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COMMUNICATION IN SMART GRIDS USING LTE

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
ACSI	Abstract Communication Service Interface
AMI	Advanced Metering Infrastructure
AuC	Authentication Centre
DERs	Distributed Energy Resources
DPWS	Devices Profile for Web Services
EMM	EPS Mobility Management
ESM	EPS Session Management
GOOSE	Generic Object Oriented Substation Event
GSE	Generic Substation Event
GSSE	Generic Substation State Event
HAN	Home Area Network
IEC	International Electro Technical Commission
IEDs	Intelligent Electronic Devices
LNs	Logical Nodes
LTE	Long Term Evolution
MAC	Media Access Control
MDMS	Meter Data Management System
MIMO	Multiple-Input Multiple-Output
MMS	Manufacturing Message Specification
NAN	Neighborhood Area Network
NAS	Non-Access Stratum
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PDCP	Packet Data Convergence Protocol
PLR	Packet Loss Ratio
PTP	Precision Time Protocol
QoS	Quality of Service
RLC	Radio Link Control

RRC	Radio Resource Control
SC-FDMA	Single Carrier-Frequency Division Multiple-Access
SCADA	Supervisory Control and Data Acquisition
SCL	System Configuration Language
SCSM	Specific Communication Service Interface
SCTP	Stream Control Transmission Protocol
SE	State Estimation
SNTP	Simple Network Time Protocol
SV	Sample Value
UCA	Utility Communication Architecture
WAN	Wide Area Network

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ABSTRACT

The world today is focusing on the enhancement of efficient use of energy and it has compelled the energy industry to research and seek for measures for increasing energy efficiency. Out of various fields related to energy, Smart Grid has emerged itself as one of the effective contributor to fulfil the approach of efficient use of energy. The term smart grid has been evolved from power grid where the energy is generated, distributed and finally consumed by a consumer. The smart form of this power grid is actually smart grid which facilitates smart way of communication of smart devices between grids, so that the effective mode of controlling and monitoring can be achieved. In order to achieve this, the devices should be smart enough so that they can be interoperable and remotely accessed. For the smart devices to communicate in real time so that controlling and remote access becomes possible, it demands an advanced communicating medium.

LTE is one of the most challenging, famous and widely adopted communication technology that meets the requirement imposed by broadband wireless mobile communications. Early tests, evaluations and their pre-commercial deployments have proved that they fulfil all the requirements like high-data-rate, low latency and optimized system that advanced communication demands.

Thus, this paper focuses on the evaluation of integration of LTE in Smart Grids so that automation in Smart Grids can be achieved.

KEYWORDS: LTE, Smart Grids, IEC 61850, MMS, Intelligent Electronic Devices.

1. INTRODUCTION

It is evident that the world is concerned about the proper use of electricity and every individual wants the efficient use of energy so that lower electrical bills have to be paid. Misuse of electricity, lots of wastage of energy, stealing of energy etc. are the factors that have compelled the energy market to seek for an alternative solution that would lead to efficient use of energy, eradicate such energy theft and other drawbacks. In the process of search for the solution of above mentioned problem, Smart Grid has emerged itself as a promising technology for the alternative solution in order to eradicate the issue. For the efficient working of the Smart Grid, every utilities connected to Smart Grid must be able to communicate with each other. IEC 61850 has emerged as a standard that every utilities related to Smart Grid has to follow in order to be interoperable. This also facilitates the energy created by distributed energy resources to be injected at any point in the grid. (Jose et al. 2011: 193-194).

However, there are some earlier technologies that does not adhere to this IEC 61850 standard. As a result, those earlier technologies does not facilitate smooth and continuous communication of every utilities connected in the Grid. A project was then carried out aiming to design a standard that uses IEC 61850 standard and Devices Profile for Web Services (DPWS) whose target was to ease in the continuous communication by all utilities in the Smart Grid. For those devices that does not comply both IEC 61850 and DPWS, a connector called NEMO-C is used. (Jose et al. 2011: 193-194). Similar solution has also been talked by Bernard et al. (2012: 403-404) that IEC 61850 standard could be mapped with earlier technologies and this mapping task has already been done. 4G Long Term Evolution (LTE) defined by 3rd Generation Partnership Project (3GPP) is the latest technology aiming to provide an alternative Wide Area Network (WAN) technology to support IEC 61850. (Pham 2013: 1-2).Thus, the purpose of this research is to examine the Bit Error Rate (BER) when this mapping is done and when LTE is used as a communication medium.

1.1. Motivation for integration of IEC 61850 MMS and LTE

IEC 61850 is a standard that is widely adopted by the power system automation market. The earlier version of the standard that was published in 2005 failed to consider two main important redundant protocol: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR). IEC 61850 however corrected this lag bringing these two protocols into picture. These two protocols play a vital role in facilitating seamless (0 s) network recovery times fulfilling the most demanding requirement for substation automation network (Taikina-aho 2011: 10). MMS which is the OSI protocol that runs over TCP/IP or OSI networks is mapped with IEC 61850 for metering purpose. At present the MMS uses Ethernet that is widely used as Local Area Network (LAN) protocol. However, besides high setup cost and non-flexible nature that Ethernet possesses, it is also impossible to apply Ethernet in distribution networks that covers a very huge area. For this reason it is preferable to use IEC 61850 MMS on top of another Wide Area Network (WAN) technology that can facilitate smart metering communication in wide area (Pham 2013: 2).

The most important technical requirements of smart grids with regard to network are reliability, latency, throughput and QoS (quality of service). Several tests done on laboratory and field suggests that LTE networks undoubtedly meets the technical requirement for smart grid communications. (Ericsson 2013:2).

4G Long Term Evolution (LTE) is the latest and a promising cellular WAN technology defined by 3rd generation partnership project (3GPP). LTE facilitates increased capacity and high speed to withstand rapid increase in data traffic approximately 5 billion mobile broadband subscriptions in 2016. 154 operators have adopted this technology throughout 60 different countries along with huge number of ongoing LTE trials. Currently, over 200 million people are benefited with LTE. More than 300Mbps of speed can be achieved with this technology. In 2010, Ericsson demonstrated the theoretical peak rate of LTE up to 1.2Gbps. (e-netsource 2010).

Thus, integration of LTE with IEC 61850 MMS can be a solution for intelligent electronic device (IED) or smart grid communication. Prediction of load profile, load forecasting, support real-time pricing etc. can be achieved by collecting real time meter data. However, the question lies whether this solution proves to meet the performance criteria of real-time meter data collection provided that there are a huge number of smart meters present in a large territory. Moreover, analysis on the network imposed by smart meter traffic and LTE network traffic is necessary. Therefore, this research aims to investigate whether this proposed solution succeeds in meeting the performance criteria of real-time meter data collection along with the impact on the LTE network due to mutual traffic between smart meter and LTE background user traffic.

1.2. Research Questions

While investigating whether the integration of IEC 61850 MMS with LTE will support communication between intelligent electronic devices (Smart meters) and the central meter data management system, three major research questions are considered.

1. How can IEC 61850 MMS and LTE be integrated?

This question concerns the requirements for metering demanded by IEC 61850 along with the challenges in integrating IEC 61850 MMS with LTE.

2. What are the performance requirements and challenges?

This question identifies the key requirements that smart metering application demands.

3. How does the bit error rate gets influenced by the different modulation techniques used in LTE and how does convolution coding enhance the BER performance?

The answer to this question is addressed partly by answering question 2. Furthermore, the performance requirements are discussed in detail and in fact, the answer to this question will be obtained from our simulation.

2. CONCEPT AND REQUIREMENT OF SMART GRID

Smart Grid is an advancement to the existing power grid and it is automatic, interactive and IT-based. With strong grid structure, deployment of IT platform and intelligent control, Smart Grid covers six segments starting from power generation, transmission, transformation, distribution and consumption to dispatching (Jin, Zhang & Wang 2012: 1-2). A Smart Grid is one that makes use of communication technology along with IT so that all components of power grid starting from generation station, distribution facilities, transformers, businesses and households can be linked so that stable supply and efficient usage of electricity can be achieved (Renesas 2010). According to the Electric Power Research Institute (EPRI), Smart Grid is one that includes information and communication technology into every stages from electricity generation , transmission, delivery to consumption aiming at reducing environmental impacts, enhance markets, improve reliability and Service and reduce cost (Pham 2013: 6). Smart Grid is an idea which combines the process of power generation to its distribution as a whole in one frame making the proces very smart.

We are all aware about the worldwide need of utilisation of clean energy. Use of energy very smartly and efficiently is also similar to using clean energy. The term Smart Grid was used by Michael T.Burr for the first time when he wrote an article in 2003 where he explains about the weakness of existing power grid and how the weakness can be solved in order to better smart power flow starting from the process of generation to distribution. The use of protection system of the power grid and the central control system achieved by Supervisory Control and Data Acquisition (SCADA) system, diagnosing and monitoring of all transmitting equipment, Grid computing, making the power system a self-healing network actually makes Smart Grid so Smart (Shuva et al. 2014: 2). The diagnosing, monitoring and self-healing capability in smart grid is achieved by state estimation (SE) process. Monitoring of the state of the grid and energy management system is achieved by State estimation which in turn helps in performing various control and planning tasks. For instance optimizing power flows or help in bad data detection/analysis. In addition, SE also helps in determining SE-based reliability/security assessment that is run in order to detect faults and to determine necessary actions to be done in order to get rid of failures in the power system. In other words, this is how self-healing is carried out in the system by the help of SE. As we can see that state estimation plays a very vital role in the performance of smart grid, there are some aspects that will influence SE process in smart grid. First, some of the highly advanced technologies like phasor measurement units (PMUs) offers room for real-time monitoring of smart grids. Normally, PMU takes around 30 measurements and offers possibility of viewing the dynamics of power system. However, incorporating PMUs with higher measurement frequency delivers enormous stress on the communication and data processing infrastructure of the grid. Thus, rather than taking measurements when it is not required a different approach of event-triggered SE solutions that works on-demand sensing (event-triggered), estimation and communication is needed. Second, Smart Grid facilitates two-way power flow and demand response to which the utility companies needs to have SE at both distribution systems and transmission systems. So far, SE has been implemented well enough at transmission systems but very few has been done at distribution level. As the grid is becoming smarter, more distribution automation will be needed and naturally SE at the distribution will be equally important. (Huang et al. 2012: 33-34). Figure 1 shows the conceptual diagram of Smart Grids.

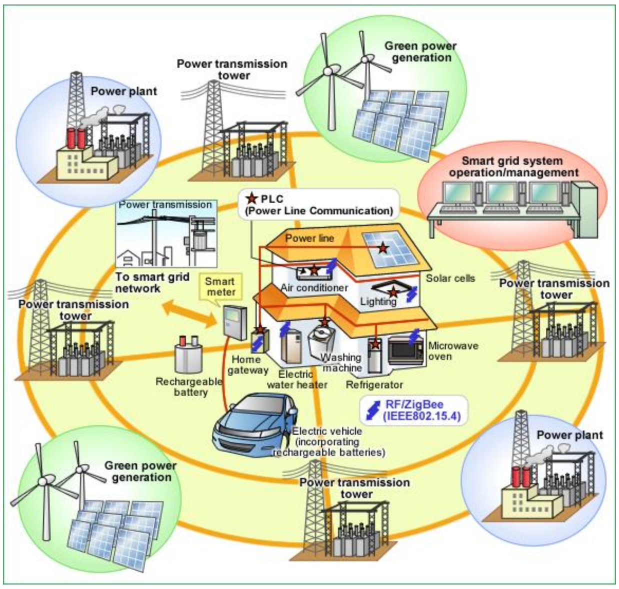

Figure 1. Conceptual diagram of Smart Grid. (Renesas 2010).

A better understanding about Smart Grid along with its features is necessary in order to be able to use Smart Grid efficiently. Among many features of Smart Grids, some of the very key features of Smart Grids that makes it smart are listed below. (Shuva et al. 2014: 201).

- Smart Meters (SM)
- Distrubuted Generations (DG)
- Renewable Energy Integrations (REI)
- Bidirectional Community System (BCS)
- Automatic Healing Capability (AHC)
- Data Security/Cyber Security
- Carbon Emission Reduction
- Meter Data Management (MDM)
- Field Area Network
- IT and Bank Office Computing
- Demand Response
- Electricity Storage Devices
- Distribution Automation

There will be great impact of Smart Grids on future economy, deployment of clean energy will facilitate green platform for energy-saving equipment, energy optimization structure, efficiency improvement, reduction of emission and combating climate change. Some of the strategic objectives of Smart Grid are listed below. (Jin, Zhang & Wang 2012: 2).

- Great Capability to optimize resource allocation
- Stable operation and good level of Safety
- Good adaptation and contribution to clean energy process
- Grid dispatching process done with high smart application level
- New Service demands such as EVs will be fulfilled
- Ease of interactivity between grids and customers
- IT-based and intensive management of Grids

2.1. Difference between Smart Grid and exiting Power Grid

Traditional power grid system was not suitable in many aspects. There were many drawbacks that differentiates traditional Grids from Smart Grids. Some of them are lack of supply of real time data, imperfect system of data measurement, insecurity, theft etc. (Shuva et al. 2014: 200-201). The difference between Smart Grids and traditional power grids is depicted in Table 1. Traditional Grid is not flexible in terms of power source as well as its transmission. It does not take into account the power source from renewables. Hard to form real time data analysis, poor visibility, and inadequate self-healing and self-recovery capability are some of the key drawbacks of traditional power grid. On contrary, Smart Grid fulfils all the above mentioned drawbacks present in traditional grid along with two-way interactive power supply. It considers user as part of the system by interacting with the user equipment and acknowledging user about their electricity usage (Hou et al. 2011).

Table 1. Difference between traditional Power Grid and Smart Grid. (Wei 2014).

Traditional grid	Smart grid
Electric machinery	Digital
One-way communication	Two-way communication
Centralized power generation	Distributed power Generation
A small number of sensors	Full grid sensor layout
Manual monitoring	Automatic monitoring
Manual recovery	Automatic recovery
Failures and power outages	Adaptive and Islanded
Few user options	More user options

Smart Grid on the other hand addresses and smartly handles all the above mentioned issues. Monitoring the whole system from supplier end to user end, consumer being able to see the amount of electricity he/she is using, fault identification and self-healing capacity of the smart grid are the key points as to why smart grid is undoubtedly the solution for efficient electricity usage in this modern world. Also, unlike traditional grid which is electromechanical in nature the smart grid is totally digitized and controllable by computer. It can be seen from Figure 2 that existing power grid took very few concern on customer's choices. However, smart grid regards user as a part of the power system and gives priority to customer's choice. (Shuva et al. 2014: 200-201).

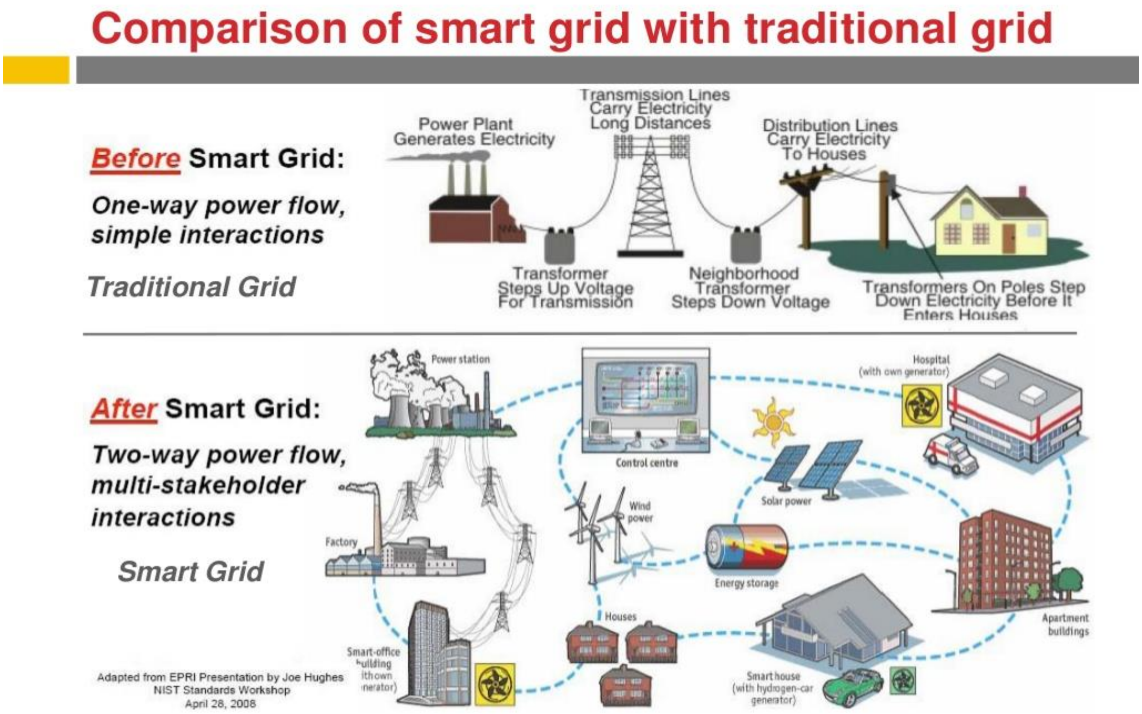

Figure 2. Comparing Smart Grid with traditional Grid. (Jalan 2015).

2.2. Advanced Metering Infrastructure Architecture and its Requirement

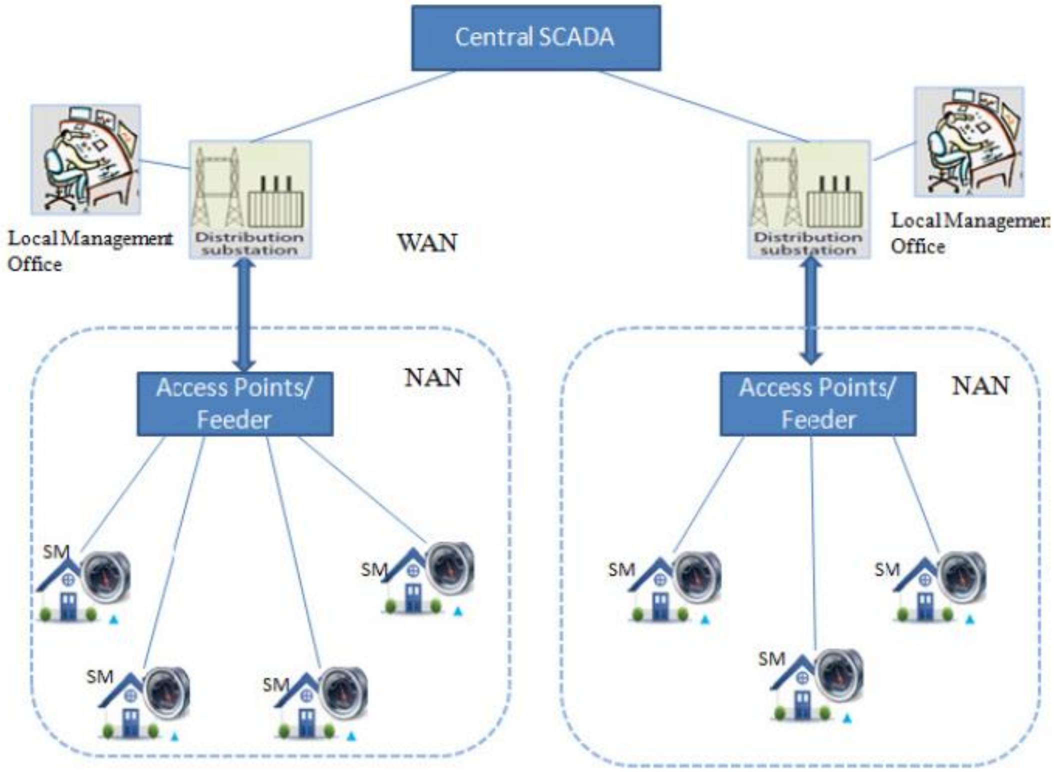

Figure 3. Smart Grid AMI Components System Architecture. (Mehra, Dehalwar & Kohle 2013: 395).

The advanced Metering is done by communicating all the entities involved in the system from lower end distribution substation to main distribution offices, transmission control centres and to production plants as can be seen in Figure 3. The smart meters that are located at the customers houses send their data to the local management office that are present in every distribution substation and to do so they use access points or feeders through which the data is sent.

The access points also helps the base station in the downlink communication where the base station sends information to the smart meter to optimize and control the power consumption of all the smart intelligent home appliances. The meter reading of all the customers is received from the management office present at every distribution substation and the reading is passed to central Supervisory Control and Data Acquisition (SCADA) system. Using either wired communication technology such as optical fibre or wireless technologies such as WiMax, SCADA delivers its bulk data across the main domain.

Here, each base stations (BS) is assumed to work in its area of network coverage where the BS communicates with the smart meters that fall in its territory. From the figure, we can see different networks in their hierarchies. A short description about those networks is listed below.

- Wide Area Network (WAN): The connectivity between WAN base station, its local management office, Central SCADA system and access point/feeder that acts as a NAN gateway is obtained by WAN.
- Neighborhood Area Network (NAN): It is responsible for the communication between the access point/feeder and the smart meters.
- Home Area Network (HAN): This network is used to connect all the smart intelligent home appliances with the smart meter so that the power consumption can be monitored every time and also be controlled to optimize power consumption.

The Neighborhood Area Network (NAN) and HAN (Home Area Network) is implemented through wireless communication technologies like cellular systems or multi-hop wireless networks as it offers less cost, minimum complexity and facilitates access extension without the need of cables for data communication. (Mehra, Dehalwar & Kohle 2013: 394-395).

AMI systems are beneficial to both the customers and the service providers in many ways. For instances, AMI system notifies the customers about how much energy they have consumed and what is the cost. Thus, the customer will control the use of electricity if it starts to go beyond their budget. Another benefit of AMI is dynamic pricing. Meaning that, the customer can shift their usage of energy from times of high demand to low demand. The price of energy at the time of low demand is comparatively less. In addition, it also guides for the development of future smart grid applications. (Pham 2013: 6-7).

All the above mentioned qualities of Smart Meter that makes it smart is made possible by virtue of Advanced Metering Infrastructure (AMI). AMI consists of meters which are really smart not only in terms of recording the consumed power data but it also collects and analyses energy consumption and demand data from home appliances. In addition, it also communicates and performs control operation in order to optimize energy management, power quality etc. Two way flow of information between the smart meters and the control centre so that direct load control can be achieved is obtained by AMI. (Mehra, Dehalwar & Kohle 2013: 394-395).

Through communication network, utilities can have more information about the grid which will help utility to estimate the availability and quality of the power they provide to the customers. Also, good communication infrastructure will also facilitate high penetration of DERs into the grid. Earlier, power transmission was done by only one way from generators to customers through transmission lines. However, if robust communication infrastructure is present then more DERs can be used to inject power directly on the distribution site. The DERs would be mostly based on renewable sources of energy like sun, wind, tide etc. For this, the communication network should notify the status of DER to the operating centre so as to avoid any accidents for humans. For instance, if the high power transmission line breaks and falls down then the network has to inform immediately to the operating centre to ensure that the DER power supply is in offline mode so that the human safety can be ensured.

Electric Vehicle is highly encouraged as it helps in reduction of fuel consumption and pollutant emissions. The introduction of electric vehicle puts forward increased demands on the grid. Communication must be ensured in control of the charging of electric vehicle so that the electric vehicle can be operated normally. In a nutshell, communication plays a key role in the transformation of the current grid into smart grid and utility companies are moving towards the deployment of advanced metering infrastructure (AMI) that facilitates two way communication and also does not allow utilities to work like its earlier Automatic Meter Reading (AMR). Through AMI, utilities instead of working like AMR, will be able to work on demand response way, dynamic tariffs facility to customers for load management will be done. It is for all these reasons, AMI is a very important requirement. (Pham 2013: 7-9).

2.3. AMI Components

There are a number of components involved in AMI system.

- Smart Meter: Smart meter is a measuring instrument for measuring the electricity consumed by the consumers. It takes the reading of the electricity consumption at certain time interval for few times a day as illustrated in Figure 4. This reading helps the consumers to understand the billing procedure and control the usage of electricity depending upon their budget. Likewise, it also helps the suppliers to calculate accurate electricity usage bills by the customers. (Shuva et al. 2014: 200-201).

Figure 4. Smart Meter. (Shuva et al. 2014: 200).

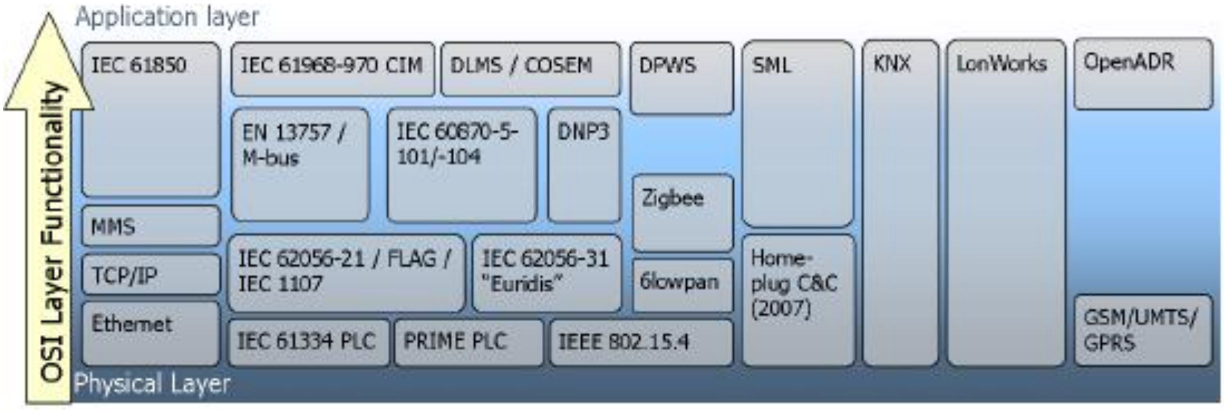

Figure 5. A place for OSI layer in the analysed standard. (Craemer & Deconinck 2010).

Smart Message Language (SML)

SML facilitates in data validation and parameterization and provides simple structure to be used in low-power embedded devices. SML lies on the upper layer in the OSI layer functionality presented in Figure 5. Apart from defining a file and document structure so that the data can be carried between measuring point and a collection centres, it also provides options for presentation layer: readable XML encoding or more efficient SML binary encoding. For specific applications involving metering, SML messages will be transported using protocols like transmission control protocol/user datagram protocol over IP networks. However, for serial links such as direct readout or GSM/PSTN SML transport protocol is available. (Craemer & Deconinck 2010).

IEC 62056-21

IEC 62056-21 standard also known as IEC 1107 describes standards for data exchange with utility meters. The exchange of meter data can be local or remote. IEC 62056 is limited to local data exchange, whereas other standards of IEC 62056 series covers remote data exchange. It consists of software protocols and hardware suitable for data exchange with utility meters. On hardware end, an optical interface along with a 3 two-wire system is described. In addition, asynchronous half-duplex ASCII-based RS232 data transfer is used. This standard is based upon the reference model for communication in open systems. It is one of the first meter data exchange standards that is very much in use today. (Pham 2013: 10-11).

Home Area Networks (HAN): HAN technology makes it possible to remotely connect and control the automated devices used in home. By combining smart meter with HAN helps to know about the peak electricity usage times and gain control accordingly as per requirement. HANs help in managing demand response. For instance, on a hot day, a smart controller would send a signal to the HV AC to operate whereas on a normal day or cold day, it would send a signal to the HV AC to turn off. (Huq & Islam 2010).

Meter Data Management System (MDMS): A meter data management system is a database consisting of tools whose primary function is to edit, validate and estimate the AMI data to ensure that the data flowing in the network is complete and accurate despite disruptions in the communication network or at customer premises. It also helps to interact with another information systems like Consumer Information System (CIS), billing systems, outage management systems (OMS), etc. (Pham 2013: 10).

Operational Gateways: These are the interfaces that facilitates the process of transmission and distribution in the grid. (Pham 2013: 10).

IEC 61850 Communication Stack

As the science and technology advanced into the digital world, certain requirements like high speed IED to IED communication, guaranteed delivery times, multi-vendor interoperability, security issues etc. increased. Along with the need to fulfil these requirements, the work on a standard architecture for communication began which gave birth to Utility Communication Architecture (UCA) in 1988. Later, combining the concepts and fundamental work done in UCA, International Standard IEC 61850 was founded for Communication Network and systems in substations.

Earlier protocols explained the transmission of bytes on the wire but they did not consider the arrangement of data in devices according to the application. Because of this the power engineers had to manually configure objects and map them to power system variables and low-level register numbers, I/O modules, etc. In order to address this issue, IEC 61850 provides a comprehensive model as to how the data should be organized in a power so that consistency to all types and brands of device is maintained. Thus, we get rid of the problem of non-power systems configuration as the devices can configure themselves. IEC 61850 device model is represented in Figure 6 that consists of different layers namely Physical Device, Logical Device, Logical Node, Data Object and Data Attribute. (Mackiewics 2006: 623-624).

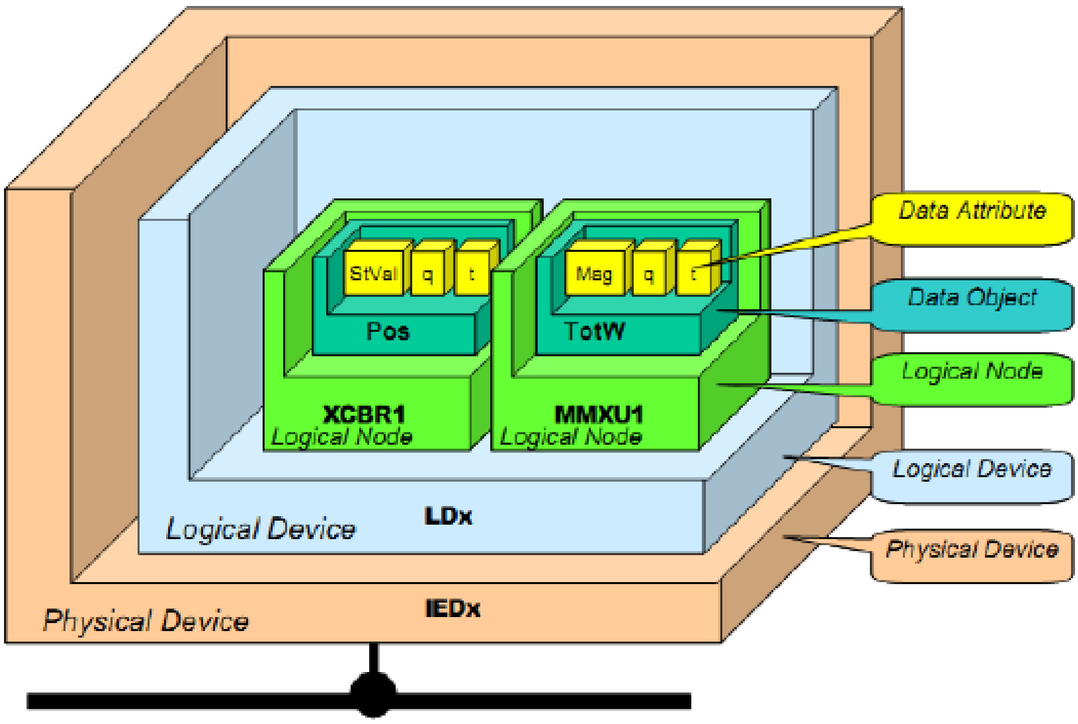

Figure 6. IEC 61850 data model. (Pham 2013: 13).

The physical device is used to connect to the network and is actually represented by its network address. The logical device facilitates a single physical device to serve as a gateway for multiple devices. Also, there is no fixed rule as to how the arrangement of Logical Devices into a Physical Device is done which offers great flexibility to the user. One or more logical nodes are present in each Logical Device. Logical node is simply a name given to a group of data and its associated services which is logically related to some power system functions. Logical Node represents the smallest functions of the device. Each Logical Node consists of one or more Data Objects and each data object has a unique name determined by the standard whose functionality is related to the power systems purpose. Each elements of data that falls under a Logical Node specifies a common data class (CDC) (Mackiewics 2006: 623-624).

In order to understand this, let us evaluate Figure 6. There is one physical device which contains one logical device in it. The logical device has two logical nodes where each node serves a specific function. Logical Node XCBR represents a circuit breaker while the other Logical Node MMXU serves as a measurement functions.

In a nutshell, IEC 61850 serves by standardizing the functions as Logical Nodes, classifying the communication interfaces between various functional layers. In addition, it models the information in terms of data objects, data attributes and abstract communication services. There are a number of internal parts in an IEC 61850 standard where each part is responsible for its specific function. Some part carries general information, introduction and overview while some parts carries information about general requirements. Figure 7 illustrates every part of an IEC 61850 standard. (Pham 2013: 13-15).

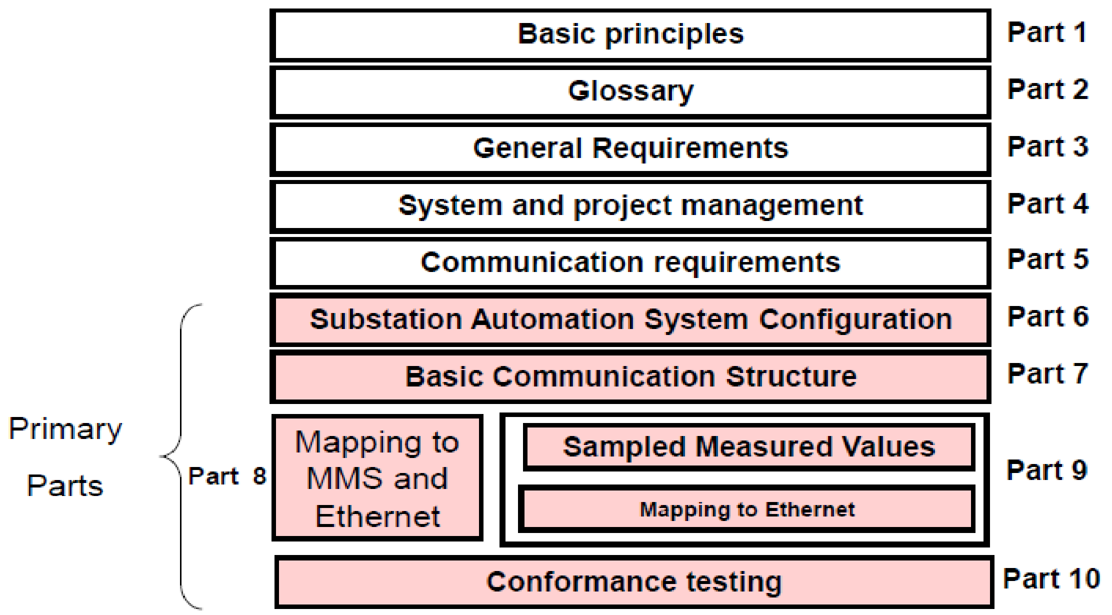

Figure 7. IEC 61850 internal parts. (Slideshare 2005: 9).

Figure 8 signifies the application of IEC 61850 deployed in different fields to define information models to be used in power plants, DERs and other areas is shown next.

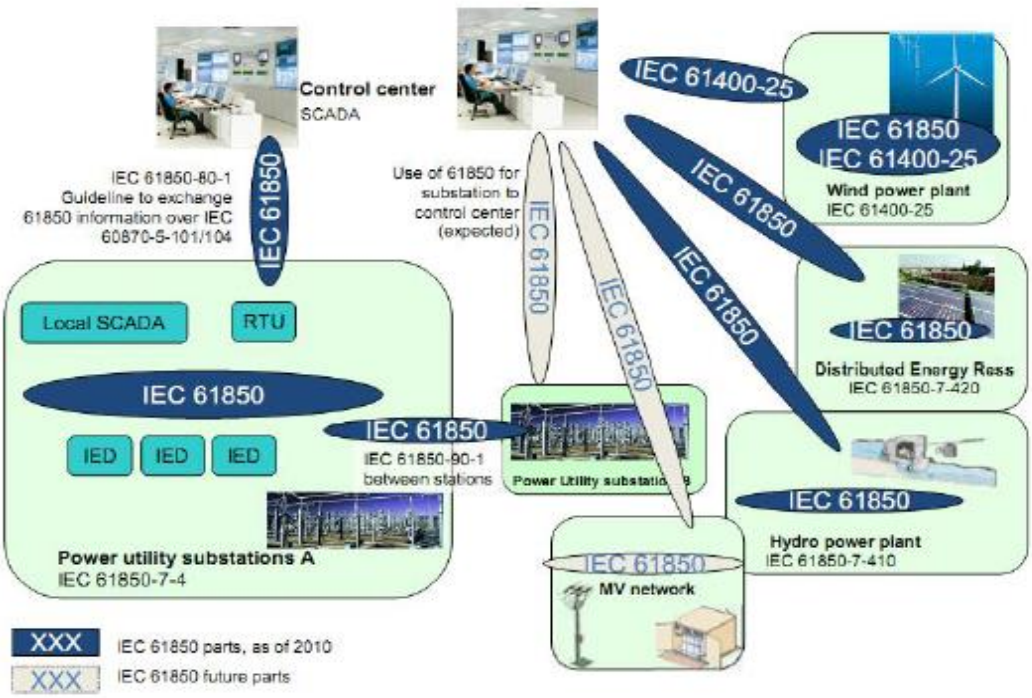

Figure 8. Use of IEC 61850 at various sites. (Pham 2013: 15).

There is a split between the communication and application and this split adds flexibility in IEC 61850. As a result, the models and service needs to be mapped to a specific protocol so that different functional requirements can be fulfilled. Figure 8 explains the split in IEC 61850 is presented next.

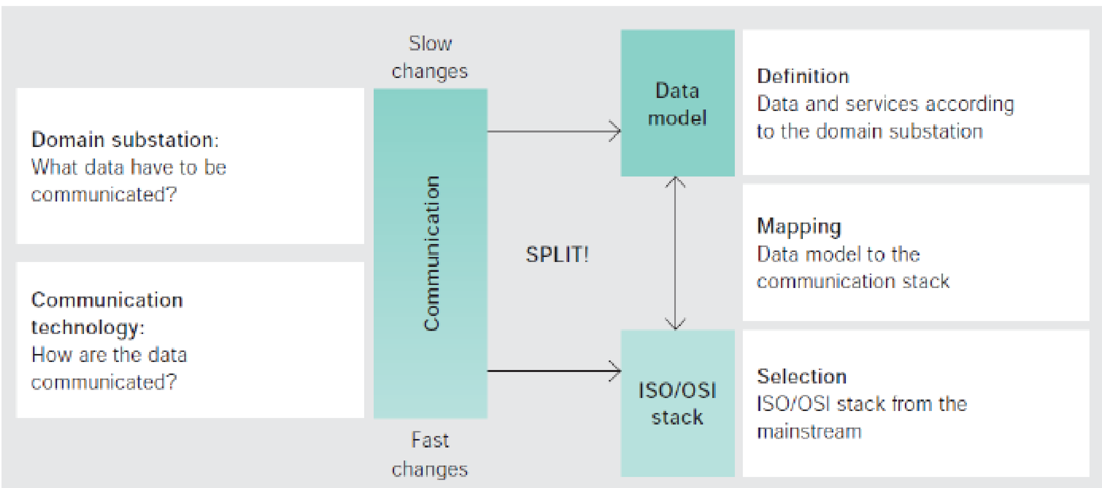

Figure 9. IEC 61850 application and communication split. (Taikina-aho 2011: 15).

2.4. IEC 61850 Communication Stack

Part 5 of Figure 7 shows that the communication service mapping of IEC 61850 has to meet several communication requirements. Therefore, all the message types belonging to respective performance class are mapped with concerned communication protocol. Meaning that, those message types that are expected to have similar performance requirements are grouped together and mapped to the same protocol. For instance, it can be seen from Figure 10 that message type 1 and 1A are mapped to Generic Object Oriented Substation Events-(GOOSE) and are directly mapped to Ethernet. The reason of mapping this message type 1 and 1A to GOOSE and to Ethernet is because these message types are very time sensitive and mapping directly to Ethernet reduces processing time caused by overhead of network and transport layer protocols. Also, if we look at type 4 then we can see that it is mapped to Sampled Value- (SV) and is directly mapped to Ethernet to obtain time sensitive performance. SV is a protocol which aims to carry raw data.

Further, message type 2, 3 and 5 supports core IEC 61850 services and are mapped to Manufacturing Message Specification (MMS). (Pham 2013: 16-17).

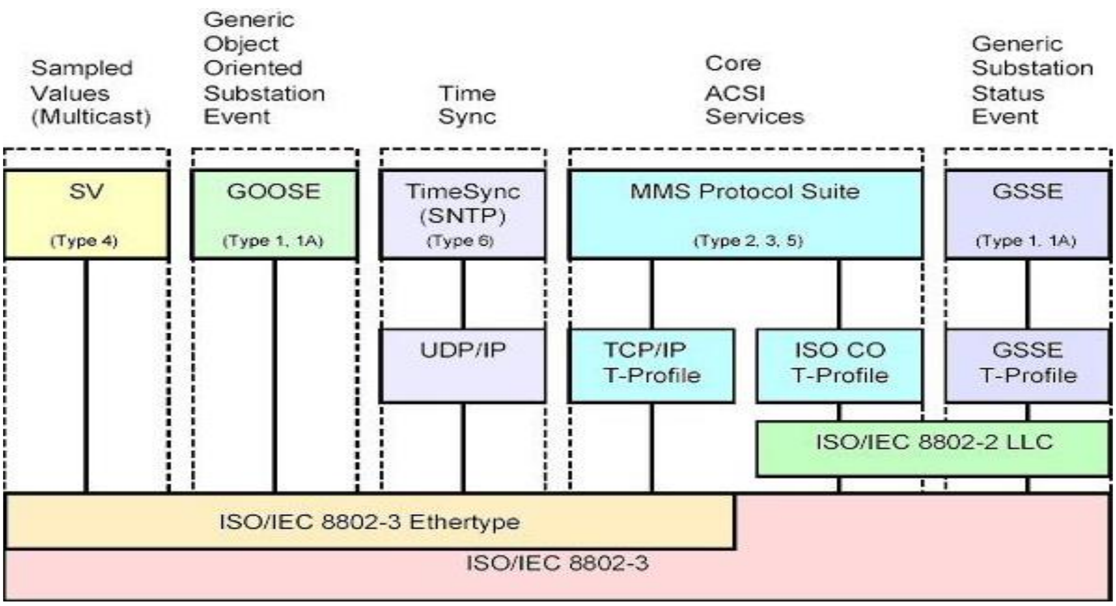

Figure 10. Mappings Profiles of Protocol. (Slideshare 2005: 8).

Explanation of GOOSE Services Communication Profile, Sampled Value, Generic Substation State Events and Time Sync.

GOOSE Services Communication Profile

Among various communication services offered by IEC 61850, GOOSE messaging is also one of them and it is a very important service. It has been designed specially to meet the time critical application requirements in order to protect systems. It is implemented over the data link layer so that it can reduce the overhead that are caused by upper layers like network layer and transport layer. GOOSE message play a vital role in exchanging critical information and data between large numbers of IEDs operating in the site. (Jiang et al. 2013: 465).

An IED contains different information or data items grouped as DataSets. One GOOSE can take care of several DataSets in its allData field. If the Data attribute of a DataSet undergoes any change then a event is generated and GOOSE message is sent repetitively. Hence, it becomes very important to configure the parameters considering the DataSet. Some of the major parameters to be configured are GOOSEID (goID), Multicast MAC addres, VLAN priority (should be atleast 4), VLAN ID (according to the Ethernet switch configuration), Application ID, Configuration revision, DataSet Name, Time to live (timeAllowedtoLive) for GOOSE message in milliseconds. (Sidhu, Kanabar & parikh 2011: 1386).

GOOSE is directly mapped to Ethernet unlike mapping to the TCP/IP profile. As a result, the Ethernet frame is shortened (no upper layer protocol overhead) resulting in the improved performance for real-time messages by reducing the processing time. In addition, it is also possible to undergo priority tag value within the Ethernet frame so that the traffic which are time sensitive can be prioritized as compared to traffic that are not time sensitive. GOOSE offers multicast services by virtue of which simultaneous delivery of the substation event information can be broadcasted to many device. GOOSE server sends an information about the change of its status by SendGOOSEmessage service. The receiving device on receiving this understands that the status have been changed. The reason to send such message by the server is because if the protection relay detects some faults at some point which can be fatal to humans, then the server multicasts SendGOOSEmessage to various device (Pham 2013: 18-19). The transport profile for GSE/GOOSE is presented next below in Table 2.

Table 2. Transport profile for GOOSE messages. (Pham 2013: 24).

OSI Model Layer	Specification			m/o
	Name	Service specification	Protocol specification	
Transport	Connection Oriented Transport	ISO/IEC 8072:1996	ISO/IEC 8073:1997	m
Network	Connectionless Network	ISO/IEC 8348:2002	ISO/IEC 8473-1:1998 ISO/IEC 8473-2:1996	m
	End System to Intermediate System (ES/IS)	ISO/IEC 9542:1988		m
Link Redundancy	Parallel Redundancy Protocol and High Availability Seamless Ring	IEC 62439-3		o
DataLink	Logical Link Control	ISO/IEC 8802-2:1998		m
	Carrier Sense Multiple Access with collision detection (CSMA/CD)	ISO/IEC 8802-3:2001		m
Physical (option 1)	10Base-T/100Base-T	ISO/IEC 8802-3:2001		c1
	Interface connector and contact assignments for ISDN Basic Access Interface. [a]	ISO/IEC 8877:1992		
Physical (option 2)	Fibre optic transmission system 100Base-FX	ISO/IEC 8802-3:2001		c1
	Basic Optical Fibre Connector. [b]	IEC 60874-10-1, IEC 60874-10-2 and IEC 60874-10-3		

Sampled Value (SV)

Sampled Values services uses protocol on top of Ethernet and as a result offers fast distribution of sampled values within the substation. The messages are exchanged in publisher/subscriber model like GOOSE. However, Figure 11 shows the nature of slight difference in the message exchanging procedure between GOOSE and Sampled Value where, in sampled value the message exchange procedure can be done in unicast (if there is unicast sampled value) or multicast (in case of multicast sampled value) while message exchanging is done only in multicast in case of GOOSE. The server publishes unicast or multicast sampled values and the client subscribes and configures in order to respond to the intended multicast address. MULTICAST-SAMPLE-

VALUE-CONTROL-BLOCK– MSVCB controls the transmission of sampled value in case if multicast is used. In the event of unicast, transmission is controlled by UNICAST-SAMPLE-VALUE-CONTROL-BLOCK – USVCB. (libiec61850 2013).

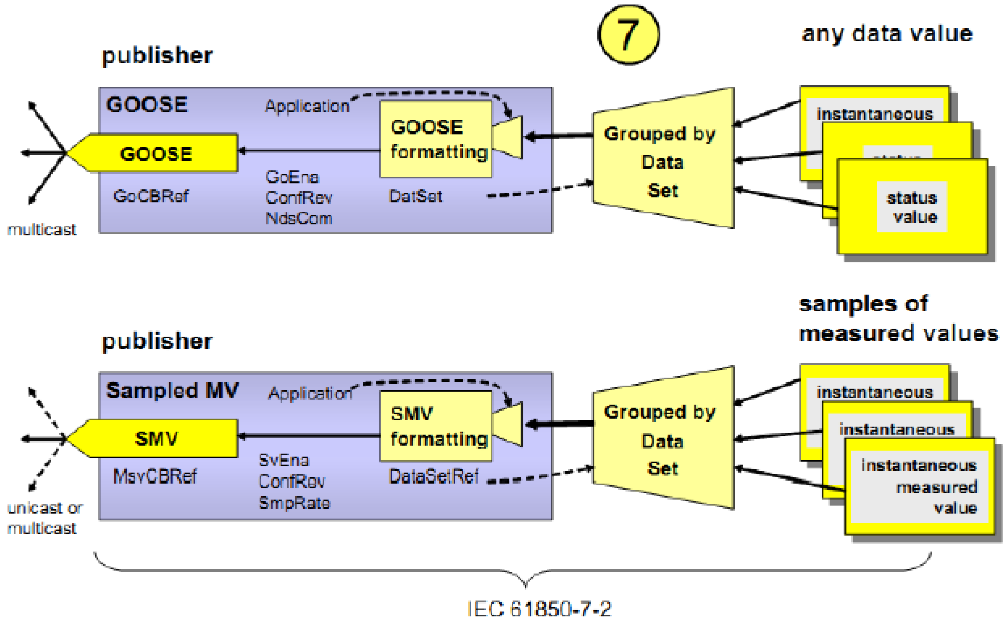

Figure 11. Data publishing model for GOOSE and SV. (Nguyen 2013: 17).

IEC 61850 Series defines several configurations for mapping of SV to Ethernet. Figure 12 shows the communication profile that IEC 61850 defines in its part. One drawback of such direct mapping of GOOSE and SV is that, the routing is not possible if there is a need of communication outside the substation. However, there are applications like tele-protection between substations that makes routing possible in WAN. By using L2 tunnelling or gateway/proxy approaches and following some guidelines, transmission of GOOSE and SV over WAN can be achieved (Pham 2013: 21-22).

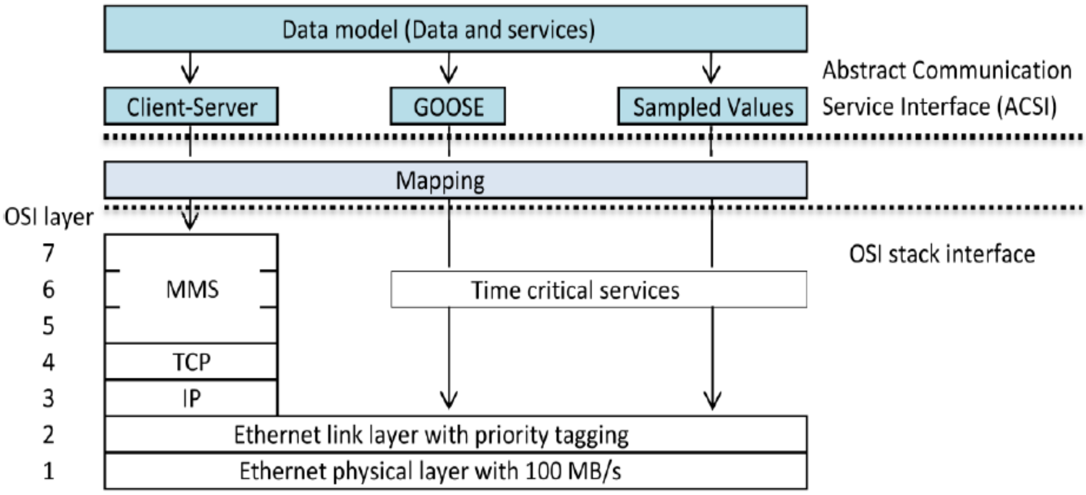

Figure 12. Mapping of communication schemes and services. (Taikina-aho 2011: 20).

Generic Substation State Events (GSSE)

There are two real-time communication messaging methods offered by IEC 61850 namely Generic Substation Events (GSE) and Sampled Value (SV) messaging. GSE message are further divided into two types: Generic Substation Status Events (GSSE) and to Generic Object Oriented Substation Status Event (GOOSE). GSSE supports data only in binary form. It does not support Analog data. (Taikina-aho 2011: 21).

Time Sync

Time synchronization is very crucial in order to examine the events or other data. All the devices within the system is time synchronized and the time source is usually an external source from satellite or radio clock. IEC 61850 requires five different levels of accuracy in time synchronization ranging from 1 millisecond to 1 microsecond compared to real time. In addition, it also consists the protocol Simple Network Time Protocol (SNTP). SNTP uses a single time server at a time and offers synchronization over LAN reaching an accuracy of 1 millisecond. But this accuracy is not enough for Sampled Value in order to provide protection, which requires an accuracy of 1 microsecond. Thus, other time synchronization methods like IRIG-B and PTP (Precision Time Protocol) that are more accurate must be used.

IRID-B is easy to implement and is widely used today. However, the drawback of IRIG-B is that a separate cabling has to be done to all the devices that needs accuracies in microseconds.

PTP is similar to SNTP synchronizing time over LAN, it can reach an accuracy up to some sub microseconds as it allows hardware assisted time stamping. When a packet arrives in the device, it contains a time stamp and while the packet is leaving the time correction is done in the packet. Due to this, a high level of time synchronization is obtained. (Taikina-aho 2011: 23).

2.5. Manufacturing Message Specification

In order to achieve real-time data communication and supervisory control information among networked devices, MMS plays a vital role. These days, MMS has become world-wide standard for real-time communication. It defines a set of standard object which every device must consist, defines set of encoding/decoding rules and also defines set of standard information exchange pattern between client-server so that monitoring, controlling and other services becomes feasible. MMS facilitates devices to communicate with each other even though the devices belong to different manufacturers. In order to implement MMS, we have two programming strategies called Object-Oriented Programming (OOP) and singleton patterns.

OOP divides program into small modules that it can handle well. Also, OOP eases reuse of fragments of large program to fragments of other program. Singleton pattern on the other hand is used when there is the need of one object throughout the system. There are many MMS services that are mostly confirmed. Below in Table 3 some MMS confirmed services out of 78 services are shown.

Table 3. MMS confirmed Services. (Jongjoo et al. 2012: 330).

TAG	Service
0	status
1	getNameList
2	identify
3	rename
4	read
5	write
6	getVariableAccessAttributes
7	defineNamedVariable
8	defineScatteredAccess
9	getScatteredAccessAttribute
10	deleteVatiableAccess
11	defineNamedVariableList
12	getNamedVariableListAttributes
75	fileRename
76	fileDelete
77	fileDirectory

IEC 61850 MMS communication stack consists of 3 steps called initialization step, processing step and communication step.

The initialization step models IED from System Configuration Language (SCL) file. During initialization step, Abstraction Communication Services Interface (ACSI) is performed.

The processing step creates messages so that the IEDs can communicate. During this step, Specific Communication Service Mapping (SCSM) is done. SCSM responsibility involves mapping of ACSI to real communication protocol. The message whether it is MMS or SV/GOOSE is created in this step and is used later in communication step of step 3. The difference between MMS message and SV/GOOSE message is that MMS message uses all the seven layers of OSI while SV/GOOSE is directly mapped to

Ethernet because of which the Ethernet frame is shortened as there are no upper layer overhead in the message. Thus, improved performance for real-time messaging is obtained.

Since there are client and server involved in the MMS communication stack. Interaction process between the client and server is carried out where the client sends request to the server. The server upon receiving the connection request indication, takes proper action and sends response back to the client. In order to undergo MMS communication, 15 layers each consisting of their own functions has been classified. Figure 13 explains the client server connection scenario. Figure 14 shows those 15 layers and their function is shown in Table 4. (Jongjoo et al. 2012: 329-331).

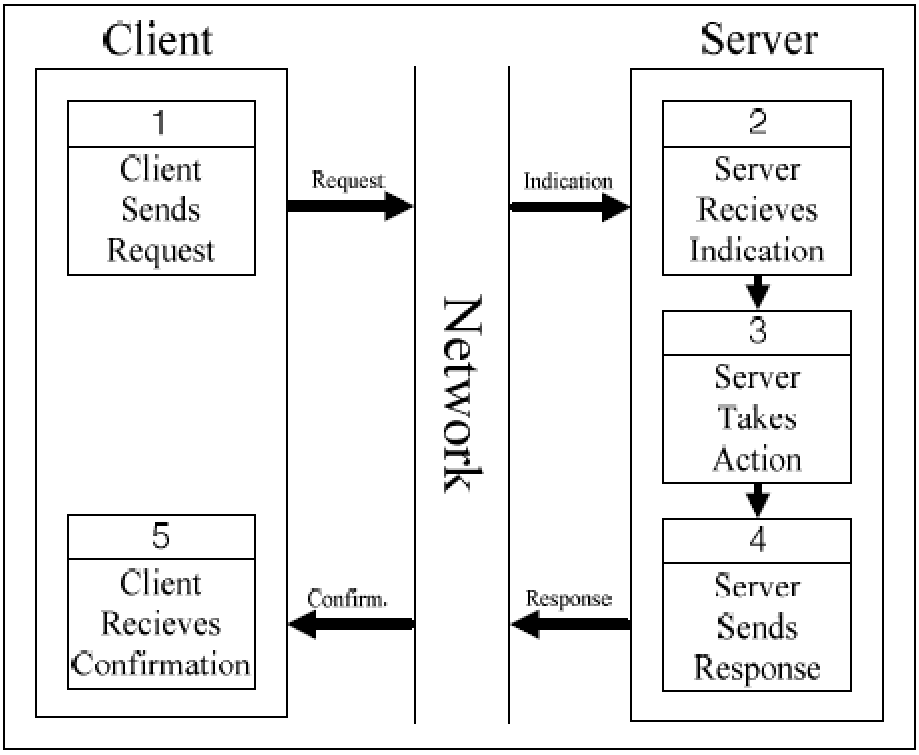

Figure 13. Interaction between client and server. (Jongjoo et al. 2012: 331).

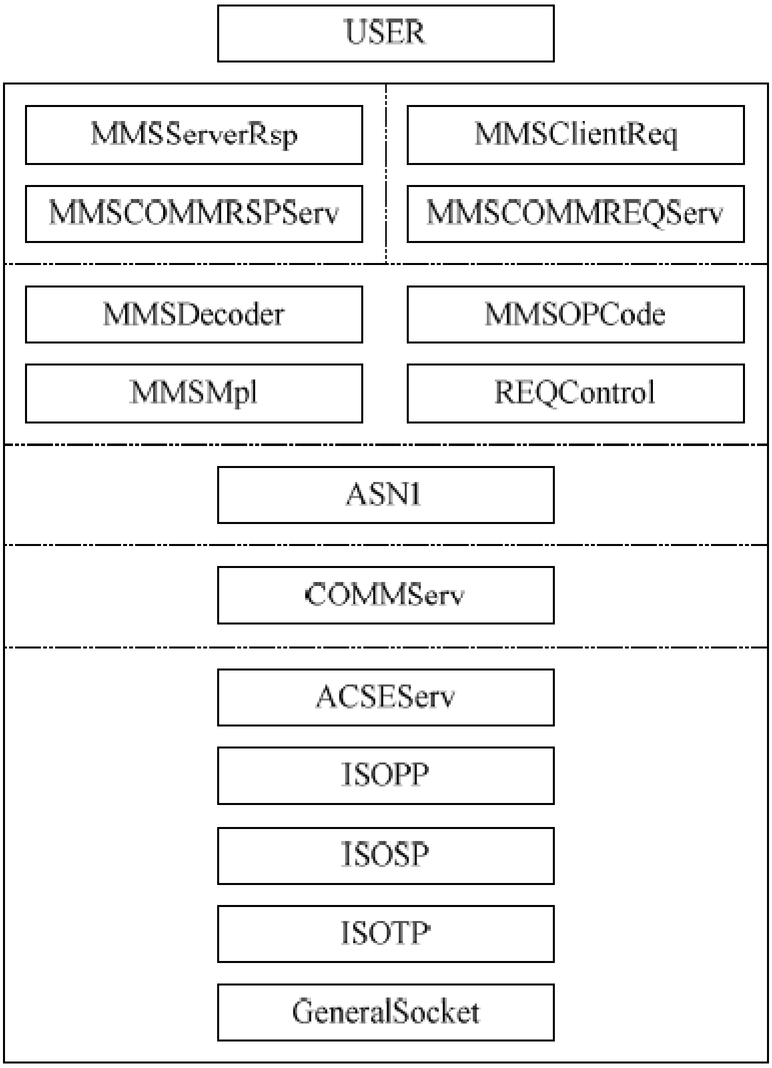

Figure 14. Client Server Communication function layers. (Jongjoo et al. 2012: 331).

Table 4. Function of each layer involved in client server communication. (Jongjoo et al. 2012: 331).

Name	Description
MMSClientReq	Functions to request data or operational information to server
MMSServerRsp	Functions to response the requested behavior to client
MMSCOMMREQServ	Functions to make messages for requesting to server
MMSCOMMRSPServ	Functions to make messages for responsing to client
MMSDecoder	Functions to decode MMS messages
MMSOpcode	Functions to get demanded information by result of MMSDecoder layer
MMSMpl	Functions to make MMS messages for requesting/responsing
REQControl	Functions to manage request messages and check whether the response messages are recieved or not
ASN1	Functions to encode or decode response/request messages to ASN.1 format
COMMServ	Functions to set or free the connection and take responsibility for receiving and sending packets
ACSEServ	Functions to provide environment of client-server type program
ISOPP, ISOSP, ISOTP	Functions to negotiate the transfer syntaxes, manage session and check error
GeneralSocket	Functions to manage packets for actual communication

3. LONG TERM EVOLUTION

The development of mobile communication technologies is a process that has been carried out from generations. In the beginning, 1G came as an Analog mobile radio communication technology. Then came 2G as the first digital mobile systems and later came 3G as the first mobile systems capable of supporting broadband data. LTE is known as 4G but many proclaim that LTE release 8 was just an evolution from 3G to 4G and LTE release 10 known as LTE-Advanced is an actual 4G. As a matter of fact, LTE and LTE-Advanced have the same technology with the advanced features and improved function in LTE-A. Hence, LTE and LTE-Advanced are same. Two main technologies that enables LTE are Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO). (Abdullah & Yonis 2012: 236-237).

Many consider LTE as a successor of the current 3G technology based on WCDMA, HSDPA, and HSPA. LTE is an update of UMTS technology which aims to provide fast data rates in both the uplink and downlink. Verizon Wireless was the first carrier in America to use LTE. AT&T also deployed LTE and the customers of AT&T and Wireless experienced a download speed of more than 15Mbps and an upload speed at the range of 10Mbps. (mobileburn).

Single carrier-FDMA is used in the uplink and OFDMA is used in the downlink. During transmission, Inverse Fast Fourier Transform (IFFT) is applied and during the reception Fast Fourier Transform (FFT) is applied. This helps in the reduction of peak to average power ratio and decreases the power consumption in the user terminals. (Abdullah & Yonis 2012: 237-238). The transmitter and receiver communication system is delineated in Figure 15.

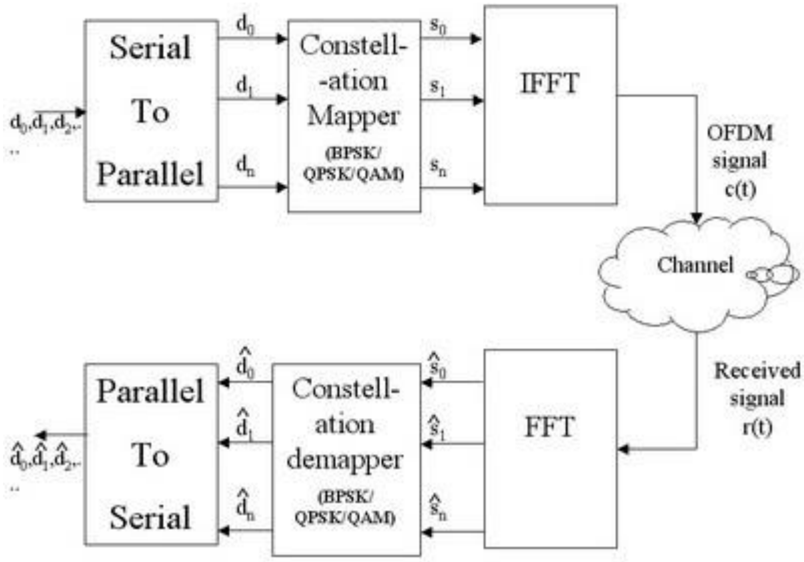

Figure 15. OFDM transmitter and receiver communication system. (Mathuranathan 2011).

Multipath fading effects is one important parameter concerning the performance of the wireless communication. Multipath fading effects is related to power-delay profile that constitutes two components: a vector of relative delays and a vector of average power parameters. Multipath fading can be both flat-fading and frequency-selective fading. In wireless communication, signals are transferred from transmitter to the receiver via base station. On the signal transmission process, the signal takes many routes before finally arriving to the receiver. On doing so, the signals will be reflected off buildings or by other reflectors present in the outside environment. When they finally reach to the intended receiver, they travel through many paths and undergo time delay and attenuated power. The mobile receiver receives the linear combination of all those multipath signals and the net signal is obtained by the convolution of input signals and the impulse response of the channel. Talking about frequency domain, the channel responses differently at different frequency and thus, we have frequency-selective fading. (Zarrinkoub 2014: 115-118).

In the wireless communication by LTE network, the degradation of the channel is because of the fading caused by the signals propagating in the multipath. These effects of fading are necessary to be considered in order to facilitate with an accurate LTE system performance. Since the position of a mobile terminal is not fixed but mobile, the channel impulse response of such mobile terminal varies accordingly. In other words, the fast and slow fading of the channel indicates the speed with which the mobile terminal is moving. This effect of fading of channel impulse response depends on the speed of the mobile terminal, termed as Doppler effects. (Zarrinkoub 2014: 115-118).

In the context of Smart Grid, the increasing interest of the world for LTE and deployment of LTE in most of the countries have motivated to use LTE in different applications. LTE enables in obtaining real time data communication by smart metering, it enables fault detection and many other important aspects. Therefore, as we move further from here, we will see discussions about the technologies used in LTE and also how LTE can be used for the purpose of smart metering services with IEC 61850.

3.1. Orthogonal Frequency Division Multiple Access (OFDMA)

Orthogonal Frequency Division Multiplexing is a multicarrier transmission technique where the whole carrier is divided into a large number of subcarriers. The benefit of this is that the symbol time becomes more than the channel delay spread which is how the inter symbol interference (ISI) is removed. Thus, it can be understood that OFDM is robust against frequency selective fading. Also, it offers low-complexity by means of Fast Fourier Transform (FFT) processing.

In OFDM, all the subcarriers that are divided from a single carrier is assigned to a single user. Therefore, if other user needs to communicate with the Base Station (BS), it needs to wait for some time as they are operated in a Time Division Multiple Access (TDMA). However, in Orthogonal Frequency Division Multiple Access (OFDMA) the subcarriers are divided into sets and this sets of subcarriers are assigned to multiple users. Thus, the total bandwidth is divided into M sets each consisting of L sets subcarriers. Therefore M users can simultaneously communicate with the base station. The most beneficial aspect of OFDMA is its exploitation of frequency and multiuser.

Frequency diversity is obtained by randomly distributing the subcarriers of a single user over the entire band. This reduces the probability of deep fading as all the subcarriers would not experience similar kind of fading. Multiuser diversity is used by assigning same sets of subcarriers to those users who are getting good channel conditions. (Abdullah & Yonis 2012: 237-238).

The assignment of subcarrier band is either distributed or localized. Figure 16 is presented below that shows the distributed and localized subcarrier assignment.

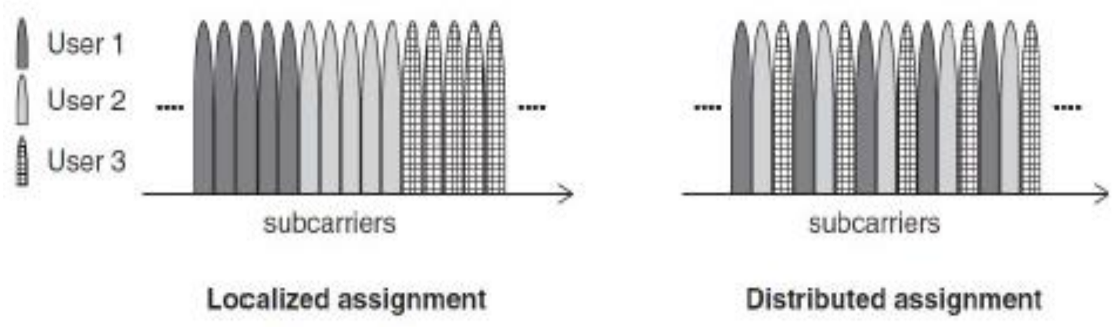

Figure 16. Ways of assigning distributed and localized subcarriers. (Abdullah & Yonis 2012: 239).

Single Carrier Frequency Division Multiple Access (SC-FDMA)

SC-FDMA is used in uplink as it offers low peak to Average Power Ratio which is very important to the user equipment (UE) because if the PAPR is high, than it consumes a lot of power. Therefore, low PAPR helps the UE to improve its power-amplifier efficiency, reduces the terminal power consumption and cost, and increases the coverage. SC-FDMA has an orthogonal subcarrier for transmission of symbols but the transmission is not done in a parallel way like it is done in OFDMA. Instead, the transmission is done in sequential form by all the subcarriers. (Pham 2013: 27-28).

Multiple Input Multiple Output (MIMO)

The concept of MIMO was thought long back. It is a radio technology where multiple antenna is used at both the transmitter and the receiver side so that the data can be transmitted through many paths with the help of multiple antennas and they can be received from different paths by the help of multiple antennas on the receiving side. In the earlier days, MIMO systems mainly focused on spatial diversity where it was used to control the degradation and disturbance in the signal caused by multipath propagation. Two researchers named Arogyaswami Paulraj and Thomas Kailath were the first who thought and proposed the use of spatial multiplexing by the help of MIMO. As a result, multipath propagation that earlier was a reason for the degradation in the signal quality became an advantage. Diversity enables the user to choose the signal with the best power out of many transmitted signal. Such diversity helps in performance improvement and error reduction. Different modes of diversity (Time diversity, Frequency diversity and Space diversity) carry numerous advantages. (radio-electronics 2015).

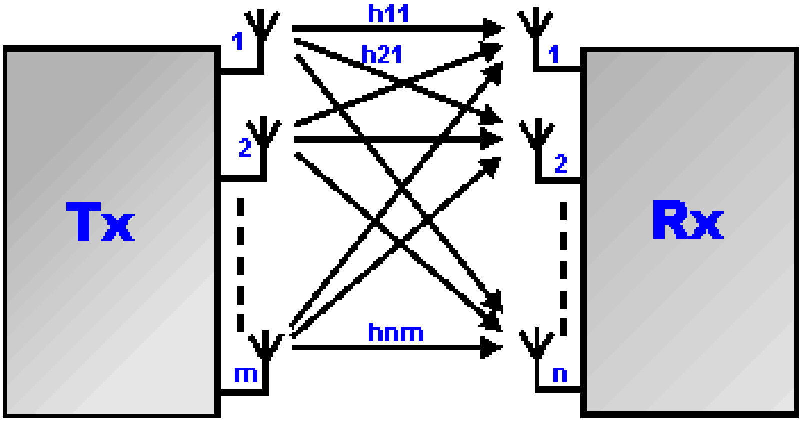

Figure 17. MIMO system. (radio-electronics 2015).

In Figure 17, we can see that the transmitted data takes many paths before they reach the receiver, resulting in transmission diversity. Transmission diversity are important to delay sensitive services. However, this diversity was not made in use properly for our benefit until the MIMO technique was introduced. In earlier transmission procedure, a single data stream was transmitted but in MIMO a multiple transmitting antenna at the eNB in combination with a multiple receiving antenna at the UE is used. As there are multiple transmitting and receiving antennas involved, multiple data stream transmission is enabled and higher peak data rates are achieved. MIMO has proved to be one of the most promising means in achieving high data transmission rates. (Abdullah & Yonis 2012: 238-239).

3.2. LTE Network Architecture

The basic system architecture configuration consists of logical nodes and connections. The presence of these elements and functions indicates the involvement of E-UTRAN. Figure 18 presented next shows the architectural division into four main high level domains: User Equipment (UE), Evolved UTRAN (E-UTRAN), Evolved Packet Core Network (EPC), and the Services domain. The functions of these domains resembles to those existing in 3GPP systems. The three layers UE, E-UTRAN and EPC are actually representing a layer responsible for the Internet Protocol (IP) connectivity layer. Also known by the name Evolved Packet System (EPS), this layer is highly optimized for the purpose of connectivity. (Holma & Toskala 2009: 25).

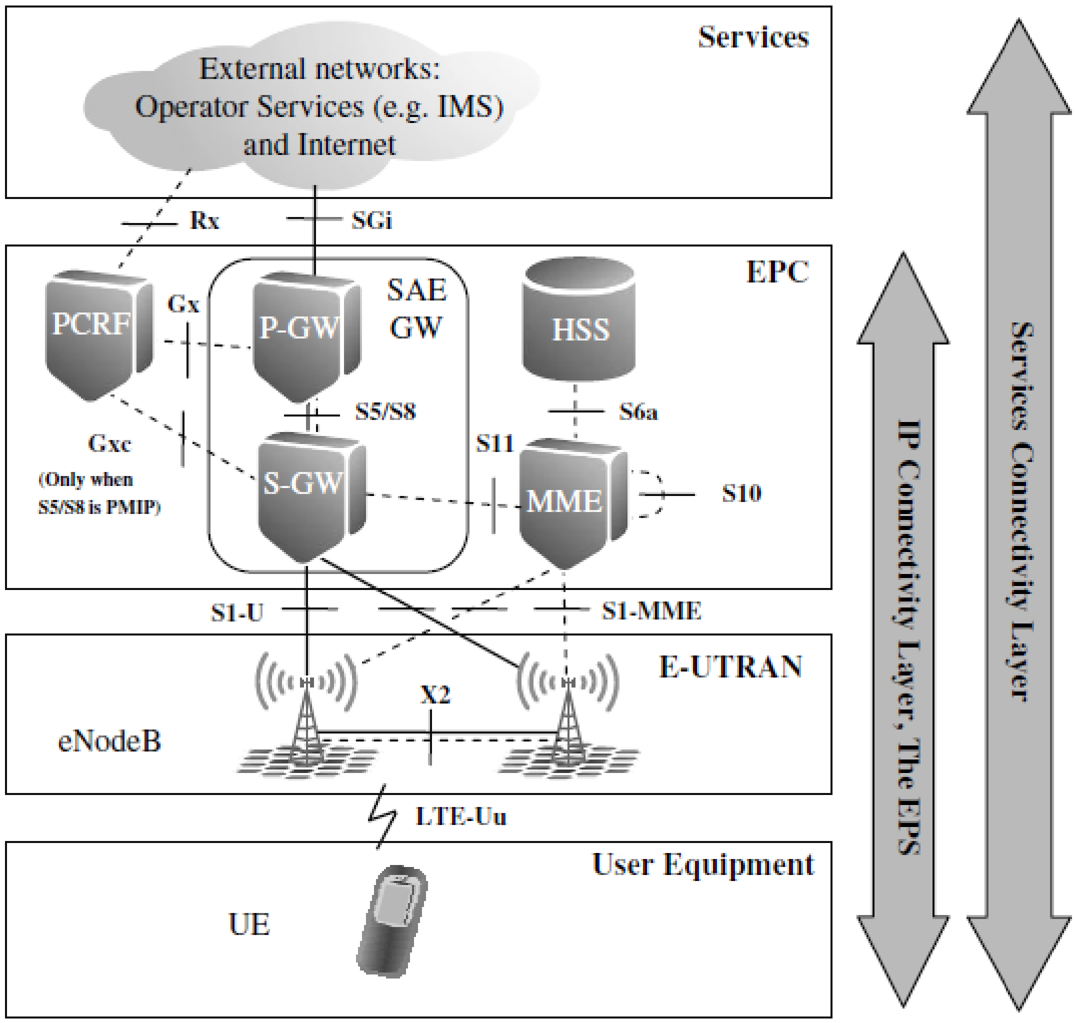

Figure 18. Network Architecture in LTE. (Holma & Toskala 2009: 25).

3.2.1. User Equipment, E-UTRAN Node B (eNodeB), Mobility Management Entity

User Equipment

User Equipment are the devices that are used by the end user such as mobile phone, a data card used in 2G or 3G or it can also be a laptop. The User Equipment serves as a platform that enables the end user to be able to carry out communication applications. It signals the network so that the network setup and its maintenance can be carried out. UE facilitates the end user by providing an interface to be able to use applications such as VoIP for voice call. (Pham 2013: 29).

E-UTRAN Node B (eNodeB)

eNodeB is the only node in the E-UTRAN which is actually a base station under the control of all functions related to radio communication. eNodeB serves as a bridge between E-UTRAN and EPC. It terminates all the radio protocols towards the UE and relays the data towards the EPC. The eNodeB serves many functions in the control plane (CP). It manages Radio Resources by controlling the radio interface, monitoring constantly the nature of resource utilization, allocating resources based on request and priority as well as traffic scheduling based on demanded Quality of Service (QoS). In addtion, eNodeB is also responsible for mobility management (MM). Apart from the Controlling of radio signals, it also examines the level of radio signal measurement that is done by the User Equipment. Moreover, it also carries out similar measurement on its own, compares the result and makes decisions of handover accordingly. Figure 19 portrays the general functions of eNodeB. (Holma & Toskala 2009: 27-28).

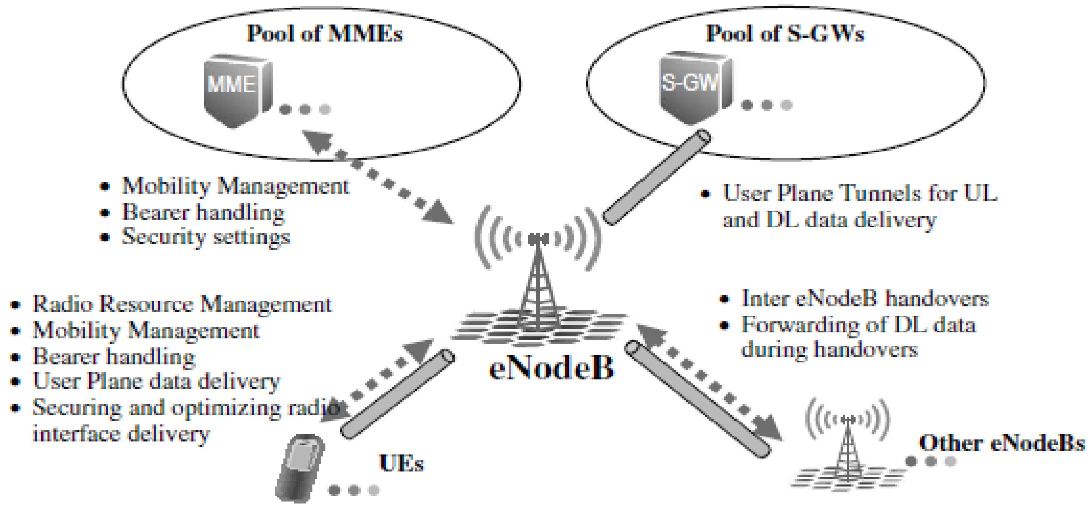

Figure 19. Main functions of eNodeB. (Holma & Toskala 2009: 27-28).

Mobility Management Entity

Mobility Management Entity acts as a heart of EPC serving as the main control element. MME actually is a server located at a safe place. It has a control plane (CP) connection to the UE and is not involved in the User Plane (UP) data. Some of the main functions of MME are:

- Authentication And Security: If a UE approaches to a new network, MME initiates the process of authentication. First, it searches for the UE permanent identity and requests the Home Subscription Server (HSS) located in UE's home network to send the authentication vectors that contains authentication challenge - response parameters. It then sends the challenge to the UE and compares the response received from the UE with the one received from the home network. If it matches, then it is assured that the UE is correct. In addition, MME also gives a temporary identity called the Globally Unique Temporary Identity (GUTI) so that the privacy of the UE is maintained. (Holma & Toskala 2009: 28-29).
- Mobility Management: All the UE is tracked by MME that fall on its territory. Upon arriving to a new network, the MME creates an entry for the UE, and

signals the location of HSS in the UE home network. Requesting the appropriate resources to be allotted in the eNodeB and S-GW for the UE, MME keeps tracking the UE's location either from a single eNodeB, if the user is in active state or from the group of eNodeBs, if the user goes to idle mode. There are some more functions of mobility management that are not mentioned here. (Holma & Toskala 2009: 27-28).

3.2.2. S-GW, P-GW, PCRF and Home Subscription Server

Serving Gateway (S-GW)

S-GW facilitates User Plane (UP) tunnel management and switching. If the S-GW interfaces (S5/S8) uses GPRS Tunnelling Protocol (GTP), then S-GW performs mapping between IP services and GTP tunnel in P-GW and it requires no connection to the PCRF. With minor role in control function, S-GW takes care of its own resources and the allocation of those resources is based on the requests it receives from MME, P-GW or PCRF. Upon receiving the request from PCRF or P-GW, S-GW relays the command to the MME. Likewise, if it receives request from MME, S-GW signals either to P-GW or to the PCRF. When there is mobility between eNodeBs, S-GW serves as an anchor for local mobility. Here, S-GW is commanded by MME to switch the tunnel from one eNodeB to another eNodeB. In addition, MME may also request S-GW to provide resources to enable data forwarding from source eNodeB to target eNodeB. (Holma & Toskala 2009: 29-30). Figure 20 illustrates the connection of serving gateway with other EPC equipment and its function.

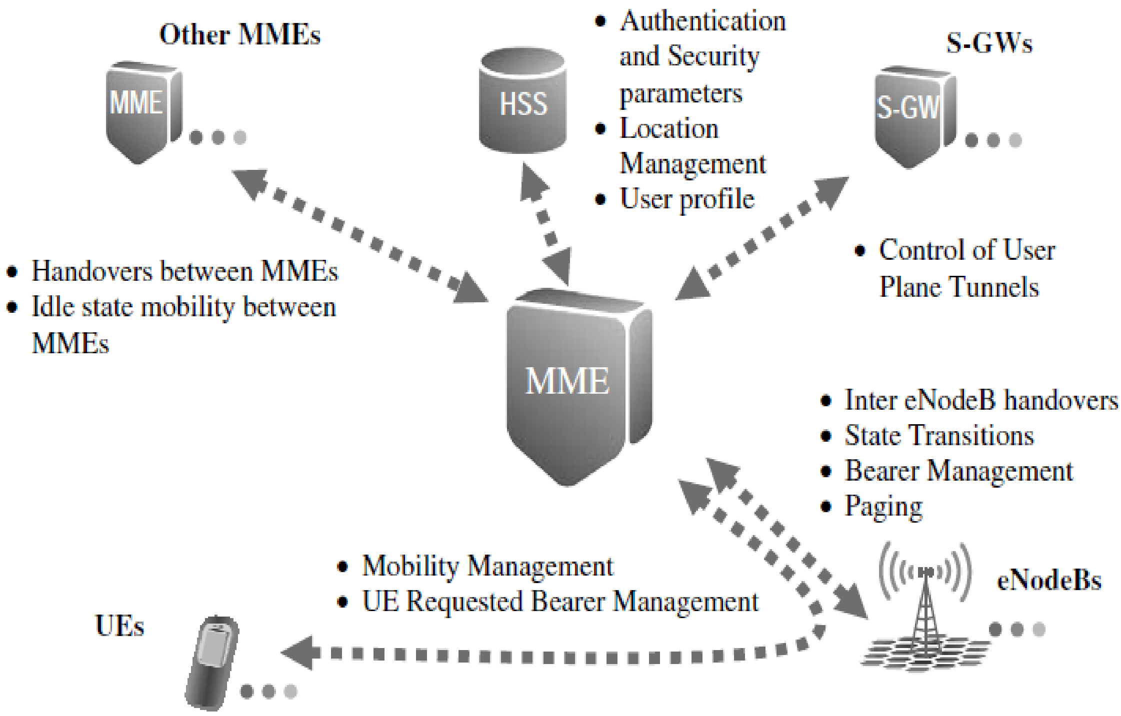

Figure 20. S-GWs connection with MME. (Holma & Toskala 2009: 30).

Packet Data Network Gateway (P-GW)

Packet Data Network Gateway, also abbreviated as P-GW or PDN-GW acts as a router connecting the IP connectivity layer, the EPS and the external networks. Traffic gating and filtering are some of its functions. Actually, the allocation of the IP address to the User Equipment is done by P-GW by virtue of which the User Equipment communicates with other network, for instance the internet. The external packet data network to which the user equipment is connected may also allocate the IP address to the user equipment where the P-GW then tunnels all traffic to that network. When the user equipment tries to connect to a network, it requests PDN connection. In this event, the P-GW performs a function named Dynamic Host Configuration Protocol (DHCP) and provides an address to the User Equipment. In addition, the Packet Data Network Gateway contains the Policy and Charging Enforcement Function (PCEF) by virtue of which it performs policies like gating and filtering function that is set for the User Equipment. (Holma & Toskala 2009: 31-32).

Policy and Charging Rules Function (PCRF)

Policy and Charging Function is part of a network that aims at making policy and charging control (PCC). It does so by incorporating decisions related to QoS and provides information to the Policy and Charging Enforcement Function that is present in the P-GW. The information provided by the PCRF to PCEF is termed as PCC rules. PCRF is actually a server associated with other Core Network (CN) elements. (Holma & Toskala 2009: 32-33). Figure 21 gives the idea about the working of PCRF.

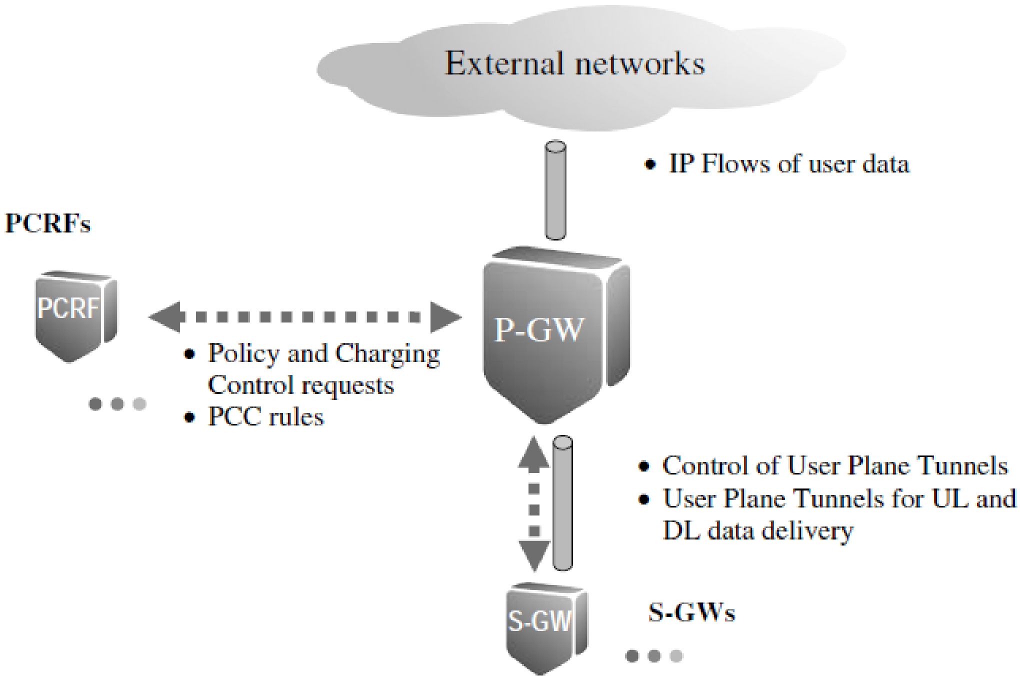

Figure 21. Connection of P-GW with main functions and to other logical nodes. (Holma & Toskala 2009: 33).

Home Subscription Server (HSS)

The Home Subscription Server is a combination of Home Location Register (HLR) and the Authentication Centre (AuC) where HLR takes care of storing and updating the database that contains every information about the user subscription. The AuC on the other hand is responsible for the generation of the security information from user identity keys. This security information is passed to the HLR and other entities of the network. (Pham 2013: 31).

3.3. Interface Protocols

Interfaces that link networks within the IP connectivity layer (The EPS) and between the EPS layer and the Service Connectivity Layer can be categorized into two groups, named as control plane protocols and user plane protocols (Pham 2013: 31). Before we go deep into the control plane and user plane protocols, it is good to look at some of the very important interfaces in LTE. Figure 22 is presented further so that understanding interfaces and their work becomes easy.

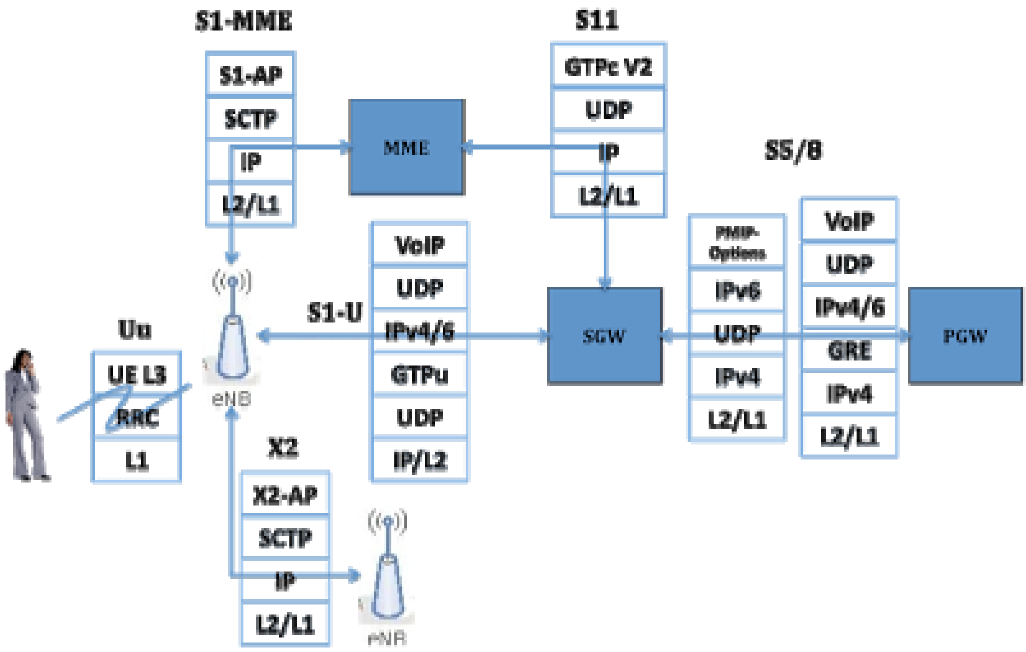

Figure 22. Interfaces in LTE. (Elgindy 2010).

LTE Uu: This is an air interface between the UE and the eNB and in order to communicate in this air interface, the Radio Resource Control (RRC) protocol is used. On top of this, there is a layer named Non-Access Stratum (NAS).

LTE S1-MME: This IP interface helps eNB and MME to communicate with each other. It contains the transport layer protocol called Stream Control Transmission Protocol (SCTP).

LTE X2: Using this interface, eNB communicates with other eNBs. This is also an IP interface with SCTP as transport protocol.

LTE S11: This is also an IP interface responsible for the communication between mobility management entity and the serving gateway. This interface runs GTPv2 which is a protocol used at the application layer.

LTE S5: This is again an IP interface which uses the Serving Gateway and the Packet Data Network Communication.

LTE S1-U: This is an interface between Serving Gateway and the eNB. The protocol used here is GTP-U v1 which is the application protocol that is used to encapsulate the UE payload.

The interfaces from a single MME have been presented into two bodies in Figure 23 where the first depicts the protocols between the UE and the E-UTRAN while the second shows the interface protocols towards the gateways. (Elgindy 2010).

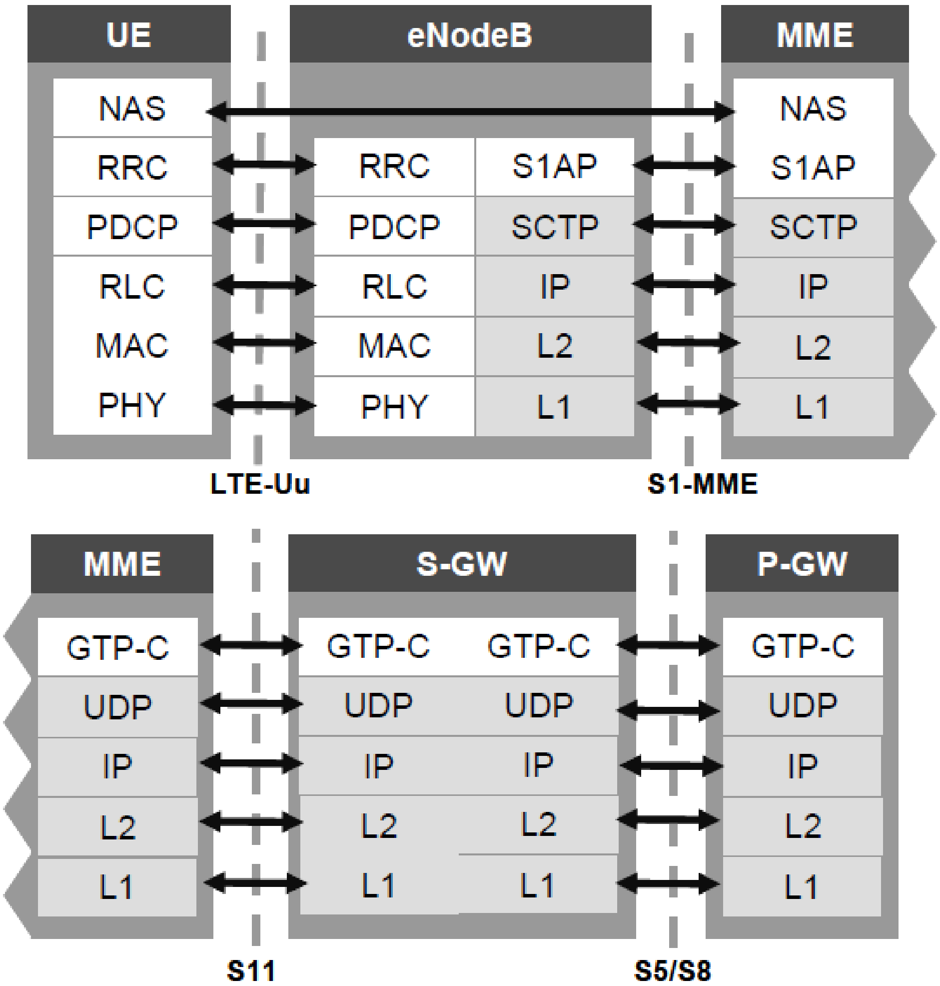

Figure 23: Protocol Stack of Control Plane in EPS. (Holma & Toskala 2009: 36).

The layer on the top is called Non-Access Stratum (NAS) and it contains two separate protocols where the signalling transport between the UE and the MME is done directly. The two protocols of the NAS layer are, EPS Mobility Management (EMM) and EPS Session Management (ESM).

The EPS Mobility Management (EMM) protocol is responsible for the management of UE the mobility within the system which means that it takes care of the UE whether to attach or detach it from a network. Furthermore it keeps updating location of the UE as well. This phenomena is termed as Tracking Area Updating (TAU) and this is carried out in idle mode.

The EPS Session Management (ESM) protocol on the other hand takes care of the bearer management between the UE and the MME. This also facilitates in E-UTRAN bearer management procedures.

The radio interface protocols in the UE are shortly described below.

- Radio Resource Control (RRC): This protocol depends on the extent of the radio resource usage. Moreover, it manages UEs signalling and data connections along with handovers.
- Packet Data Convergence Protocol (PDCP): It helps in IP header compression in the user plane, encryption and integrity protection in the control plane.
- Radio Link Control (RLC): RLC helps in the segmentation and to combine PDCP- PDU in order to undergo the radio interface transmission. In addition, it contains the Automatic Repeat Request (ARQ) method that helps in errror correction.
- Meduum Access Control (MAC): This layer performs data scheduling based on priorities. It also helps in multiplexing data to transport blocks and error correction.
- Physical Layer (PHY): This is the bottommost layer of LTE-Uu radio interface. It provides interface for the UE to connect to the upper layers.

After E-UTRAN, we have a S1 interface that links E-UTRAN to EPC. The protocols of this interface along with their functions are briefly explained below.

- S1 Application Protocol (S1AP): Their function includes handling of the User Equipment’s CP and UP connection between E-UTRAN and EPC. Also, they assist in handover process.
- SCTP/IP Signalling Transport: SCTP/IP stands for Stream Control Transmission Protocol and Internet Protocol. They represent IP transport, applicable for signalling messages. In addition, they help in transport reliability and delivery functions.

There are two other alternate protocols for interface S5/S8 in EPC and these protocols play an essential role when GPRS Tunnelling Protocol (GTP) is used in S5/S8.

- GPRS Tunnelling Protocol, Control Plane (GTP-C): This manages User Plane connections by signalling the QoS, contributes in mobility management functions inside the EPC, and also takes care of some other parameters. When GTP is used in S5/S8 interface then GTP-C manages GTP-U tunnels as well.
- UDP/IP Transport: It stands for Unit Data Protocol (UDP)/Internet Protocol. They are used as a standard for IP transport instead of Transmission Control Protocol (TCP) as the upper layers already assures reliable transport along with error recovery and re-transmission. (Holma & Toskala 2009: 36-38).

3.4. Performance Requirements

This part of the thesis addresses the second research question. While evaluating the performance requirements, it is first essential to figure out communications on different levels as the requirement of communication varies depending on the nature of data communication at each level. Figure 24 is presented next in order to have clear picture regarding the nature of communication at each interface level.

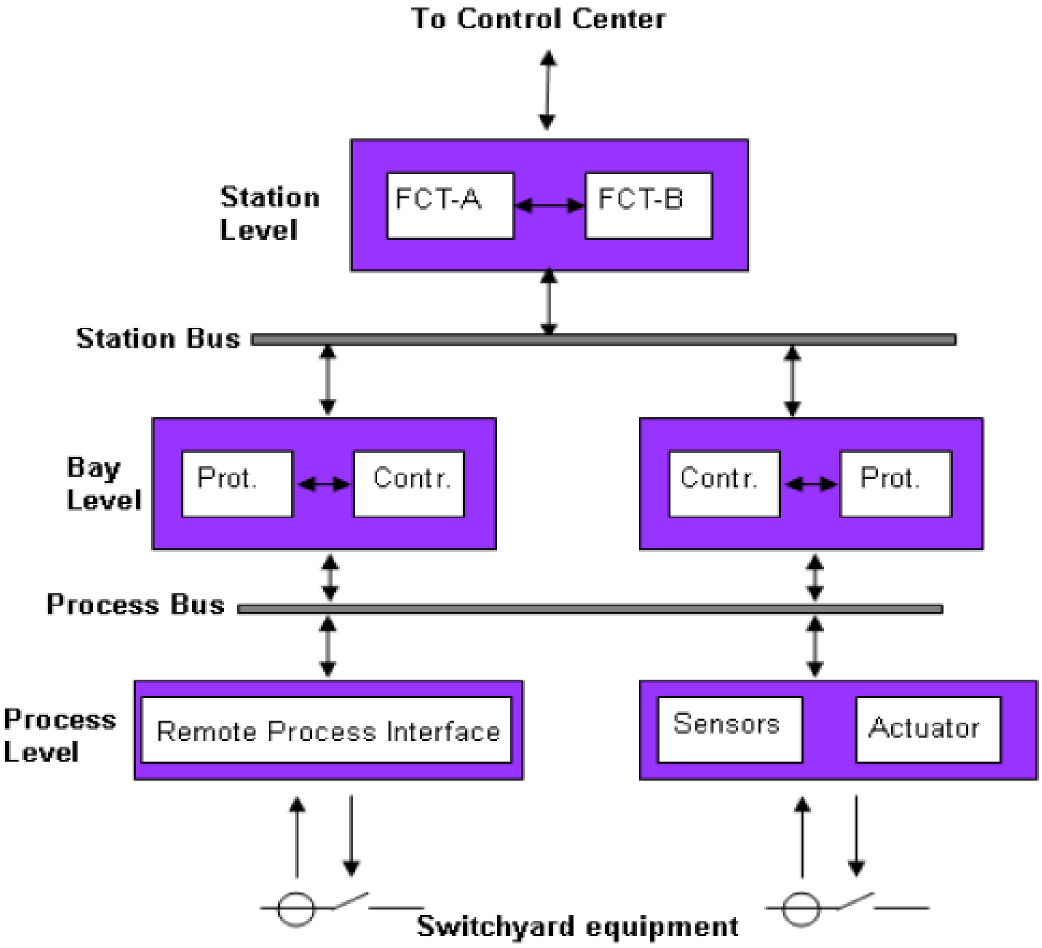

Figure 24. Model of an interface in Substation Automation. (Tarlochan et al. 2008: 473).

The above model illustrates three levels of functional hierarchy namely Station Level, Bay level and Process Level.

In process level, equipments like Remote I/O, Current Transformer (CT), Potential Transformer (PT or VT) etc. are involved. Bay level consists of IEDs that are used for communication. These IEDs main function is to provide protection and control of different bays. At Station level, human interaction with computer are carried out much. Collection of data from various stations and functions that require those data are implemented. (Tarlochan et al. 2008: 473).

Thus, we we have to consider all sorts of data communication required for SAS. The above figure clearly shown the picture of communication within substation. However, this is not the only case. We also have communication between substations and communication between substation and control centre. Figure 24 illustrating scenario of such communication process is presented below.

The protection and control data are exchanged within a substation and between the substations (Pham 2013: 37-39).

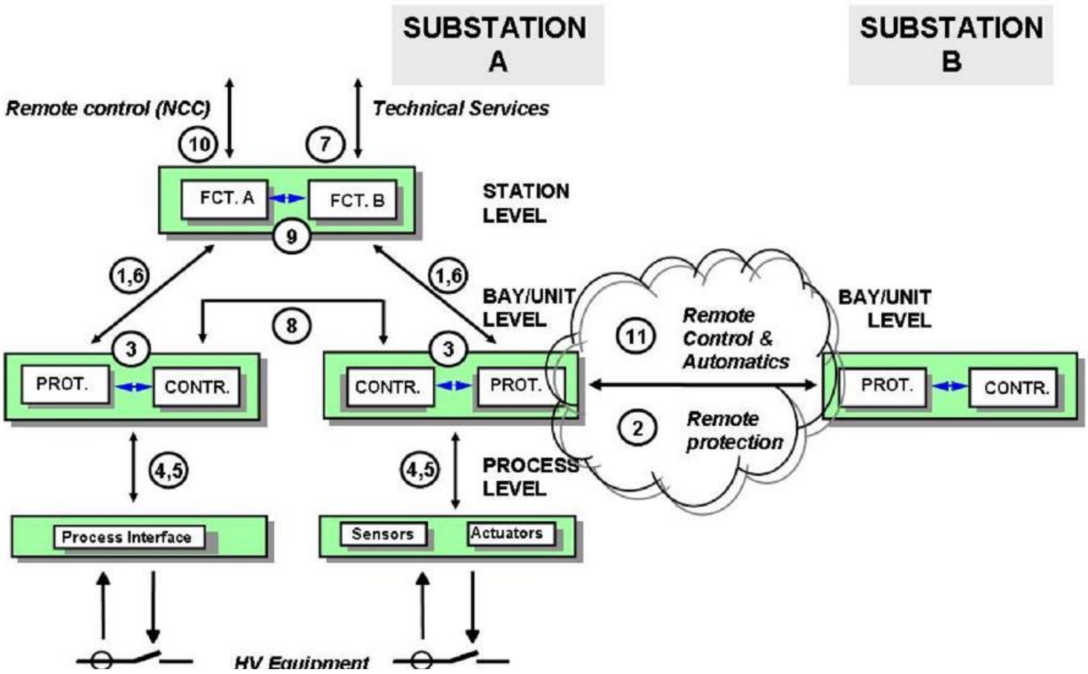

Figure 25. Logical Interfaces in IEC 61850. (Pham 2013: 38).

Out of all the interfaces mentioned in figure 25, interface number 10 is the only one that is used for the exchange of data between smart meters and the meter data centre over a WAN connection in a distributed network. Therefore, we will focus mainly on this interface. However, depending on the type of communication needed by all the interfaces, there are several classes with different transfer time requirements. (Pham 2013: 37-39). They will be discussed in brief in section 3.4.1.

3.4.1. Essentials of Message Performance

The total time taken by a message to be transferred from sender to the receiver is the message transfer time. (Steinhauser & Vandiver 2015). Below in Table 5, various message transfer times and their respective classes are shown.

Table 5. Transfer time classes. (Steinhauser & Vandiver 2015).

Transfer Time class	Transfer Time [ms]	Application examples: Transfer of
TT0	>1,000	Files, events, log contents
TT1	1,000	Events, alarms
TT2	500	Operator commands
TT3	100	Slow automatic interactions
TT4	20	Fast automatic interactions
TT5	10	Releases, status changes
TT6	3	Trips, blocking

IEC 61850-5 has grouped the transfer times and based on that, the performance classes have been classified into 7 classes.

- Type 1 – Fast Messages ('protection'): These types of messages are time critical. Therefore, when the IED receives such messages, it acts immediately. The message in this class are in simple binary code format which contains command or simple messages. All the fast messages holds are very important in this class. However, the ''Trip'' is the most important fast message in the substation, containing the most demanding requirements.
- Type 2 - Medium speed messages (''Automatics''): These are the messages that require medium speed and they are carried out for the operation between substations for automatic functions. The message types may include analogue values for instance root mean squared (r.m.s.) values.
- Type 3 - Low speed messages (''Operator''): Operator messages that are not very time critical fall under this type. Auto-control functions, transmission of event records, reading or changing set-point values and general presentation of

system data are some of the slow speed required messages. (Reaction time > 1s).

- Type 4 – Raw data messages (‘’Samples’’): The data obtained as an output from the transducers and transformers that are independent from the transducer technology (magnetic, optic, etc.) falls under the category of raw data messages. Each IED will have continuous streams of synchronized data samples and one IED data are interleaved from other IED data.
- Type 5 – File transfer functions: Messages which are large files of data from disturbance recording, messages that are required for IEDs settings etc. belong to this category.

The requirement for interface 10 which is responsible for the communication between substation and the control center is not time-critical. Hence it falls on type 3, 5 and 6. The messaging process between control centers and the smart metres can also be of this type. The message types in all the interfaces that have similar performance class requirements can be observed in the Table 6. The message types that is carried out between substation and the control centre is mapped with the Manufacturing Message Specification (MMS). (Pham 2013: 39-40).

Table 6. Time performance requirements for message type 3. (Pham 2013: 40).

Performance class	Requirement description	Transfer Time		Applicable for interfaces in Figure 22.
		Class	ms	
P5	The total transmission time shall be half the operator response time of = 1 s regarding event and response (bidirectional)	TT2	≤500	1,3,4,5,6,7,8, 9,10
P6	The total transmission time shall be in line with the operator response time of = 1 s regarding unidirectional event	TT1	≤1000	1,3,4,5,6,7,8, 9,10

3.4.2. Performance Metrics

There are several parameters that must be evaluated in order to examine whether or not the proposed solution meets the requirement criteria well. Network performance characteristics such as Bit Error Rate(BER), Average Throughput, Packet loss ratio, Delay and Jitter play a vital role for the efficient operation of the modern grid systems. For this reason, accurate monitoring of these parameters is a must. (Papadogiannakis et al. 2006: 1-2). Let us first define all these metrics in brief so that understanding them becomes easy. However, the purpose of this research work is to examine the performance of the bit error rate in the downlink direction in QPSK and 16QAM modulation.

- Average Throughput: The amount of data the receiver receives successfully through a network while transmitting it from the transmitter to the receiver is known as average throughput. It is expressed as the data received by the eNB where user equipment acts as a sender in the uplink direction and the data received by the user equipment where the eNB sends the data in the downlink direction. (Pham 2013: 78).

$$Avg.Throughput = \frac{eNB\ data\ in\ UL + UE\ data\ in\ DL}{Simulation\ Time} \quad (1)$$

- Bit Error Rate (BER): In a transmission system, the Bit Error Rate (BER) is defined as the ratio between the numbers of errors observed from the total number of bits. The formula to calculate bit error rate is

$$BER = \frac{Number\ of\ errors}{Total\ number\ of\ bits} \quad (2)$$

While evaluating the BER curve in a QPSK modulation scheme in an additive white Gaussian channel, the theoretical results are expressed by the equation mentioned below. There are three different variables used in the following equation. They are erfc which is called the error function, Eb is the energy per bit and No is the noise power spectral density. Note that the value of error function is different for different kinds of modulations. (radio-electronics 2015).

$$BER = \frac{1}{2} erfc(\sqrt{Eb}/No) \tag{3}$$

- Packet Loss Ratio (PLR): One of the very important metrics that determines whether the network condition is suitable or not for messaging between substation and control centre and between control centres and smart meters is the packet loss ratio. Packet loss can highly influence the throughput performance and end-to-end data transfer quality. Packets are mostly lost because of congestion. For instance, if there are a lot of packets in the queue of some router, due to some routing problems or it may be due to poor network conditions. Packet loss highly affects the throughput and end-to-end connection quality. Thus, it is very desirable to measure the packet loss accurately. (Papadogiannakis et al. 2006: 1-2). The formula for packet loss ratio in the uplink and downlink is given below.

$$PLR(UL) = \frac{packets\ sent\ by\ UE - packets\ received\ by\ eNB}{Packets\ sent\ by\ UE} \tag{4}$$

$$PLR(DL) = \frac{packets\ sent\ by\ eNB - packets\ received\ by\ UE}{Packets\ sent\ by\ eNB} \tag{5}$$

- Delay : Delay is an important aspect as it links with the performance of the network and directly affects the quality of service. The components of LTE are EPC (Evolved Packet Core), eNB and UE. In the downlink transmission, the packet is received by the EPC where the EPC converts the IP packet into radio signal in eNB and finally eNB transmits it to the User Equipment. The user equipment upon receiving the radio signal converts it to the original packet.

Thus, when all this procedure happens, there are several stages where the end-to-end delay occurs (Nagai et al. 2013). Transmission delay process is presented in Figure 26.

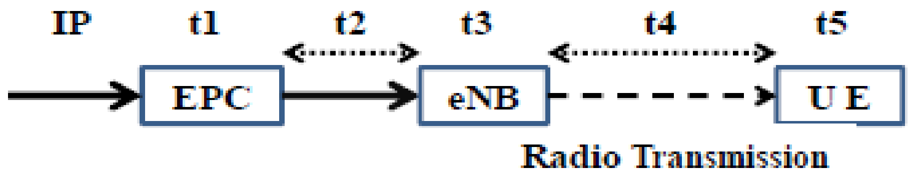

Figure 26. Transmission delay in LTE. (Nagai et al. 2013).

- Jitter: The variations in the delay are termed as jitter. They are responsible in buffering performance for all downstream network and devices. If the jitter is very high then it may lead to buffer overflow also termed as buffer overrun or buffer underflow or buffer underrun. (Pham 2013: 79).

Since the work now focuses on evaluation of the bit error rate for QPSK and 16QAM Modulation in the downlink direction, therefore along with these performance metrics, knowledge on Additive White Gaussean Noise channel (AWGN) and Signal To Noise Ratio (SNR) is also important.

- Additive White Gaussean Noise Channel: Normally in a communication system we assume that when a signal is transmitted, it reaches to the receiver with some distortion caused by noise. Out of different noise, the most common noise assumed is the Additive White Gaussean Noise (AWGN). The noise added on the channel is actually Gaussian(i.e. Normal distributed).

  A Gaussean channel is represented by a time-discrete channel where there is an input X and an output Y where Y = X + Z as shown in Figure 27. This Z is the noise normally distributed, $Z \epsilon N(0,\sqrt{N})$. (Cover & Thomas 1991: 239-241).

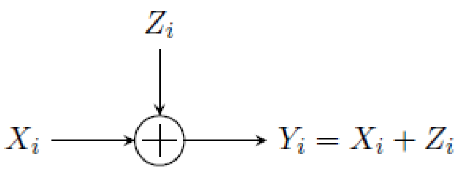

Figure 27. Gaussean Channel. (Cover & Thomas 1991: 239-241).

- Signal To Noise Ratio(SNR): Signal to noise ratio is a way of measurement regarding the sensitivity performance on the receiver side. This is very important aspect for any radio receiver whether it is a simple broadcast receiver, fixes/mobile radio communications or wireless. There are several ways of measuring noise performance. However, the most common and effective way is to measure signal and its noise level known as SNR.

Note that the greater the SNR ratio value, the better the radio receiver sensitivity performance becomes. Figure 28 is presented below that gives an idea of SNR. (radio-electronics 2015).

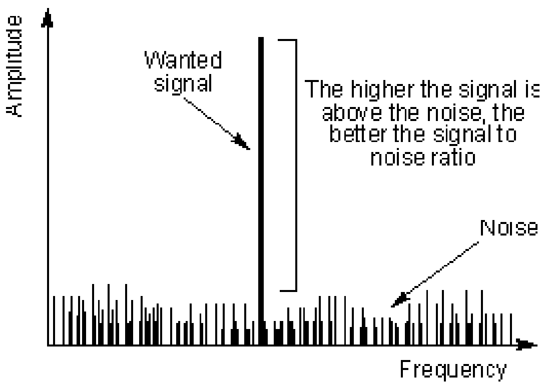

Figure 28. Radio receiver Signal to noise ratio. (radio-electronics 2015).

The formula for Signal to noise ratio is

$$SNR = \frac{Psignal}{Pnoise} \tag{6}$$

where Psignal is the wanted signal and Pnoise is the unwanted signal.

$$SNR = 10log10(\frac{Psignal}{Pnoise}) \quad (7)$$

Here, SNR is expressed in logarithmic basis in decibels.

In the event of all levels expressed in decibels, the formula is then simplified as,

SNR_{db} = Psignal (db) – Pnoise (db) (8)

$$SNR = (\frac{Rb * Eb}{No}) \quad (9)$$

Where Rb = bit rate in bits/second

Eb = Energy per bit in Joules/bit and

No = Noise power

3.4.3. IEC 61850 MMS Scenerio

A Substation Automation system (SAS) consists of methods like controlling, monitoring, protection, communication and so on that helps in the enhancement of stability in substation using. Connecting SAS with IT helps in achieving better performance. The controlling, monitoring, protection etc. is achieved by the fast and effective way of message communication. There are three types of messages in SAS portrayed in Table 7.

Table 7. Different types of messages in SAS. (Jongjoo et al. 2012: 330).

Type	Description
MMS	A message of general operational information, medium priority
GOOSE	A message of error or warning for example trip commands, interlocking information, high priority
SV	A message of transformer's voltage of current value, high priority

They are Manufacturing Message Specification (MMS), Generic Object Oriented Substation Event (GOOSE), and Sampled Value (SV). In this section, MMS will be discussed.

MMS defines some set of standard objects that is required to be present in every device. In other words, it must contain a standard application that eases the set of exchange of information between client and server, so that the purpose of monitoring, controlling, encoding/decoding for protection can be fulfilled. There are around 78 services in MMS that are already confirmed. There are other communication protocols as well but MMS provides more functions than others and it provides a structure. In addition, it also defines meaning to message. Thus, different devices manufactured by different developers are able to interoperate easily.

IEC 61850 Communication stack consists of 3 steps as described in Figure 29 namely initiation step, processing step and communication step. In the initiation step, modelling of the IED is done from the System Configuration Language (SCL). In the processing step, the message is created so that the IEDs can communicate by sending and/or receiving message from other IEDs. In the communication step, communication is done by sending or receiving a message that was created in the processing step. (Jongjoo et al. 2012: 330-331).

Figure 29. IEC 61850 Communication Steps.

In Figure 29, Information Models and Abstract Communication Services Interfaces (ACSI) are implemented in the initialization step. It is this initialization step where ACSI facilitates an abstract interface for environment where client-server based communication is needed. After the initialization step comes the processing step where Specific Communication Service Mapping (SCSM) is done. The function of SCSM is to map the ACSI to the real communication protocol. SCSM even contributes in the communication step for which GOOSE/SV messages and MMS messages are made. (Jongjoo et al. 2012: 330-331).

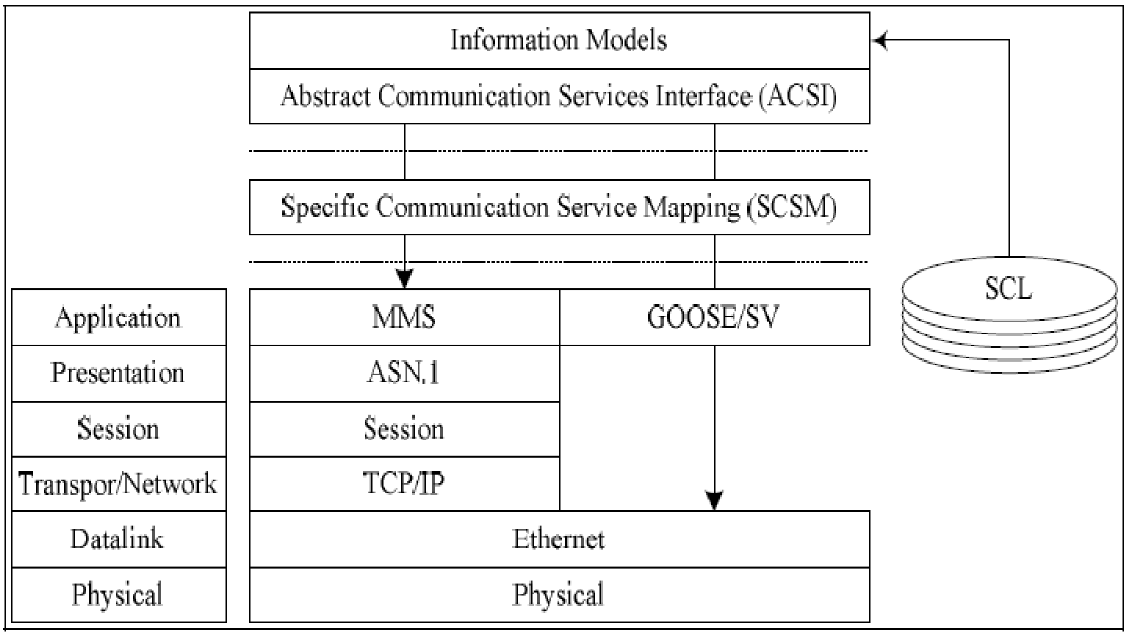

Figure 30. IEC 61850 communication structure. (Jongjoo et al. 2012: 331).

The communication structure of IEC 61850 is depicted in Figure 30. MMS messages are based on client-server communication. Here, the client sends a request to the server for data or operational information. The server upon receiving the request takes necessary actions and sends back a response message to the client. The interaction between client and server is shown in Figure 13. Furthermore, the layers responsible for this client and server communication is shown in Figure 14. In additon, the function of each layers is presented in short in Table 4. To achieve such sort of client-server message communication, the functions are classified on layers based on their purpose. (Jongjoo et al. 2012: 331).

4. EXPERIMENT AND ITS OBSERVATION

The answer to question number 3 in the research questions is addressed here. Focusing about the bit error rate performance in the downlink direction, the aim is to evaluate the performance of integration between IEC 61850 and LTE to support smart metering. Regarding simulation, there are certain things that needs to be discussed before we move deep further. For the simulation, Matlab and its communication system toolbox has been used. Matlab is a programming language for technical computing from the company MathWorks.

In this chapter, there are 3 sections. The first section 4.1 describes about the scenarios considered for the simulation. The second sector describes the different simulations done in the same scenario. Finally, the third section shows the output of those simulations carried out. The idea and help for the simulation has been taken from the book Understanding LTE with MATLAB by the author Houman Zarrinkoub.

4.1. Simulation scenarios

The aim of this research is to examine the performance of bit error rate in the downlink for the integration of IEC 61850 and LTE is carried out here. Since the position of smart meters are not mobile but fixed, therefore single cell has been considered and the Doppler effect was not considered since they do not occur. Neither, handovers between different eNodeBs happen here because of the fact that the location of smart meters are fixed. It is also assumed in this simulation that out of many smart meters developed by various manufacturers, only those smart meters have been used that are LTE enabled specifically meant for the data reception in the downlink direction in a smart grid. The benefit of this approach is that the communication time decreases which makes the task of real time communication easy. Using Smart meters by different manufacturer demands a data concentrator with which smart meters would communicate. The data concentrator would then communicate with the eNB and vice versa resulting in increased communication time. Thus, the use of LTE enabled smart meters that are designed for metering application in Smart Grids becomes more effective. Figure 31 illustrates the simulation scenario.

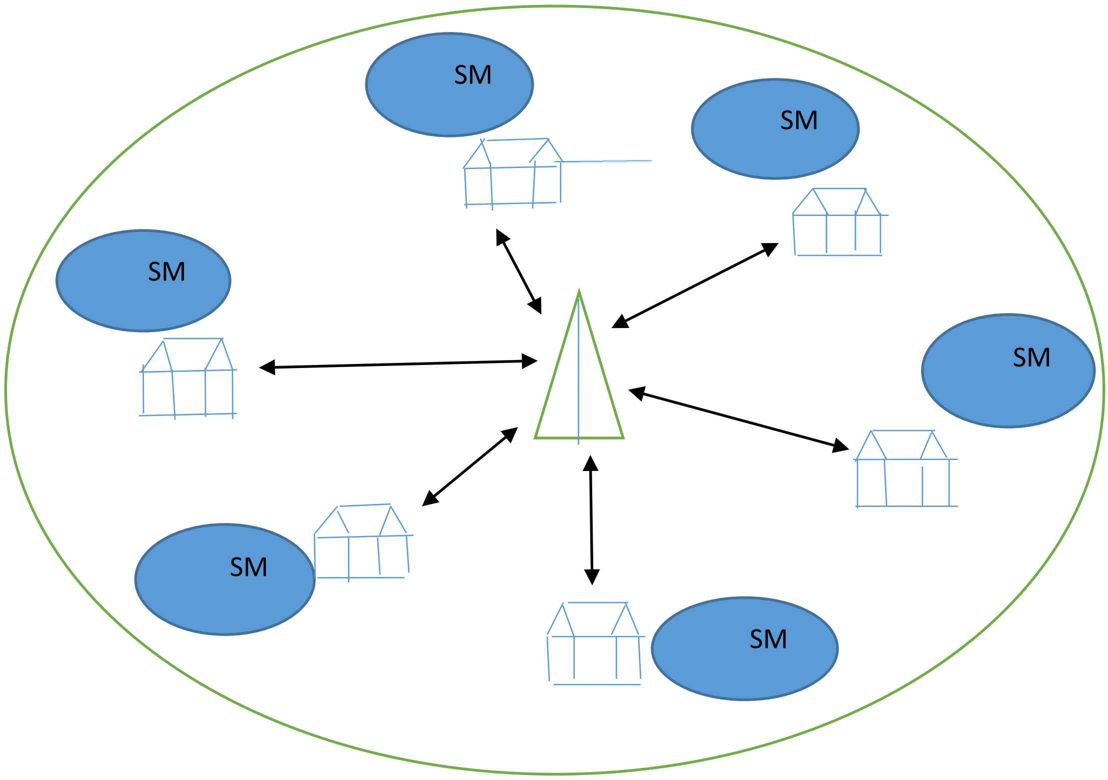

Figure 31. Smart meters operating within one cell radius.

There are two processes involved in channel coding and they are error detection and error correction. In error detection, Cyclic Redundancy Check (CRC) bit is available using which the receiver checks the received signal and asks the transmitter for retransmission. The second process is Hybrid error detection and forward error correction method HARQ (Hybrid Automatic Repeat Request) that is widely used in 3G and LTE standards. Such error correcting codes are mostly categorized into block codes and convolutional codes.

Convolution code is obtained by the convolution of the input sequence with the encoder's impulse response. The k-bit input samples are used by the encoder which then operates on the current data block and previous data block and yields output of n-bit block. The parameters of the encoder are n, k, m where n is the n-block output samples, k is the k-bit input samples and m is the previous input blocks. Thus, convolutional coding technique will also be evaluated in order to see the influence of convolutional coding the bit error rate performance. While undergoing the simulation, there are some of the most important points

- Bit Error Rate: In a transmission system, Bit Error Rate (BER) is defined as the ratio of number of errors observed to that of total number of bits processed.

While evaluating the BER curve in a QPSK modulation scheme in an additive white Gaussian channel, the theoretical results are expressed by the equation mentioned below.

$$BER = \frac{1}{2} erfc(\sqrt{Eb}/No) \tag{10}$$

- Additive White Gaussean Noise Channel: A Gaussean channel is represented by a time-discrete channel where there is an input X and output Y where Y = X + Z. This Z is the noise normally distributed, $Z \epsilon N(0,\sqrt{N})$.
- Signal To Noise Ratio(SNR): Signal to noise ratio is a way of measurement regarding the sensitivity performance on the receiver side. This is very important aspect for any radio receiver whether

MATLAB is a high level language that enables to solve numerical problems in a very short time compared with other low level language like C, C++ or FORTRAN. Supporting interactive development, MATLAB eases in programming and developing algorithms. There are numerous number of engineering and mathematical functions available in MATLAB. Hence, there is no need to write code and test the functions. Furthermore, MATLAB facilitates with all the features contained in traditional programming language. Simulink in MATLAB is used for modelling, simulating and analyzing dynamic systems like control signal processing, communications and other complex systems. Using Simulink, models can be built from the initial stage and the tools helps in analyzing the results. In any system, there are different parameters and conditions involved from the initial stage to the final stage. Theoretical estimation is based on the assumption of these parameters and the conditions in general. However, while simulating the values of these parameters must be specified and the result obtained from the simulation could differ slightly or to a greater extent from the theoretical estimation.

Matlab consists of System objects that facilitates in the representation of the communication model easily making the code written in Matlab simple and readable. This system object present in the communication system toolbox belongs to a package called (comm) communications package. It means that in order to use any object from the communications package, we must begin with the prefix comm followed by a dot. For instance, in order to modulate the bits used in the QPSK modulation system, we have to use the system object for modulation technique and we can name it by ourself. We can also change the pre-set default values depending on our requirement. One such modulation type system object where the system object modulation is named as Mod.

On typing >> Mod =comm.QPSKModulator it displays the properties that have been set in the modulation object by default.

```
Mod =

System: comm.QPSKModulator

Properties:

     PhaseOffset: 0.785398163397448

     BitInput: false

     SymbolMapping: 'Gray'

    OutputDataType: 'double'
```

In order to change the internal properties value, it should be implemented like this.

```
>> Mod.BitInput=true
```

This command changes the internal value of the BitInput from default false to true and the properties looks like this shown next.

Mod =

System: comm.QPSKModulator

Properties:

PhaseOffset: 0.785398163397448

BitInput: true

SymbolMapping: 'Gray'

OutputDataType: 'double'

This was an instance for modulation. Likewise, demodulation is also followed by prefix comm with dot (.) added after. And to change the default value, the same process is applied.

DeMod=comm.QPSKDemodulator

DeMod =

System: comm.QPSKDemodulator

Properties:

PhaseOffset: 0.785398163397448

BitOutput: false

SymbolMapping: 'Gray'

OutputDataType: 'Full precision'

Fixed-point properties:

DerotateFactorDataType: 'Same word length as input'

Hide fixed-point properties

The command below changes the value of the BitOutput from false to true.

```
>> DeMod.BitOutput=true

DeMod =

  System: comm.QPSKDemodulator

  Properties:

            PhaseOffset: 0.785398163397448

            BitOutput: true

            SymbolMapping: 'Gray'

           DecisionMethod: 'Hard decision'

           OutputDataType: 'Full precision'

Fixed-point properties:

DerotateFactorDataType: 'Same word length as input'

Hide fixed-point properties
```

The generation of the random bit is done by the command randi and this generated bit is first modulated. After modulation, this bit is passed through the Additive White Gaussean Channel. The command for treating the bit to Gaussean Channel is

```
>> Channel = comm.AWGNChannel
```

The command for Channel yields its properties that has been set.

```
Channel =

  System: comm.AWGNChannel

Properties:

         NoiseMethod: 'Signal to noise ratio (Eb/No)'

          EbNo: 10

          BitsPerSymbol: 1

          SignalPower: 1
```

SamplesPerSymbol: 1

RandomStream: 'Global stream'

After passing it through the AWGN channel, the bits are again demodulated. This bit is then examined from the original bit produced by the command randi and the error in the bit is determined. The command to use the system object for calculating the error along with its properties from the communication system toolbox is

```
>> BitError = comm.ErrorRate

BitError =

  System: comm.ErrorRate

  Properties:

        ReceiveDelay: 0

        ComputationDelay: 0

         Samples: 'Entire frame'

         ResetInputPort: false
```

Matlab provides a command called bertool from where we can examine the required biterror rate graph vs Eb/No. For this, we must type the command provided next.

```
>> bertool
```

Figure 32 shows the window after the command bertool is appllied. In the monte carlo option set the range of E_b/N_o as required. Click on the Browse button and provide the name of the file by selecting the desired .m file that is saved in Matlab. Provide the number of errors and the number of bits and click on the run button. This gives the simulated result for the given QPSK code. Likewise Figure 33 shows the window for the theoretical result, go to theoretical section which is on the leftmost side of Monte Carlo simulation and fill the parameters in a similar fashion like in the case of Monte Carlo.

Similarly, for the simulation of the bit error rate evaluation using convolutional code, follow the similar steps in bertool as mentioned above. However, the slight different approach here is that when we are working inside the theoretical section, we must choose the type of convolution in the channel coding section and also the type of decision whether it is a hard decision or soft decision. In this simulation, hard decision has been chosen.

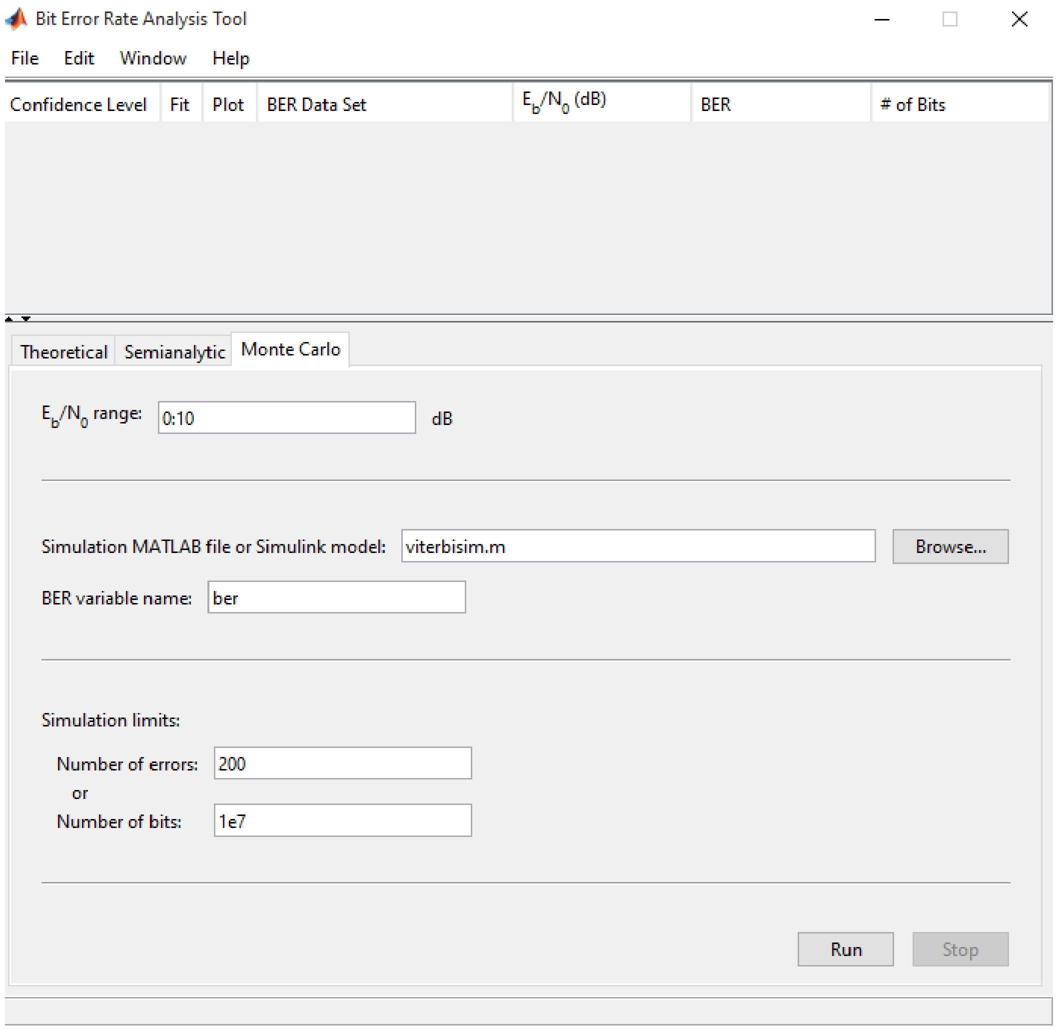

Figure 32. Monte Carlo window for BER simulation.

The theoretical value can be obtained similarly by filling in the parameters for modulation type and Eb/No value etc.

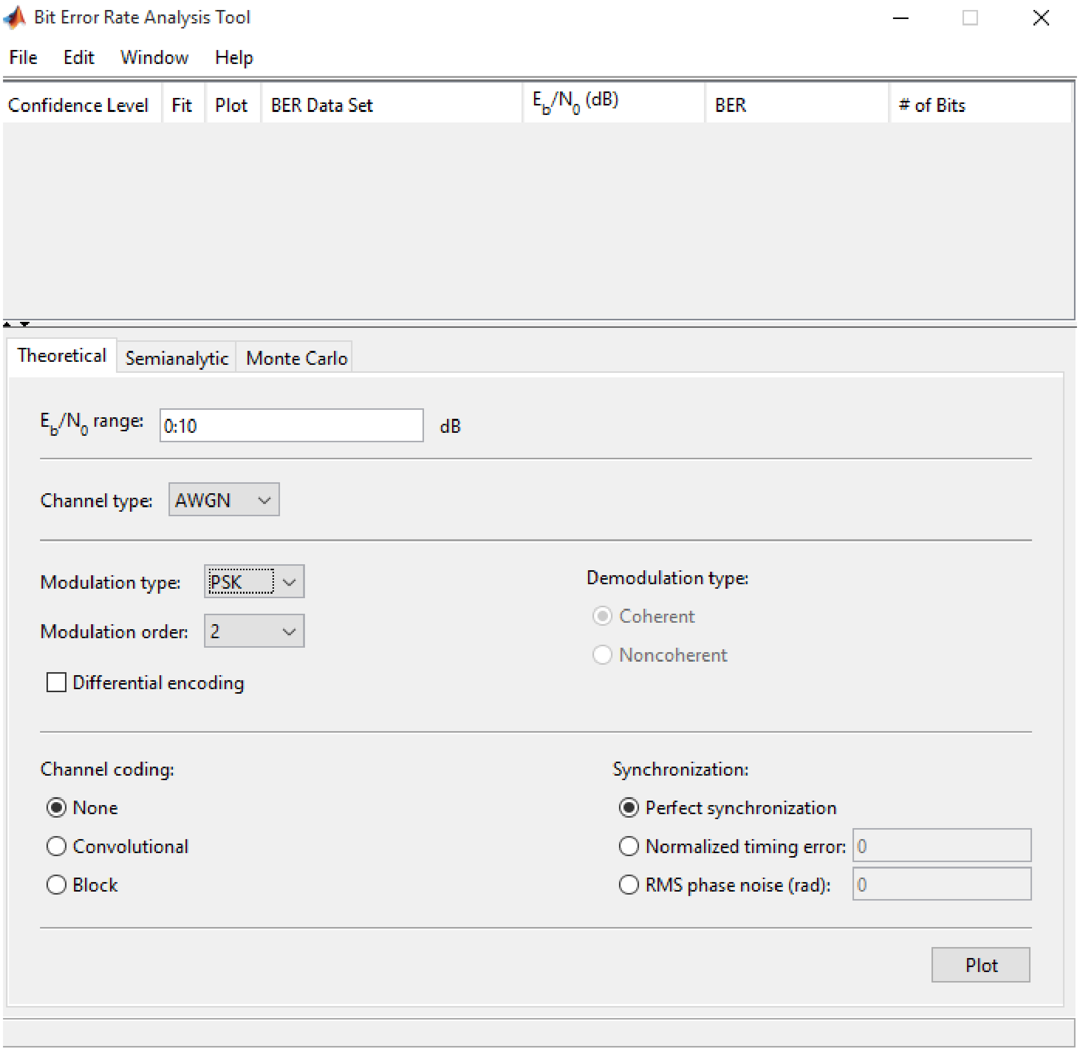

Figure 33. Theoretical window for BER simulation.

4.2. Simulation Result

The result obtained by the simulation of QPSK and 16QAM is presented below in Figure 34 and Figure 35. Here, the range of EbNo is kept from 0 to 10 and the number of bits processed is 50,000. Using the object of the Communication system toolbox, the output for QPSK and 16QAM is obtained.

Both the codes for the QPSK and 16QAM has been combined in a single program. A final function has been implemented which asks the user to press 1 for the result of QPSK modulation and 2 for the result of 16QAM modulation.

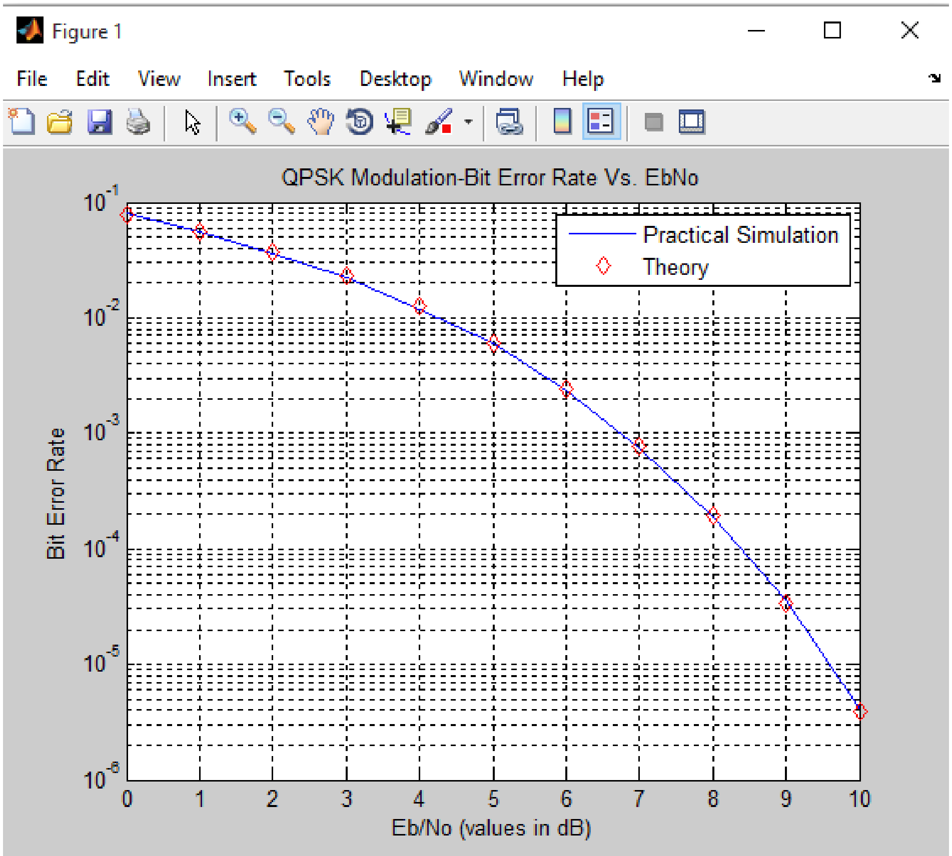

Figure 34. Simulation result for QPSK modulation in LTE.

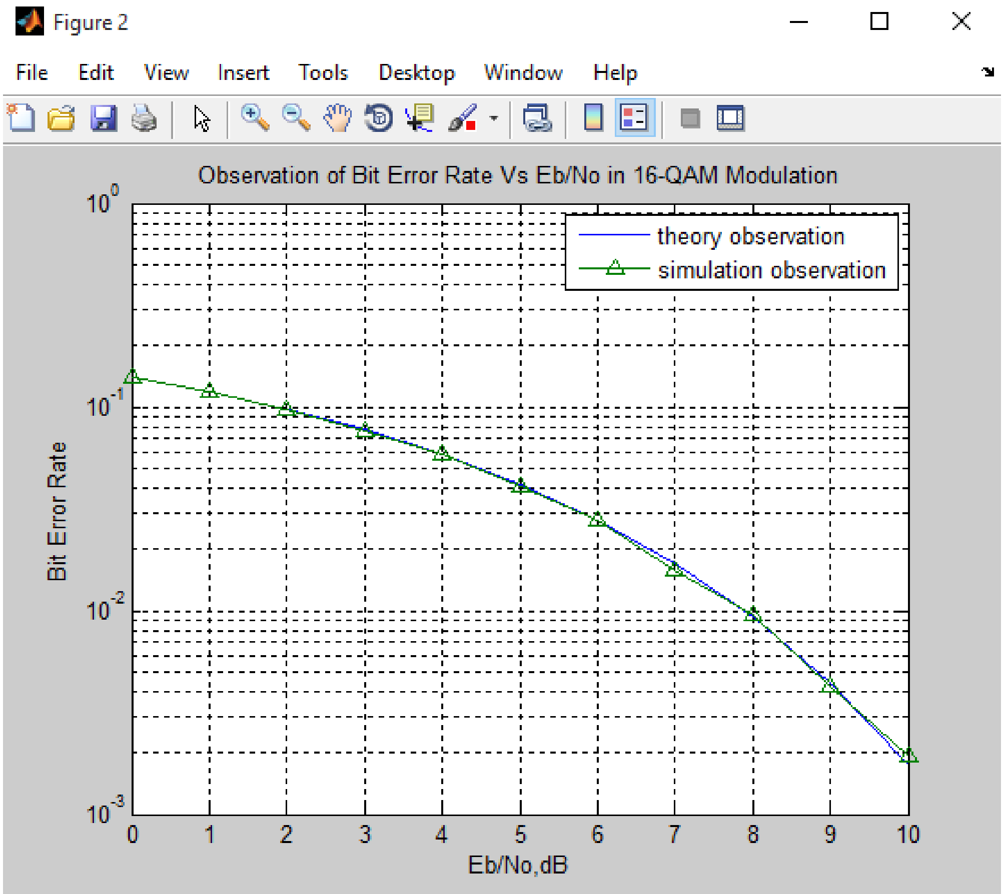

Figure 35. Simulation result for 16QAM modulation in LTE.

In the simulation of QPSK and 16QAM, it can be observed that the performance of bit error rate starts below 10^-(1) at the lowest EbNo value. As the EbNo value increases, the bit error rate value decreases gradually.

Observing at 16QAM, it can see that because it is a higher order modulation technique sending more data, the cost of being able to send more data can be seen on the performance of BER value. At a point where EbNo value was 6 dB, the BER is close to 10^-3 while for QPSK at this point of EbNo, the value for BER was in between 10^(-5) and 10^(-6).

Finally, evaluation of BER performance is observed when convolutional coding is applied. The outcome of BER for convolution coding is shown next in Figure 36.

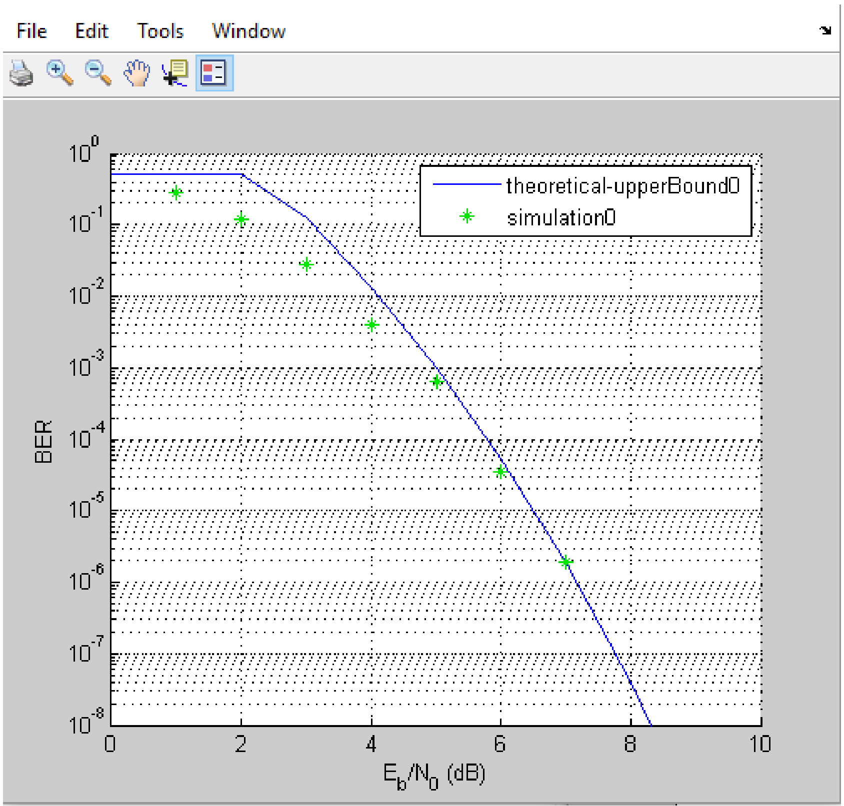

Figure 36. Simulation result for QPSK modulation using Convolution Coding in LTE.

Convolution Codes are generated by the convolution of the input sequence with the impulse response of the encoder. The simulation result for BER obtained with Convolution Coding Technique clearly delineates that the bit error rate performance can be certainly enhanced using such coding techniques.

5. CONCLUSION AND FUTURE WORK

The final chapter summarizes the work done throughout the thesis. Among the three research questions, first and second concerning to the integration of IEC 61850 MMS and LTE and the performance requirements have been answered theoretically in chapter 2 and 3. It can be seen that IEC 61850 is a very important protocol that is widely used in order to achieve interoperability among all the communicating devices in Smart Grid.

The evaluation between the integration of IEC 61850 MMS and LTE has been presented theoretically and based on that, simulations were carried out for the evaluation of performance of bit error rate in the downlink direction. The answer to the third question is given below.

EbNo is classically defined as the ratio of Energy per bit (E_b) to the spectral noise density. It is a measure of signal to noise ratio for a digital communication system. It is measured at the input of the receiver and is used as a basic measure to determine how strong a signal is. There are different forms of modulation techniques and these techniques determine how strong the signal is, i.e. the bit error rate.

Here, increasing the data rate will increase the SNR but more data rate will also increase ISI since high bit rate will bring packets closer. Thus, we cannot just increase the bit rate to increase the SNR. There must be a compromise between the data rate and amount of noise that the receiver can handle.

In the simulation of QPSK and 16QAM, it can be observed that using lower modulation the bit error rate gets reduced which is good. However, it does not facilitate with the increased bit rate. On the other hand, higher modulation technique increases bit rate but bit error rate degrades slightly.

This clearly shows that the higher the modulation technique used, the lower the BER performance becomes.

However, there are techniques to improve the BER even by using higher order modulation techniques for the achievement of high data rate. In order to prove this, a simulation has been performed using a convolutional coding technique. As a result, the performance of BER gets improved. It can be observed from the simulated figure that at EbNo value for 6dB and 5dB, the BER was close to 10^-5 and 10^-4. At this EbNo value, the BER for QPSK was close to 10^-3 and between 10^-2 and 10^-3. For 16QAM, the BER was between 10^-1 and 10^-2.

Hence it probes beyond doubt that convolution coding technique helps to improve BER performance.

For future work, more experiments has to be conducted for other promising coding techniques for instance Turbo coding analyzing the difference in the performance of turbo coding and convolutional coding.

While working on the thesis, it was found that not much work has been done regarding deployment of LTE in Smart Grid. Therefore, more experiments and simulation has to be conducted for the uplink direction as well.

Implementation of real systems and their corresponding measurements with the real system has to be done.

It is also good to notice that in this thesis work, it was assumed that all the smart meters used are LTE enabled with 4G modem integrated. However, this is not the case in real world as there are different Smart meters from different manufacturers. Investigation on the deployment of hybrid AMI architecture that helps to map LTE with sort range wireless technology like wifi, ZigBee etc. should be done.

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