noise –** composed of periodic impulsive noise generated mainly by inverters in Disperse Generation (DG) plans and aperiodic impulsive noise generated by connection and disconnection of electrical devices.

Figure 5 shows the noise level for a MV power line. As it can be seen, the inverter noise contribution is concentrated on CENELEC band.
On the other hand the noise in FCC band (150 kHz to 500 kHz) is lower than the noise present in CENELEC band. The use of multicarrier modulation based on Orthogonal Frequency Division Multiplexing (OFDM) that include an advanced forward error correction mechanism allows a robust communication with an high bit-rate over multi-kilometer in the medium power lines [7]. FCC frequencies allows cohabitation of frequencies that are reserved for other applications in power line communication like metering (CENELEC-A band) and home area network devices communication (2-30 MHz). The new generation of standards that uses narrowband PLC technologies adopts the preamble-based CSMA mechanism to share the communications medium when the devices operate in the same frequency band [8].
G3-PLC protocol has been developed some years ago for metering appliance in LV power line network and uses OFDM modulation scheme in the following frequency band:

- Cenelec-A Band 36-90 kHz
- FCC Band 154-487.5 kHz

In FCC band a total of 72 data subcarriers are transmitted between 154.6875 kHz and 487.5 kHz adaptively using one of the three differential digital modulation schemes DBPSK, DQPSK and D8PSK (Table 3).

Modulation	max rate[kbit/s]
DBPSK	62
DQPSK	124
D8PSK	298

Table 3 – G3-PLC data rates in FCC band (source[9])

Encapsulation of IEC-61850 in FCC G3-PLC

G3-PLC has been approved in October 2012 as ITU recommendations G.9901 for power spectral density specification and G.9903 for PHY and MAC layer specification. MAC sub-layer is based on IEEE 802.15.4-2006 while IETF RFC 4944 6LowPAN is used to adapt MAC layer to IPV6. In order to connect two electrical substations with a dedicated link for IEC-61850 protocol transportation, L2TPv3 represents a good choice to implement a VPN tunnels over IPv6. Figure 4 illustrates the protocol stack adopted in G3-PLC devices over MV network grid.

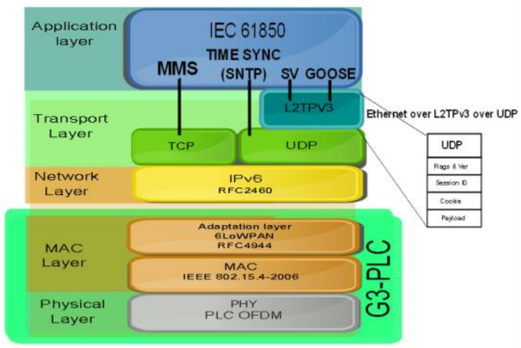

Figure 4 – G3 protocol stack for IEC-61850 transport

Practical implementation in GRID4EU Demo 4

In GRID4EU Demo 4 project a new type of capacitive coupling device interfacing MV power line to a PLC-G3 modem in the frequency band between 150 kHz and 500 kHz has been tested. Laboratory tests have been performed in a site with the presence of photovoltaic plants by the use of an LV/MV transformer and a 100m length MV cable. An improvement of SNR in FCC frequency band (Figure 5) has been observed.

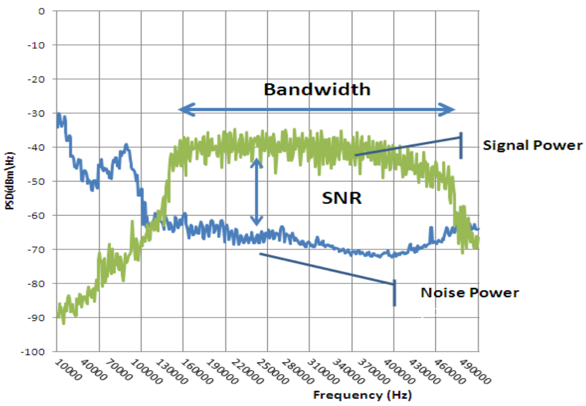

Figure 5 - G3-PLC signal and Noise PSD

The MV feeder selected for FCC band G3-PLC technology testing is located in a rural radial distribution power network.. The feeder under test involves seven substations and five underground medium voltage line trunks with a total length of 2.5 km . Different variety of switchgears and cables have been found (Figure 6).

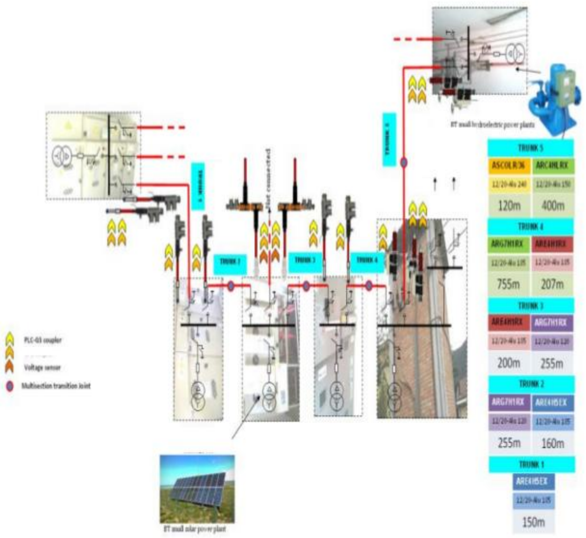

Figure 6 – MV feeder portion under test

The primary objectives of SELTA activity research in GRID4EU DEMO 4 are:

- Attenuation and noise level measurements for each trunk and between all substations.
- Data rate measurements for each network conditions between substations.
- Throughput and latency estimations for IEC61850 MMS and GOOSE message transportations over G3-PLC network.

CONCLUSION

The first experiments have proven that LTE network is a promising solution due to its low latency and large bandwidth. The proper working conditions require TelCO operator to fulfill the latency and bandwidth requirements in order to not impact the QoS and guarantee the necessary constraints. The latency less than 70 milliseconds is required for GRID4EU DEMO 4 project. The use of a dedicated communication network for MV distribution network automation by the use of FCC G3-PLC technology may be useful in rural areas where the mobile networks don't reach the same performance and availability than urban areas.

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