DEVELOPMENT OF COMMUNICATION NETWORK FOR AUTOMATIC METER READING SYSTEM

Amila Alwis Weerasinghe

108871H

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Department of Electrical Engineering

University of Moratuwa
Sri Lanka

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DECLARATION

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A. A. Weerasinghe Date:

The above candidate has carried out research for the Masters Dissertation under my supervision.

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Prof. Nalin Wickramarachchi Date:

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Dr. Narendra De Silva Date:

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Abstract

This thesis presents a research work which is carried out to find out correct network resources requirement for an automatic meter reading system. There are various technologies available to automate the meter reading such as PLC, messaging over GSM, telephone line and RF technologies.

As far as utilities providers are concerned, their focus is on a reliable AMR system to read the meter at minimum cost. Development of a reliable AMR system is highly dependant on telecommunication infrastructure which is costly. Therefore, network resource planning needs to be researched in depth to develop a reliable utility wide AMR system.

This particular research is on data concentrator based AMR system focusing on the analysing of cross relationship between channel requirements of the last mile data communication channel, data concentrator memory requirement and backbone channel bandwidth requirements.

This research has established mathematical simulation models for the last mile channel communication, data concentration memory and backbone channel communication infrastructure and integrated into a single model using software tool MATLAB Simulink. This model has established a scientific conclusion of a methodology to estimate the infrastructure requirements to design of such data concentrator based AMR system.

Developed MATLAB Simulink program is used as a computational algorithm that can repeat the program with multi variable inputs to obtain the numerical results. Monte Carlo method is quite useful for solving this kind of simulating phenomena with having many degrees of freedom, significant uncertainty in inputs and wide variety of scenarios.

Various sampling parameters were input to the system and, related results for various scenarios were obtained. These results were then used to find out cross relationships between three main components of a data concentrator based AMR systems and their requirements.

The results of this research are also adopted to develop a utility wide AMR system as pilot projects with LECO staff at various distribution networks.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AMR	Automatic Meter Reading
AODV	Ad hoc On-demand Distance Vector
API	Application Programming Interface
APN	Access Point Names
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CFE	Communication Front End
CLO	Current Loop
CSD	Circuit Switch Data
CT	Current Transformer
D-AMPS	Digital Advance Mobile Phone
DMA	Direct Memory Access
Don	Duration of channel ON
Dp	Duration of channel plan
EP	Enhanced Polling
FIFO	First-In, First-Out
FSK	Frequency Shift Keying
FTP	File Transfer Protocol
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GUI	Graphic User Interface
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IrDA	Infrared Data Association
ISDN	Integrated Services Digital Network
Kbps	kilo bits per seconds
LAN	Local Area Network
LECO	Lanka Electricity Company (Private) Limited
LED	Light Emitting Diode
LQI	Link quality Indicator
OFDM	Orthogonal Frequency Division Multiplexing
PC	Personal Computer
PDA	Personal Digital Assistant

PLC	Power Line Carrier
PSTN	Public Switch Telephone Network
RF	Radio Frequency
RMR	Remote Meter Reading
RRU	Remote Reading Unit
RSSI	Received Signal Strength Indicator
SIM	Subscriber Identity Module
SMTP	Simple Mail Transfer Protocol
SMS	Short Message Service
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
WSN	Wireless Sensor Network

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Chapter 1

Introduction

1.1 Introduction to AMR

There are various methods involved in reading energy meter datafrom remote location. Remote meter reading (RMR) is the term used in general for this technology. RMR system employs wireless telecommunication technologies such as CSD (Circuit Switch Data) service in cellular system GSM (Global System for Mobile Communications) or GPRS (General Packet Radio Service) [12]. But these technologies arebeing replacedby various new technologies due to their drawbacks.

The primary concern in RMR is to read the meter for billing purpose. Therefore the data involved in RMR is very small and the required data transfer speed is low.

In RMR a telecommunication link is tobe established between the energy meter and the base station. The telecommunication network is ever expandingas new customers keep on joining the network. While,the base station is demanding the meter readings at aninterval of 15 minute or 1 hour, all the meters will be polling and trying to establish a connection between meters and base station simultaneously. In this case telecommunication service providing company has to manage the data traffic and at the peak time it willto fail establish a link. This is gettingworse while retrying to establish the link when disconnected midway at communication. This has lead to repeating the data for initializing the link, sending same data and transmitting acknowledgment data. This will cause an unnecessary data burden over data transfer.

AMR is the most recent technology stand for Automatic Meter Reading [9]. AMR system is used more robust data communication technologies such as GPRS (General Packet Radio Service)[9,4]. In this case base station requests information from the meters and meters send the requested data in packet form. This communication happens packet wise by utilizing packet switch data transfer protocol. There are several protocols used to routing the data from base station to meters and vice versa. Some protocols consist of data aggregation algorithmto concentrate the data into a concentrator. A concentrator shall collect the data from the group of meters and bundle it and sendthem into the base station [1].

1.2 Introduction to existing technology

During the last three decays new electronics type energy meters are widely developed and more populated in the industrial sector. Modern electronics energy meters are based on microprocessors which, enabling the multifunctional features. Those meters are more accurate than the conventional electromagnetic meters. Modern energy meters can be measured more data such as active power, reactive power, average value of 15 minute load, voltage per phase, current per phase and power factor etc. Other major advantage is data communication facilities provided by the energy meters. Those energy meters can transmit data to the base station via wireless communication system, such as GPRS technology. GPRS communication systems are provided by various local companies having wide telecommunication network infrastructures. Energy meter is occupied with a SIM (Subscriber Identity Module) which has unique identification number, wireless communication transmitter, receiver and data storage unit in addition to data measurement sensors and electronics. Additional power supply is required for this data communication unit.

GPRS telecommunication service providers have their own data connection packages. Those packages are based on specific requirement ofapplications such as browsing internet etc. Those data packages may not be suitable for application such as data used in AMR. The bandwidth of the data connection and switch on duration of the wireless connection is decided by the telecommunication service provider.Finally, the cost of the data package is calculated to the energy meter readout cost and directly affects the consumer bill.

1.3 Problem identification

In AMR meter data aresent from meters to the base station through a wired or wireless network. Meters generate various data types such as fixed schedule data which reports at fixed interval, event driven data which are generatedby certain fault conditions or at threshold value and on demand data upon request from user or Electricity service provider.Electricity service providers are interested in a large variety of data with higher frequency. However, in a particular instance an energy meter will transmit only a small data packet.

To transmit this small data packet via a wireless channel,it needs to establish a point to point wireless channel in between meter and base station. When considering the large scale energy meter network, it is necessary to have a separate wireless link to each and every meter which will consume a largeamount of telecommunication network resources. Cost of establishing a telecommunication link is purely the cost of telecommunication network infrastructure. Anelectricity service provider will need a massive telecommunication infrastructure to push this data packetsfrom meter to base station. That is, such a company needs to have an in-house telecommunication infrastructure, so much so as establishinganother mobile company.

Also, it takes approximately two minutes to read out a single meter and when considering the five million subscribers it is unfeasible to read data in time from meters.

Handling of these tiny data packets and aggregating into the base station is highly dependent on each component of the telecommunication network infrastructure.Therefore it is needed to analyze cross relationship between each component of the AMR network and integrate them in order to arrive at a scientific conclusion before designing and implementation of a successful AMR networkwhich is utility wide.

Telecommunication network resources have to be organized to implement atechnically viableAMR system since it has only limited resources. The data concentrator model in AMR system is under research level which aggregates the small meter data into a concentrator via a last mile data transmission protocol and buffer at data concentrator then send into the base station via public telecommunication network. There are three main components in a data concentrator model in AMR system namely last mile RF data network, data concentrator and backbone telecommunication channel link. Development of an AMR system without consideration of cross relationship between these components will not be work as integrated system.

1.4 Objective

Thus, this research is targeted towards identification of correct network topology for AMR and right capacity requirement of each components in the AMR network, so that particular electricity service provider by them self can put a AMR system into integration.

1.5 Methodology

Study the various existing technologies and topologies related to AMR system. Then identify the problemsin existing AMR system technologies and reason to failure to develop a successful AMR system in utility wide.

Energy meter is the data source which generates tiny data at various frequencies. Base station is the destination of the data which having duty of collecting these data to calculate electricity bill and study the quality of the power etc. In between these source and destination point it can have various data carrying topologies. Data concentrator model is one of the most ‘under development’, topologies in AMR. Data concentrator is placed in between the data source and destination. Energy meters acts as a sensor network transmitting their tiny data packets via RF channels and ad-hoc topology is called last mile RF data network or radio island. Then these data are aggregated into a data concentrator which has a memory buffer to store concentrated data. The data concentrator then sends stored data into the base station via a customized data channel of a particular telecommunication service provider.

As described earlier section specification and cross relationship of each components in between source and destination of this AMR system has studied.Practically the channel width of the last mile data channel network, back bone channel and characteristics of the data concentrator. There are uncertainty variables such as channel noise, arisingdue to various environmental interference also considered. The minimum data transfer rate of the back bone channel has to be higher than the maximum transfer rate of the source in order to smoothly transfer data to the base station without any buffer at the data concentrator. If the maximum transfer rate of the back bone channel is higher than the last mile channel data rate then theoretically the memory buffer size of the data concentrator is infinite. Therefore it is evident that the data transfer rate or the throughput of the backbone channeland memory buffer size of the concentrator has to reach equilibrium at a point such that two resources are technically viable. This is understood that the memory buffer size of the data concentrator is dependent on the stochastic analysis of the variation of the channel width of the backbone and aggregated data capacity through energy meters via last mile data network. Therefor the following mathematical approach is usedtosolve such a multi variable uncertainty input phenomena.

Model the data source or energy meter which originatesthe data at various frequencies using MATLABSimulink software. Various Data sizes and transmitting frequencies of the meter were captured by using data capturing software called ‘Microsoft network protocol analyzer’. Model the last mile data network as RF channel using MATLAB Simulink. Model the concentrator memory buffer using MATLAB Simulink. Model the backbone channel using MATLAB Simulink. Various noisesare added to the RF channel and backbone channel in different time scales in order to simulate the channel model as a real world scenario. Integrate all the model and then analysis the system with various scenarios in order to identify best specification and cross relationship between each component.

Further this research extends to several solutions for memory overflow of the data concentrator such as boosting of backbone channel throughput. When data concentrator capacity reaches to a particular safety margin the backbone channel switches to the channel booting mode by extending channelopening duration dynamically. This leadsto increasing the data throughput and maintain the data capacity of the data concentrator below the safety margin.

This mode of channel operation can only be implementedby intending an agreement between the electricity service provider and particular telecommunication service provider.Telecommunication service provider has to agree to increase the channel width upon request by electricity service provider to enhance the channel width for a short duration. Implement a protocol to generate memory overflow signal of the concentrator and dynamically channel width enhancement protocol to integrate this channel operation mode. This methodology incorporates into backbone channel speedmodel of the Simulink program.

Finally integrate each model into single MATLAB Simulink program and simulates with various parameters and study the results.

This integrated MATLAB Simulink a program has used as computational algorithm that can repeat the program with various variable inputs to obtain the numerical results. Monte Carlo method is used for this telecommunication and wireless network simulating phenomenon. Monte Carlo method isquite used as engineering approach to solve problems having many degrees of freedom, significant uncertainty in inputs and wide variety of scenarios[14].

Implement the model as a pilot project of AMR with LECO staff and analysis the result. Discuss the future improvements to be taken in order enhance this AMR research by consideration techno-economic approach.

Chapter2

Literature Survey

2.1 Existing AMR technologies

AMR Technology

There are two main ways of collecting data from all kinds of meters. The first one is to perform a direct connection with particular device from the acquisition system. In this scenario GSM acts as a virtual wireless extension of physical meter interface enabling access to meter data to human operator or specialized intelligent software[11,12]. The other possibility is to perform local data readout and buffer results in internal volatile or non-volatile memory. Collected data is then uploaded automatically or on demand to FTP or SMTP servers [3,9]. Both these methods have their advantages and inconveniences. The first one seems to be easier in real implementation. Nevertheless, in this case lots of parameters have to be taken into consideration. Most of energy meters use older IEC-6205 standard.GSM latencies, possible data loss and packetization issues (such as packet size and timeout) have to be properly adjusted while configuring data collection program. GSM device and energy meter communication parameters are also responsible for reliable connection and lack of meter respond timeouts [9]. The main advantage of this approach is system flexibility. Every change in a data readout schedule or internal registers supervision is performed only on the highest system level and there is no need to modify GSM device firmware or configuration. The system is also insensitive to communication protocol changes and offers full access to meter parameters. It also makes possible to have different meters with various protocols over the same network. On the other hand, buffered readout eliminates GSM communication issues reducing the number of configuration variables [12]. The highest system level is responsible only for data processing and distribution. However, every schedule change in time or reading data demands configuration changes in collection device.

The lack of real-time transparent connection makes it impossible to fast readout of data or internal parameters that are not supported by the firmware. Both reading schemes should be supported by GSM device in spite of their advantages and disadvantages.

Some manufacturers such as CellNet Systems, Hunt Technologies and Leach Industries have alreadyworked on digitizing and equipping the currently availablemeters with various communication facilities. The major partof an AMR system then is the underlying communicationtechnology over which to deliver packets from both sides.There are four major types of AMR communication networks:power line carrier (PLC), cellular network, telephone/Internet,and short range radio frequency.

Power line carrier (PLC)

In this technology, data is transmitted over voltage transmission lines along with electrical power. Factors such as the choice of frequency, propagation speed, voltage level carried, distance between the two communicating points and the existence of transformers affect the PLC communication properties.

PLC has gained great interest as the AMR backbone network because no extra cabling is required. Every electricity meter is connected to a PLC modem through RS232 data port. Multiple PLC modems, corresponding to a group of houses under the same pole transformer, connect to a single concentrator modem. The concentration modem bridges the PLC network to a data network. Meters report their measurement when they are polled. The PLC modem buffers the frames until anretrieve signal is received, or otherwise the frame is retransmitted. No evaluation of the system is provided.The concentrator acts as a controller and aggregator. The best capacity can be achieved when a receiver initiates the connection [8].

This technology faces to problem called silent node. When a base station polls all the metering nodes, it may fail to communicate with certain nodes due to environment noise it’s called silent node. There is some solution for silent node such as modifying the polling mechanism. Where the silent node problem may occur, the base station polls all the meters in a cyclic order [8, 6]. Each meter responds immediately with its available data. If a certain meter does not respond, the Enhanced Polling (EP) mechanism is used.

PLC technology however faces some other number of challenges such as noisy medium, high signal attenuation, and susceptibility tointerference from nearby devices, leading to high loss rate.Scalability of PLC-based AMR is also in question. There isno work to show how much geographical area a PLC networkcan cover or how frequently the metering data can be reported.Lastly, PLC has already been deployed for broadband servicesin many countries. However, in certain countries such asAustralia, Russia, and United States, such deployments havebeen terminated. The reason is the high cost involved and thefact that other means of communication of higher stability andreliability are available.

Messaging over GSM Network

Short Message Service (SMS) has become a communicationprotocol allowing parties to exchange delay-tolerant shorttext messages. It is supported by different standards, namelyGlobal System for Mobile communications (GSM), Code-Division Multiple Access (CDMA2000) and Digital AdvancedMobile Phone Service (D-AMPS). The popularity and widecoverage of cellular networks have attracted researchers toconsider the use of SMS service.

AMR system design that utilizes a GSM network the system constitutes at the consumer sitea digital meter with RS232 interface and a GSM modemcontaining an SIM card dedicated for only SMS and atthe energy provider site an SMS gateway to send and receivemessages [3]. Measurements are reported once a month. The SIM card number acts as aunique number to identify a customer.

Scalability and reliability of such a network however isquestionable, especially under high load. Analysis of real data taken from a real GSM network observed and

SMS delivery success rate was found to be in between 94.9% to 73.2% of the successfully delivered messages reach to the destination within 10 seconds, about 5% of them requiremore than an hour and a half. Using SMS for AMR servicewill definitely increase the flow of messages tremendously.

Analyses are concluded that of latency and failureratio under high load. For example, on a New Year eve, the volume of SMS increases drastically.

Consequently,latency grows from several minutes to an hour. Failure rateshows an increase to 20% as well. All in all, SMS should befurther investigated before being used for AMR. For example, ability of cellular networks support messaging frequency of up to a message every 15 minutes.

Telephone lines

Telephone lines are desirable, for they offer a highly reliable,relatively inexpensive, and simple to operate solution. AnAMR system can use telephone lines for inbound, outbound,or bidirectional communication. The connection is initiatedfrom the customer site in the inbound mode, while initiatedfrom the energy provider in the outbound mode. In the bidirectionalmode, connection is initiated from either site, enablingmore services such as sending out queries and collectingmeasurements.

In AMR system that utilizes thepublic switched telephone network (PSTN) need hardware of the two end points which were Remote Reading Unit (RRU)and Communication Front End (CFE). At the customer site,RRU is installed, where it can connect up to three meters,possibly of different kinds. At the utility company site, theCFE is installed. It consists of a regular computer and amodem. The RRU and CFE communicate with each otherthrough the telephone network in both directions, allowing theRRU to send data frames, and the CFE to send commands.Measurement reporting can take place either on demand orperiodical. The CFE collects the information sent by all theRRUs, and transmits them to processing and billing servers.The ability of having two-way communication allows the utilitycompany to reprogram the RRUs, for example, to changethe reporting schedule. An RRU can store the measurementsuntil it is successfully delivered to the CFE [6].

The availability of a telephone line at each meter is arequirement that cannot be always satisfied, especially indeveloping countries. However, telephone lines can be consideredfor far and isolated locations, in which wireless coverageis missing.

Short range Radio Frequency

Short range Radio frequency (RF) in this context refersto low-power RF facility at the customer site. A number oftechnologies can be classified under RF: Bluetooth, WiFi,Zigbee, depending on the signal power and frequency band. In this proposal electricity meters equip with Bluetoothmodules to deliver the readings wirelessly to a nearby PC(or PDA) directly. Metering data is then forwarded througha dial-up connection to the energy provider or collected bya walking by person. Meters transmit their data either periodicallyor whenever they are polled. Bluetooth as a solutionto AMR is not plausible anymore today, however, it stays aviable solution in certain circumstances such as meters with Bluetooth modulesalready installed may send their data to nearby devices, whichin turn forward the data using a better technology.

Zigbee standard for the upper layers protocols propose to let the meters create awireless mesh network with IEEE802.15.4 standard. By the combination of protocols andnetwork setup guarantee real time collection of data, butno experimental validation is provided. Zigbee has receivedbig attention as a solution to AMR because the technologyis already designed for low rate applications and consumesminimal energy, enabling a device to last for a number ofyears. Also it supports a variety of strong routing protocols.However, it is worth noting a number of drawbacks. Bandwidthis very low (20 kbps at 868 GHz and 250 kbps at 2.4 GHz) [3, 6]. With the increase of the number of nodes,interference increases dramatically. That makes its connectionsand routing paths unstable and incurs high delay, thus makingthe technology hardly reliable and scalable for AMR.

Although RF has been actually used for AMR in manycountries, the services it provides are very limited.With sensornetworks, connecting to all meters may fail due to far nodes orthose whose parent nodes fail. Thus an alternative is necessaryto implement a fully automated, full-scale AMR system [7].

2.2 Future AMR and Smart meter technologies

Emerging wireless technologiesare expected to have large deployments in the near future.Thus, it is just time to explore their suitability for AMR. Therefore it is important to study automatic meter network and wireless sensor network in terms of their characteristics. Then, design a network under certain technical requirementsand evaluate the network and select suitable communication technology.

Wireless sensor network

A meter device functionally is a sensor node that providesenergy consumption measurement.The number of meters can grow to thousands, and data aretypically fused and delivered to a centralized location forprocessing and decision making. Such characteristics makemetering equipment viewable as a regular wireless sensorthat can form a wireless sensor network (WSN), which isinvestigated extensively, and for which a good number ofprotocols have been proposed that can be benefited from forAMR. Wireless sensor networks are diverse in the application objectives, density of nodes, Hardware constraints and nature oftraffic. The recent research inthe field of WSN typically takes the approach of consideringthose factors to optimize communication protocols to bestsatisfy the overall application objectives [6]. While referring toWSN, it is important to highlight the special characteristics ofAMR that may be involved in choosing or designing the rightprotocol.

To reduce traffic load of a sensor network and reduce energycost, the amount of data transmitted in the network isreduced by means of data aggregation. Data aggregation allows nodes tocombine multiple readings into one locationto analysis the results. Different algorithms are available to achievethat. In AMR, however, packets carry unique informationidentifying a specific meter and the exact timeof the measurement. Therefore, measurement data fromindividual meters must reach the collection center whilepreserving its information.

AMR must support bidirectional communication to allowfor meter set-up and reconfiguration at any time.

AMR network performance

An AMR network should meet certainquality requirements. Thus any new design has to be assessedaccording to a number of quality aspects as following.

Reliability: The AMR network must guarantee the arrival ofall meter readings to the base station.

Scalability: A designed network shall be assessed accordingto its ability to providing support to a large number of meterscovering a large geographical area. Furthermore, the frequencyof such readings should be high enough to support the desiredAMR services

Real time communication: Data reported from a given metermust arrive within a given amount of time. Certain event data loggers such as fault detection mandate a short time delay.

Security: The level of security can be expressed in terms ofthe cryptographic tools implemented at different protocol stacklayers and the number of key bits used.

Chapter3

Analysis of metering data structure

3.1 Standard metering protocol

The AMR system requiresa means of telecommunication resources for transmitting and receiving their data. The information of each meter must arrive reliably and securely to the electricity service provider for billing purpose and power quality analyzing.

The selection of which communication technology to used depends on a complex set of engineering analysis that requires significant expertise and experience in telecommunications, together with an in-depth knowledge of the application and its requirements. No single technology is available inAMR systemswhichperforms this accurately.

Energy Meters are currently offer three methods of communications, which are, the simple pulsed output, the flag optical port (IEC 1107) and RS232 port. Although the hardware for these methods is standard among manufactures, the protocols and the data are not standard. Currently all manufacturers offer their own reading and programing software and different communicating chips in order make this transparent to the user. Availability of all three communication methods incorporated into a single device obviously will incura high product cost [2].

New energy meters offer provisionsforgathering various informationfrom meter which is useful to thehouseholder and the electricity service provider. By enabling existing technologies and appropriate software can be developedto support advance metering protocols. Technological researches continue to improve the quality of products in terms of communication range, data transfer speed and reliability. Following standard communication topologies are used in AMR as metering protocol.

IrDA offers a low cost communications method for local data gathering. IrDA is stands for Infrared Data Association that supports a walk-up, point to point user model. Since this is becoming an accepted standard for computing and communications equipment is it suitable for metering. The basic communications speed is 9.6kb/s, but this can be increased to 4Mb/s. This will provide high level of noise immunity within the office environment but not outdoor.

The Internet offers a flexible network of communications based on the ever growing base of consumer equipment. The prime advantage of the internet is in providing near real time access globally with specific remote site for the cost of local call. Many complex meters are already linked by modem to provide 24 hours access to base station. These modems use TCP/IP protocol to access these meter to internet. Each meter requiresa unique Internet access address or their address could be dynamically changed to allow re-use. Internet is normally associated with data transfer rate of 14,400 baud with advanced modems operating at 56k baud. Typically an AMR system operates at 200-9,600 and systems are generally designed for asymmetrical data transfer that is large quantities from the meter.

ISDN is ideally suited for customers who already have their own ISDN network installed. ISDN has been growing in popularity over the last few years in commercial and industrial customers. In this technology the data transmission speeds over existing hardware has an improvement. The ISDN uses digital datastream which is transmitted in 64kb/s. Only complex electricity meters will be able to be interfaced into an existing ISDN network.

There are some broadcast and unicast communication technologies such as PLC, GSM, Wi-Fi and Zigbee which are widely used in AMR. GSM (Global System for Mobile Communication) is a development from cellular telephony. GSM adapts digital modulation and key technology is time division multiple access (TDMA).

Zigbee is a two way wireless communication technology featuring short distance, low complexity, low power consumption, low data speed and low cost. The reliability, large network capacity and safety are the main factors to suitability for AMR system.

3.2 Analysis of element data

Energy meter generates various data type such as load profile data, event data and billing data. These data are referred payload data of the data packet when transmit into another device. A data packet need protocol to identification both receiving and transmitting sides. This data called protocol data and consumedata space in addition to payload data. The protocol data and payload data are elementarily studied to analyze and model the energy meter.

Energy meter dataare retrieved through GPRS data link and this channel is captured through network protocol analyzing software called Microsoft Network Monitor 3.4 version which located at base station between data request device and base station GPRS modem (Figure 3.2.1)

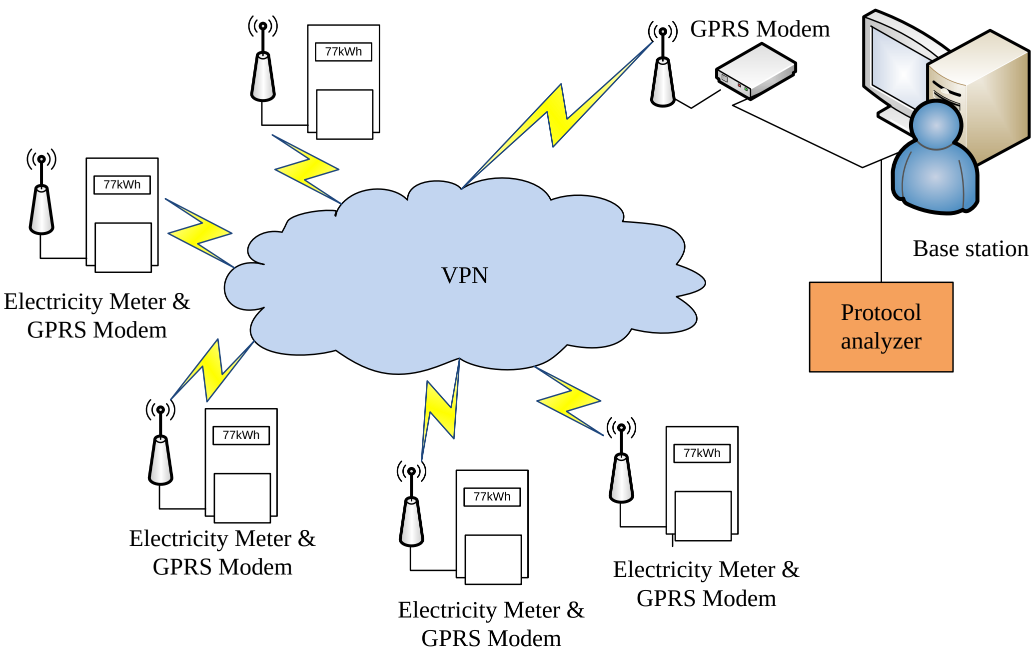


Figure 3.2.1 – Configuration of the Energy meter reading through GPRS

There are 83 energy meters at Moratuwa north area owned by bulk consumers connected through GPRS network by LECO and meter readings were taken by LECO head office by dialing each modem (Appendix A). In this case data linksare established between each meter modem and base station modem. Base station can request load profile data, event logs and billing data separately by accessing the registers in the meters. Those data are captured by protocol analyzer (Figure 3.2.2).

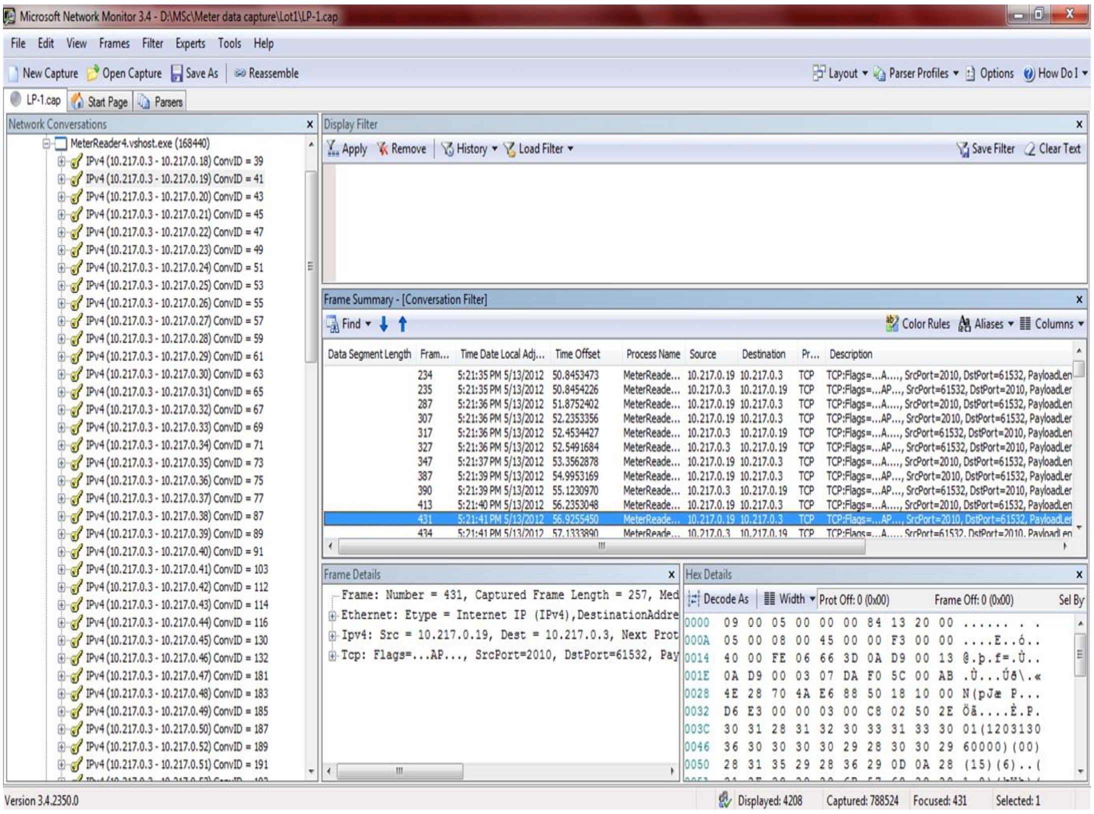


Figure 3.2.2 – Microsoft Network Monitor capturing meter data

Each meter has own IP address and network protocol analyzing software has facility to capture payload data and protocol data separately frame by frame with date, time, source IP and destination IP. Captured data are sorted and tabled in order to analyzeand comparepayload data and protocol data to model the energy meter.

Load data profile

Energy meters store load data profile in its registers as shown in the following table (Table 3.1) at fifteen minute intervals. In this profile kWh (Export), kWh (Import), kvarh (Export), kvarh (Import), kVAh (Export) and kVAh (Import) are taken into account. The meter IP is 10.217.0.18 and the destination IP is 10.217.0.3.

Table 3.2.1 – Load profile data

Register No.	Description	Interval
1.8	kWh (Export)	15 min
2.8	kWh (Import)	15 min
3.8	Kvarh (Export)	15 min
4.8	Kvarh (Import)	15 min
9.8	kVAh (Export)	15 min
10.8	kVAh (Import)	15 min

Data length is analyzed with frames of data retrieved and observed, thus most of the time data packet consists of protocol data only. Moderately data packet consists of payload data with a size of 203 bytes.Very occasionally data packets consist of payload data with a size of 534 bytes. The protocol data is 54 bytes (Figure 3.2.3).

Load data profile consists of six registers and every profile has capacity of 737 bytes of payload data. However,the total data length cannot be transmittedwithin a single frame and thus it is divided in to two or three frames. While increasing the number of frames each frame is added with additional protocol data of 54 bytes in order to utilizeunnecessary network resources. This isanalyzed by following graphical representation (Figure 3.2.4).

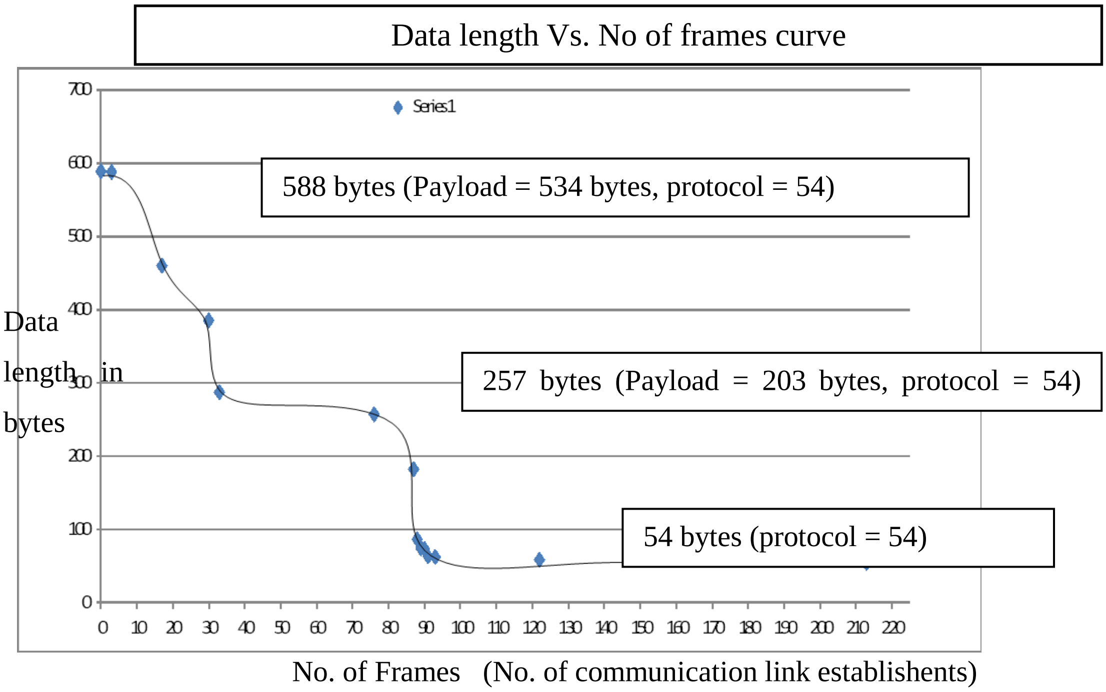


Figure 3.2.3 – Graphical analysis of Data length vs No. of frames

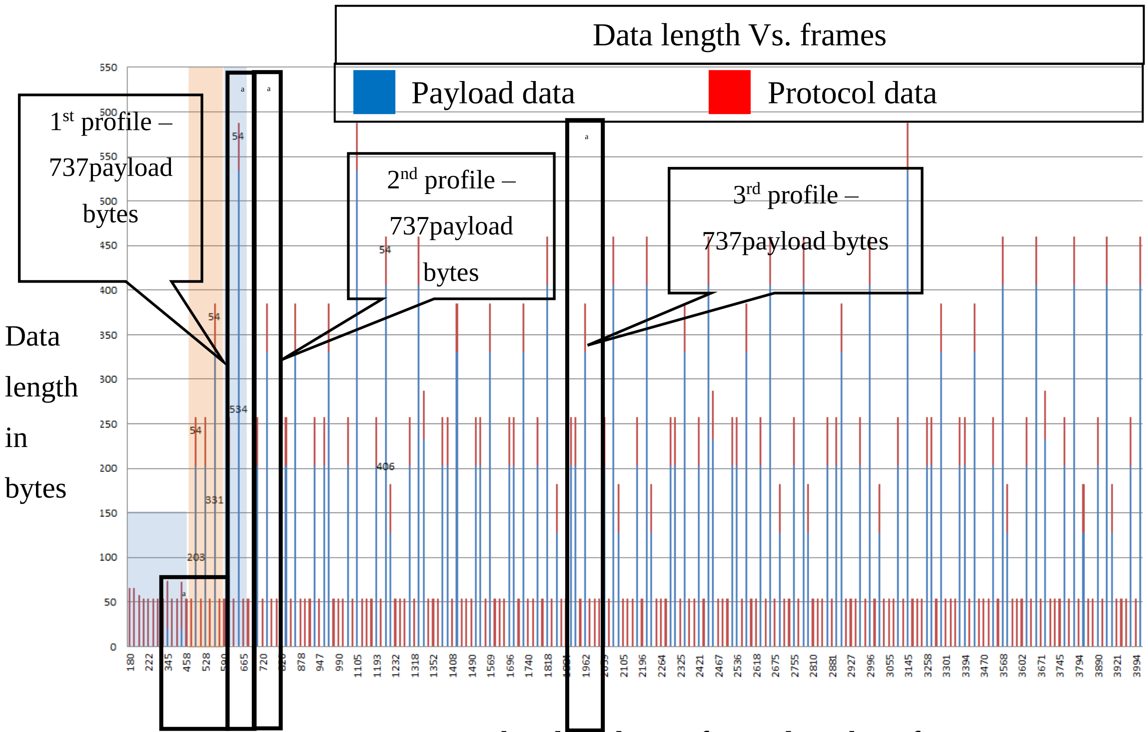


Figure 3.2.4 – Graphical analysis of Data length vs frame No.

According to figure 3.2.4, first load data profile consists of 3 frames having payload data size of 203 bytes, 203 bytes and 331 bytes. The second load data profile consists of 2 frames having data size of 203 bytes and 531 bytes. Third load profile consists of 3 frames having data size of 203 bytes, 406 bytes and 128 bytes. First and third profile consists additional 162 (54 x 3) bytes as protocol data to transmit and second profile consists additional 108 (54 x 2) bytes. The effective work done in the first and third profilesare 81.98% and second profile it is 87.21%.

Table 3.2.2 –Summary of the Load profile data

Profile	**Payload data (Bytes)** **A**	**Protocol data (Bytes)** **B**	**A/(A+B) %**
1^{st} Profile	737	162	81.98
2^{nd} Profile	737	108	87.21
3^{rd} Profile	737	162	81.98

Event data profile

Energy meter stores event logs such as voltages of each phase in special registers of 32.7, 52.7 and 72.7 (Table 3.2.3). Event log data profile has no regular interval to generates, but whenever the threshold level is exceeded, of a particular parameterthen itgenerates an event log.

Table 3.2.3 – Event data profile

Register No.	**Description**	**Interval**
32.7	Voltage R phase	Event log
52.7	Voltage Y phase	Event log
72.7	Voltage B phase	Event log

Event data profile has a payload capacity of 45 bytes and retrieved by three frames each having a payload capacity of 15 bytes. Since each frame has additional 54 bytes of protocol data, the total size of the event data profile capacity is 207 bytes. This is analyzed by following graphical representation (Figure 3.2.5).

The effective work done in an event data profile is 21.74%. This shows that while retrieving small data profile the effective work done is very low and resulting wasting the network resources.

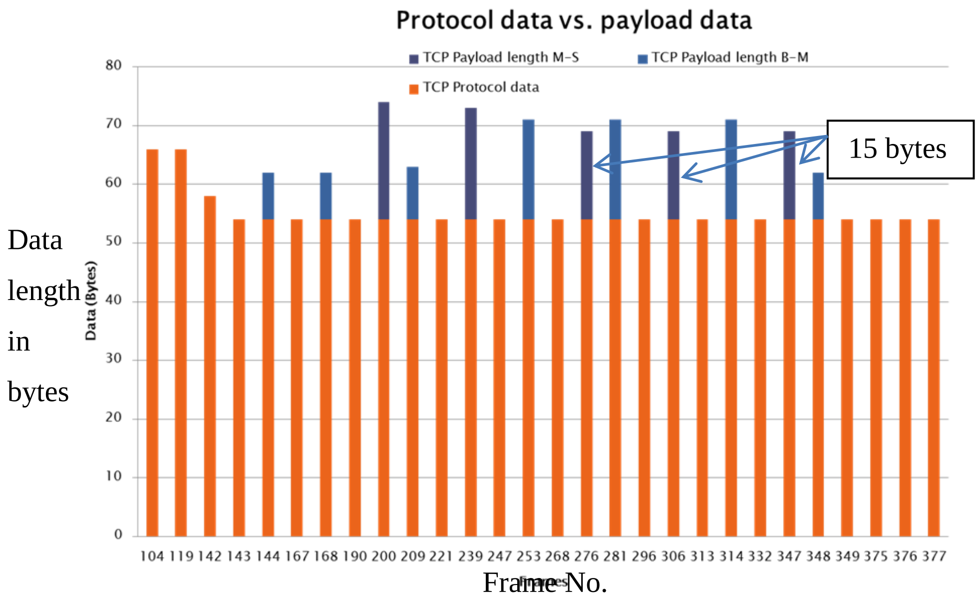


Figure 3.2.5 – Graphical analysis of Protocol data vs payload data

Billing data profile

Energy meter stores billing data logs such as kWh and kVarh in special registers of R1 1.8. Billing data profile generates data in a 60 minute interval and having data capacity of 20 bytes and requires additional 54 bytes of protocol header to transmit data to a destination IP. Effective work done through billing data is 27.02%.

Summary of data profiles

All data elements in an energy meter are captured through a network monitor while data is retrieved via GPRS connection and analyzed to implement a MATLAB simulation of AMR model. Following table shows the summary of the data profiles of an energy meter (Table 3.2.4).

Table 3.2.4 –Summary of data profiles

Profile	Payload data Size (Bytes) A	No. of frames	Protocol data (Bytes) B	A/(A+B) (%)
Load data	737	2	108	87.21
		3	162	81.98
Event data	45	3	162	21.74
Billing data	20	1	54	27.02

3.3 Simulation of data traffic

Energy meters are divided in to segments by considering geographical distribution of the meters and technological limitation of the RF channel used in the last mile data network. This segment of the RF channel network is called cluster or radio island. A data concentrator is placed within a cluster in order to analysis the data traffic of that cluster. Last mile data aggregation is done by zigbee RF module and concentrated data are pushed into the base station via GPRS network.

Clusters

Moratuwa area bulk consumer electricity supply network is selected for model implementation work. This area has three primary substation named Thelawala primary, Angulana primary and Katubadda primary. Therefore this area is divided into three clusters named cluster No. 1, cluster No.2 and cluster No. 3. These clusters have 54, 50 and 21 bulk consumer meters respectively (Appendix A). Within the clusterthere is a data concentrator and data aggregation is done by zigbee mesh network. Segmentation of clusters is illustrated in figure 3.3.1.

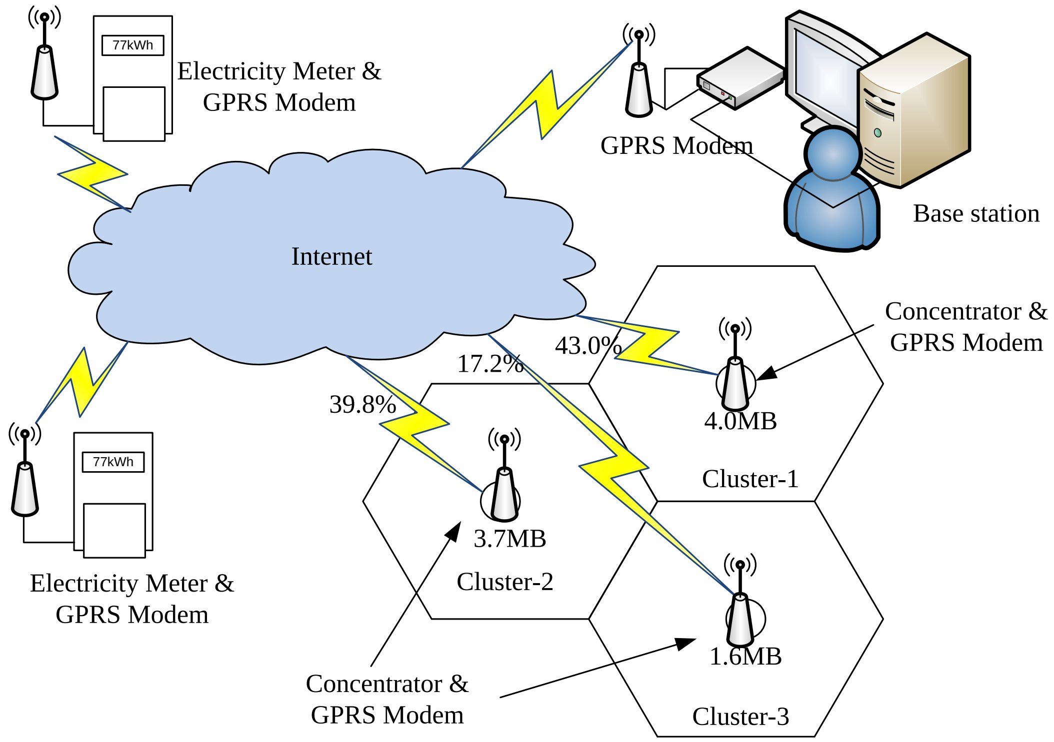


Figure 3.3.1– Dividing into Clusters

According to the above cluster analysis data concentrator collects meter data belongs to its cluster area and pushed into the GPRS network through GPRS modem and received by GPRS modem at base station. In this analysis per day data capacity of the data concentratoris calculated as the first step. But, in this case the data amount retrieved through the GPRS channel is not considered. Table 3.3.1 illustrates the summary of the data which generates by energy meter.

Table 3.3.1– Data profile & frequency

Data profile	Payload (Bytes)	Frequency (Interval)
Load data	737	15 min
Event data	45	Event log
Billing data	20	60 min

Each clusters aggregate payload data per day as shown in (Table 3.3.2). Cluster data concentrators are placed at primary substations or convenience place which can be minimize abstraction to the nearest meters having RF module.

Table 3.3.2– Payload capacity of each clusters

Description	Cluster No.1	Cluster No.2	Cluster No.3
No. of Meters	54	50	21
Load data profile	0.10 MB	0.09 MB	0.04 MB
Event data profile	0.22 MB	0.21 MB	0.09 MB
Billing data profile	3.64 MB	3.37 MB	1.42 MB
Total payload per day	3.96 MB	3.67 MB	1.55 MB

Principle of data traffic Simulation model

Meter data profiles and frequencies are considered as arrays and fed into data concentrator via RF channel. Zigbee protocol is used as RF channel data network which having characteristics of short range, low power consumption, low cost and low complexity. Aggregated data are pushed in to base station via GPRS channel having adjustable band width and planned duration without overflow the contractor memory capacity. Data concentrator memory capacity, GPRS channel width and GPRS channel planned duration are the vital parameters when considering the network resource planning. So in this MATLAB simulation model these parameters are taken as variable parameters that user can change.

Figure 3.3.2 shows the basic model concept taken into account when developing the total system data traffic simulation model.

Meter data profile

a = {a_1 a_2 a_3} where

a_1 = Load data profile (737bytes)

a_2 = Event log data (45 bytes)

a_3 = Billing Data (74 bytes)

Frequency

f = {f_1 f_2 f_3} where

f_1 =15 min

f_2 =Random

f_3 = 60 min

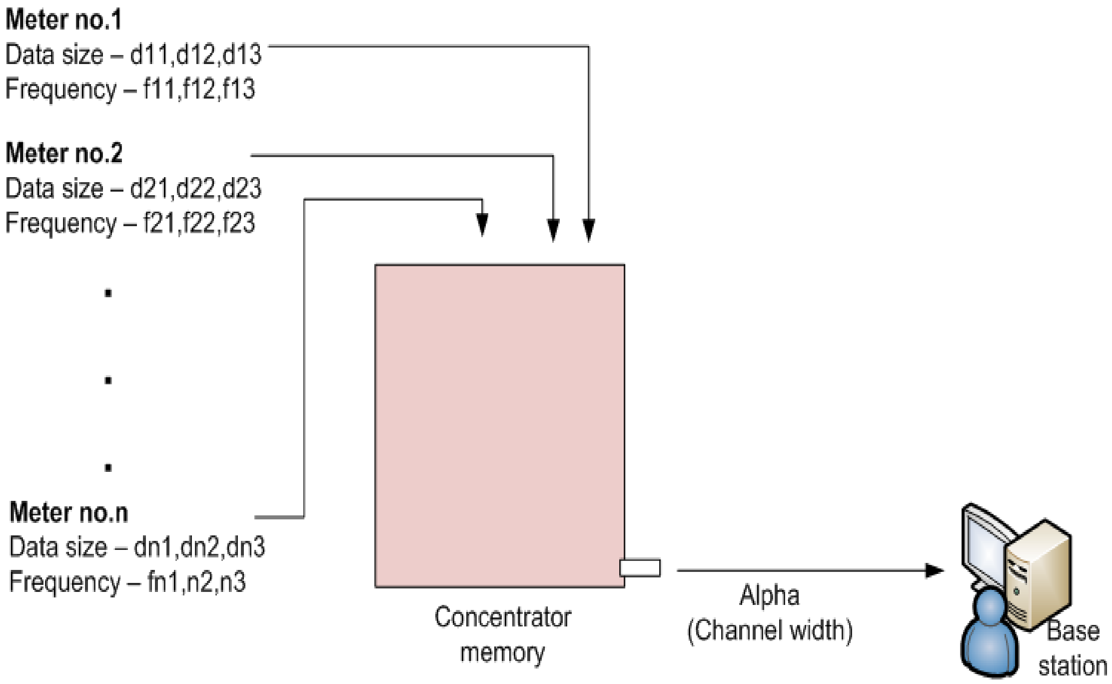


Figure 3.3.2– Basic concept of model

MATLAB Simulink

MATLAB Simulink software is used to develop this simulation of data traffic over last mile data network, data concentrator and GPRS channel. Simulink is an advanced tool provided by MATLAB in order for the user to build models by both block diagrams and instruction codes. Also, Simulink is a software package that is enabledto simulate, and analyze systemswith various inputs and the resultsare observed over time. Such systems are often referred to as dynamic systems.The Simulink software can be used to explore the behavior of a wide range of real-worlddynamic systems, including communication channels, electrical circuits, shock absorbers, braking systems, andmany other electrical, mechanical, and thermodynamic systems. In this project MATLAB Simulink is used in two-step process. First, it is used to createthe block diagram,using the Simulink model editor that graphically depicts time-dependent mathematicalrelationships among the system's inputs, states, and outputs. Finally, the Simulink software is used to simulate the system by the model from a specifiedstart and stop time.

In this case the load data profile and billing data profiles are taken into account and event data profile is omitted since this contributesto generate very low capacity in order to simplify the simulation algorithm.

3.4 Development of model for the traffic analysis

The total block diagram of the Simulink system model is as shown in the figure 3.4.1. Each part of the total block diagram are taken as separate model and build detail block diagrams and developed MATLAB Simulink program and instruction code. This means as the first step the load data profile model of the energy meter is built using MATLAB Simulink software and then billing data profile model. Energy meter model is developed by combining these two models. Likewise each model which shown in the figure 3.4.1 is developed by using MATLAB Simulink. Finally, these models are combined with each other with appropriate parameters.

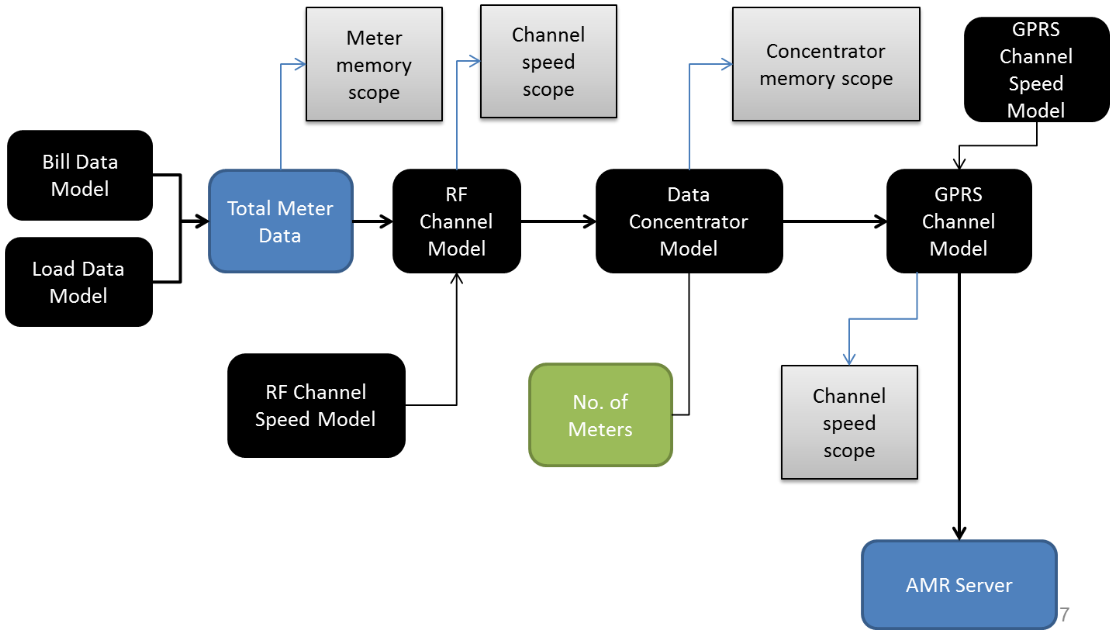


Figure 3.4.1 – Simulink System Model

Billing data profile model

To develop the billing data profile model the maximum data size that can be retrieved by the data concentrator through RF channel is taken into account. The frequency of the data retrieved is taken as 60 minutes, however user can change as appropriate. If billing data profile payload is higher than the maximum data size then payload is split into frames and pushed into the concentrator. This data transferring and data aggregation happens in the RF network channel, such as a Zigbee mesh network. Since this network is a private network it is not burden to public network resources and also no operational cost other than infrastructure cost which is very low. The output of the billing data profile model is fed into the RF channel model after aggregating the load data profile model. The flow diagram of the billing data profile model is shown in the figure 3.4.2.

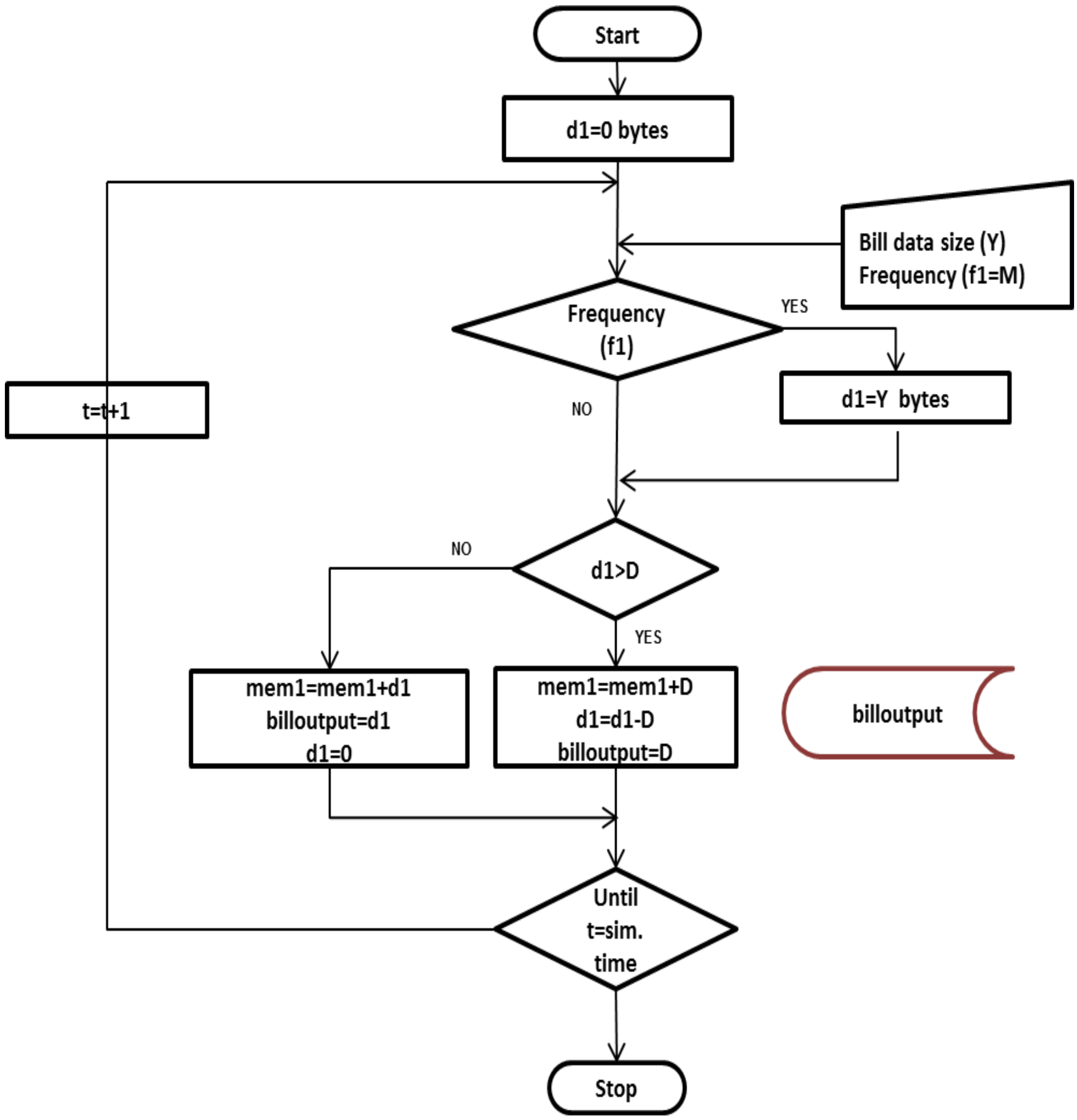


Figure 3.4.2 – Flow diagram for billing data profile model

Where

D = Maximum data size that can transfer : 257 bytes

d_1 = Billing data profile size : 74 bytes

f_1 = Billing data readout frequency : 60 min

mem1 = Meter memory for billing data

The MATLAB Simulink program consists of bill data MATLAB function which having six parameters to iterate the loop function until the end of simulation timeout. While looping the function of this program outputs the billing data at user defined time interval (frequency : f_1). If bill data size is more than the maximum data size that can transfer (D) then function output the D and remain push in next iteration. The function billdataMATLAB program is shown as in the figure 3.4.3.

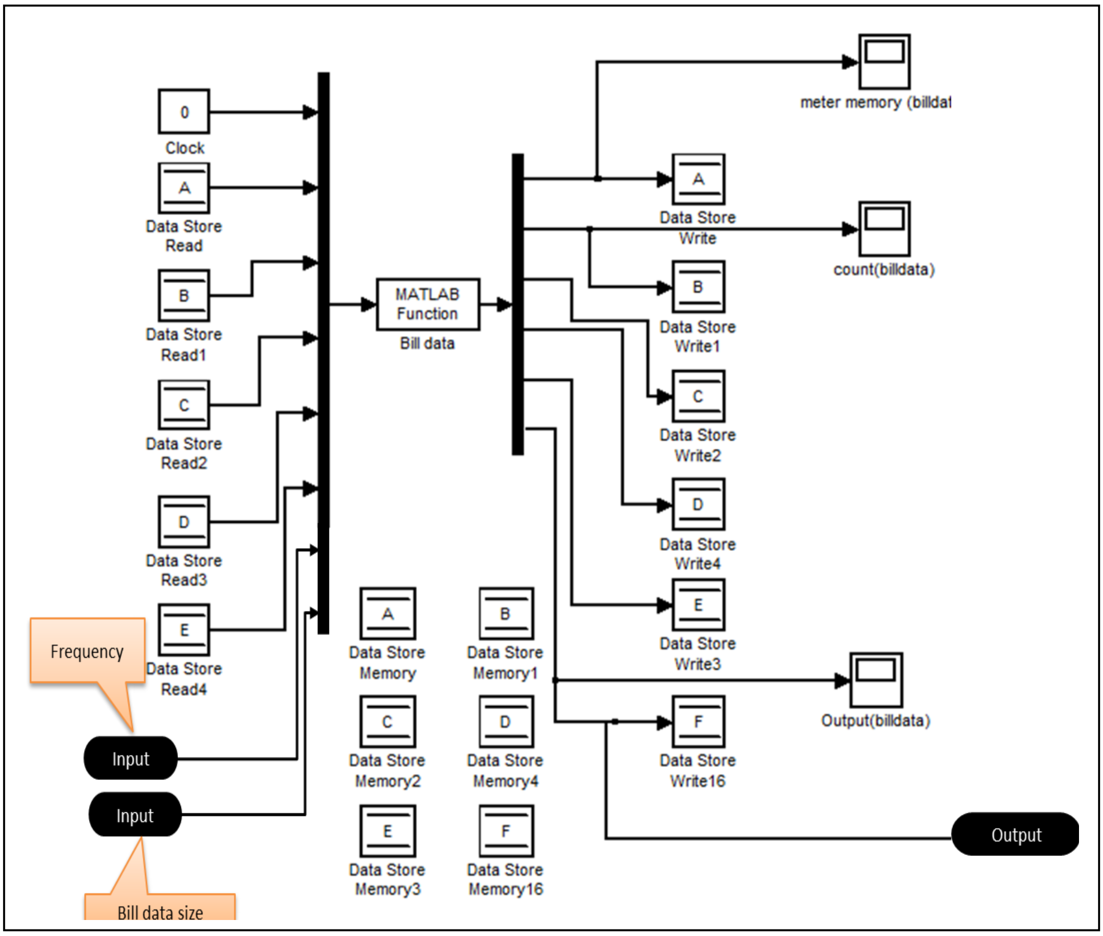


Figure 3.4.3 – Simulink Program for billing data profile model

Load data profile model

Load data profile model is similar to the billing data profile model but the payload data size and data retrieving frequency is differing as observed from data elementary analysis. The flow diagram of the load data profile model shows in the figure 3.4.4.

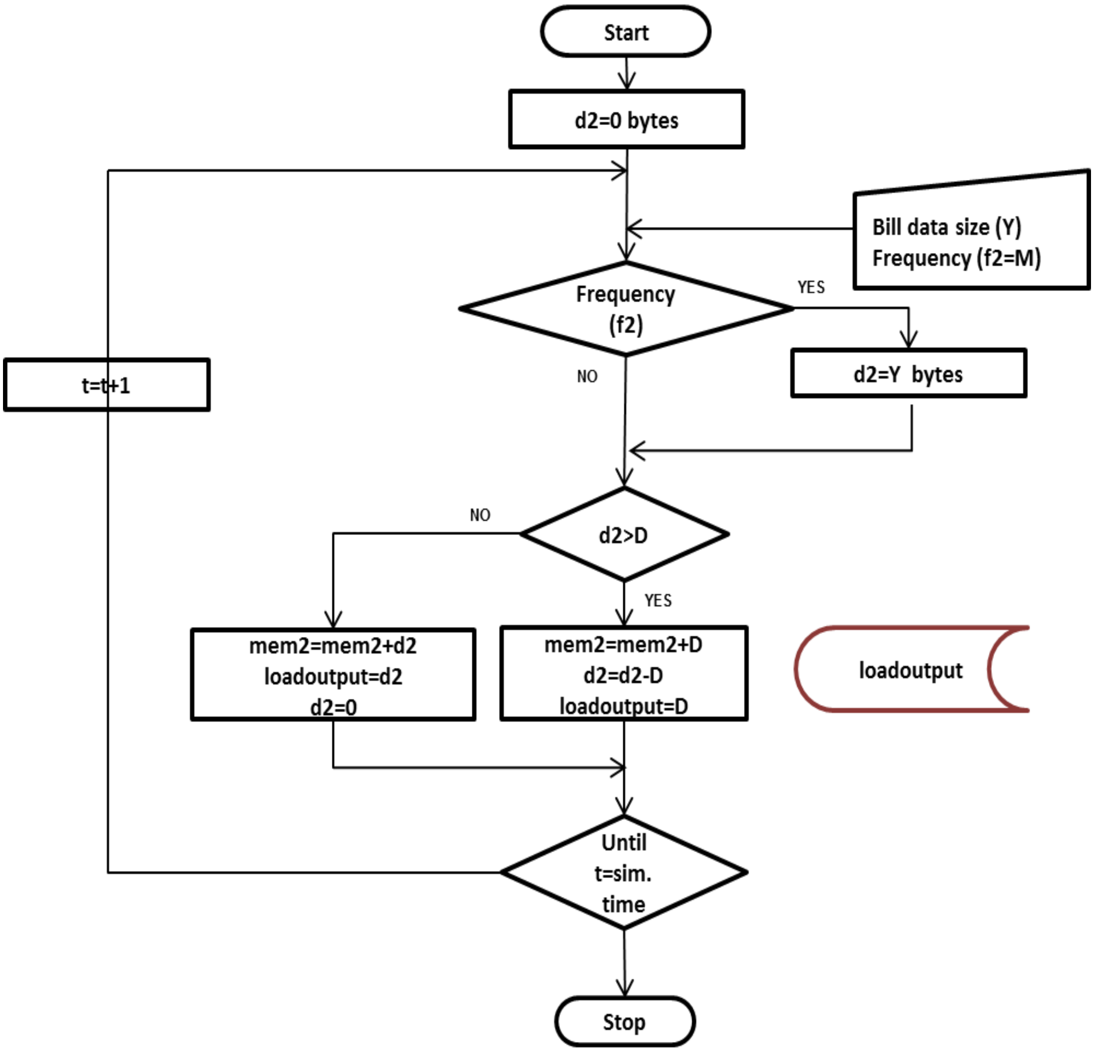


Figure 3.4.4 – Flow diagram for Load data profile model

Where

D = Maximum data size that can transfer : 257 bytes

d_2 = Load data profile size : 737 bytes

f_2 = Load data readout frequency : 15 min

Mem2 = Meter memory for Load data

In this case load data profile payload is 737 bytes which is more than the maximum data size that cab be transferred through a single frame. Therefore, the load data splits into three frames and transfers in consecutive iterations. The load data readout frequency is 15 minutes. Every readout interval load data is pushed into the data concentrator through RF channel. Above codes are written by MATLAB programming language and executed within the MATLAB function called "load data". This code is incorporated with the MATLAB block diagram program to the looping the program.

RF channel model

RF channel model is connected with total meter data model and RF channel speed as inputs. The data concentrator is connected as output channel. Meter data are stored in the meter memory and meter memory monitor via a meter memory scope link to the meter. RF channel throughput isconfigured so that not overflows the meter memory. The RF channel throughput is designed as separate model which illustrated in next section. Meter data are aggregated into the data concentrator through the RF channel model (Figure 3.4.5).

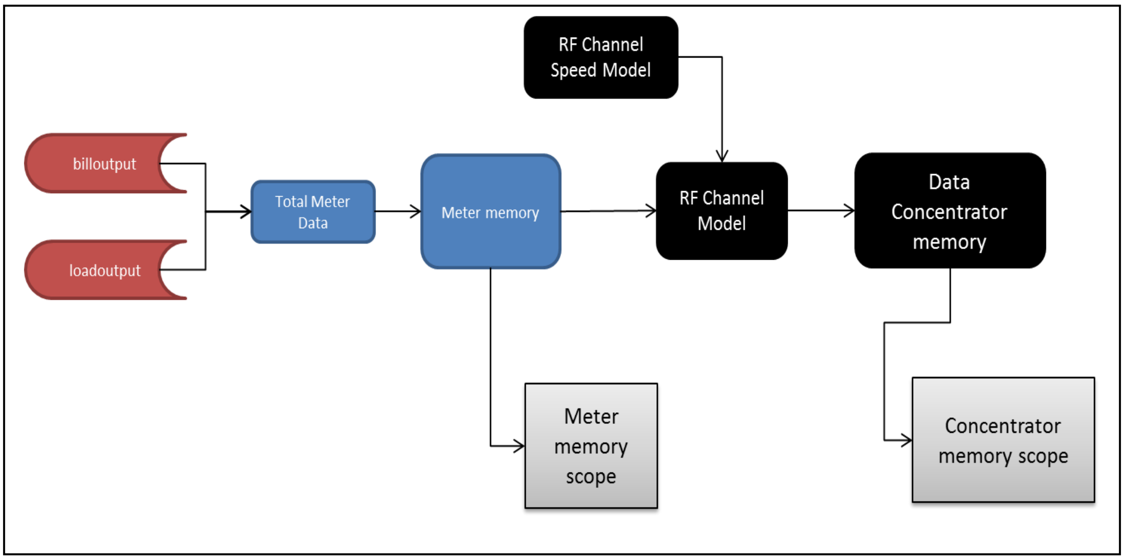


Figure 3.4.5 – RF Channel Model

There are five inputs in the MATLABSimulink function and two outputs. Inputs are Simulink time frame, Meter data, RF channel speed, concentrator memory and meter memory. The outputs of the function are concentrator memory and meter memory. Data concentrator memory and meter memory are updatedat every iteration of simulation program. Data store memory blocks in the MATLAB Simulink program are programmed to store parameters during the loop. Depending on the RF channel throughput the meter data istransferred into the concentrator memory. Program a 'waveform scope'in the meter and data concentrator and monitor the behavior of the meter and data concentrator memory. MATLAB program is illustrated in figure 3.4.6.

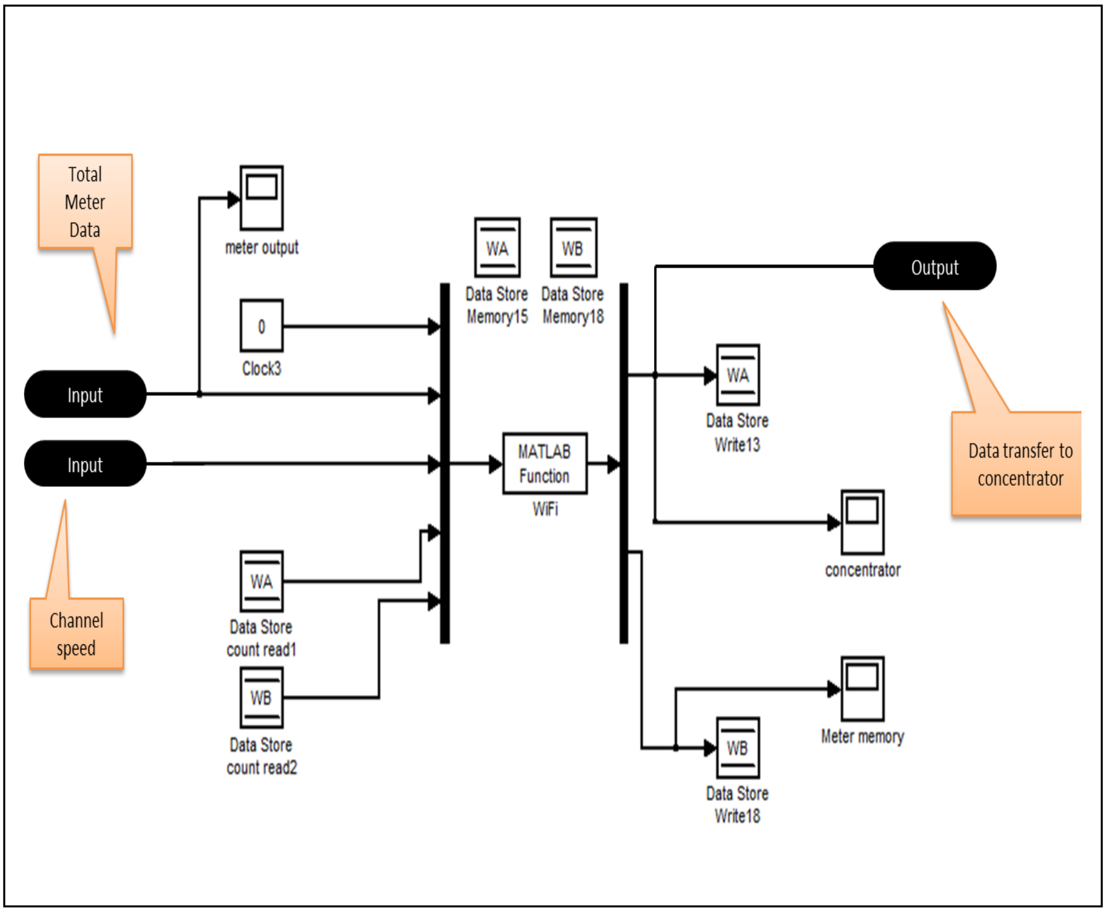


Figure 3.4.6 – RF Channel MATLAB program

RF channel speed model

RF channel basically accomplished by Zigbee and WiFi protocols since these protocol devices arehaving characteristics such as very power, low cost and low through put rate which suitable for meter data retrieve. However, Zigbee is the most suitable network protocol for cluster concept discussed earlier because, Zigbee network supports mesh topology and ad-hoc protocol. In a mesh network topology, the coordinator node is responsible for forming a network and controlling all devices in the network. Router devices route data to the coordinator device which configured as data concentrator. End devicescommunicate with adjacent router devices. Basically this protocol creates mesh network within the clustered radio island. The coordinator is responsible for starting the network and choosing certain key network parameters. Finally this establishesa very reliable network at low data rate.

To model RF channel it is necessary to consider communication mathematical equations. Shannon equation is used to model RF channel speed in this project which shown in equation 1. Shannon equation outputs channel capacity “C” in bit per second. Most complicated parameter is adding noise into the model since the channel is subjected to white Gaussian noise. The noise is influence to the channel capacity in independent time frame since it is originate from natural facts. Therefore, the noise is added to the RF channel as a different time frame when implementation of RF channel speed model. RF channel speed model is illustrated in figure 3.4.7.

Shannon’s Equation:

$$C = W log_2 \left(1 + \frac{S}{N}\right) \quad - - - - - - - - - - (1)$$

Where

- C= Channel capacity (bit per second)
- W= Bandwidth (Hertz)

- S = Signal power (Watts)
- N = Noise power
- Channel is subject to White Gaussian noise of power N

Reference [7]

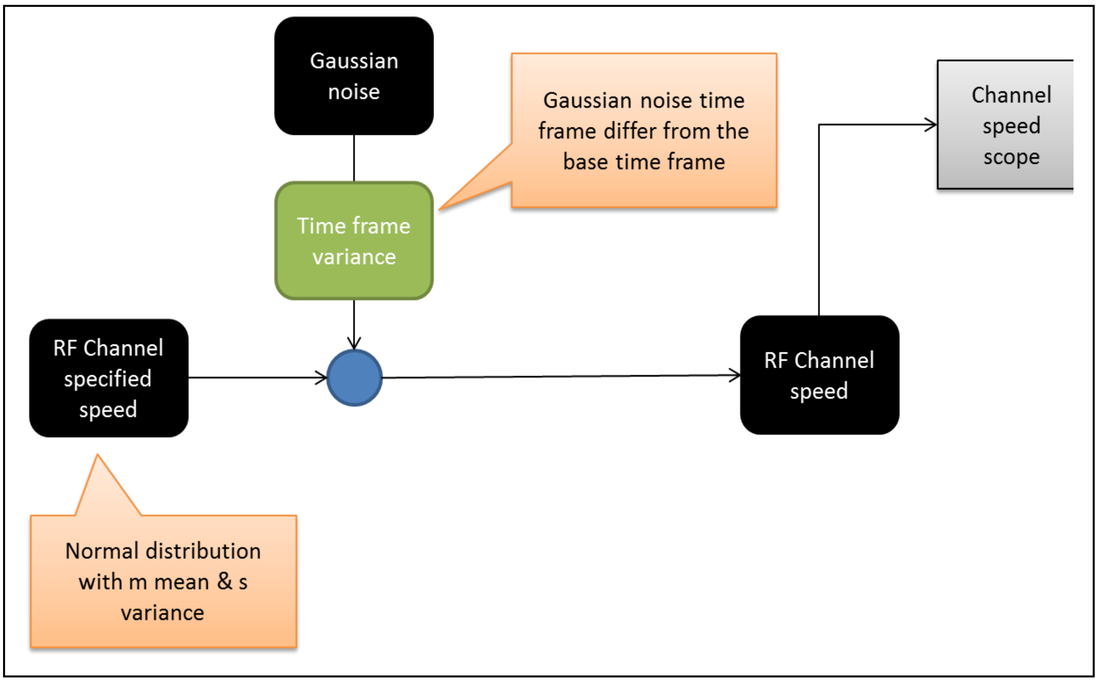


Figure 3.4.7 – RF channel speed model

RF channel speed model is mathematically modelled as normal distributed phenomena since random variations with unknown distributions are often assumed to be normal, especially in physics, telecommunication applications.

The probability density of a normal distribution is :

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)} \quad -\infty < x < \infty \quad --(2)$$

Where

- x ϵ R

- μ = mean
- σ^2 = variance

Reference [15]

In this model mean of the normal distributed function is the throughput of the RF channel and variance is the reliability of the RF channel. In MATLAB there is a source block function thatgenerates normally distributed signal called ‘Gaussian Noise’ Generator. It has parameters of mean and variance to adjust throughput and reliability of the RF signal (Figure 3.4.8).

Time frame function is programmed to shift the noise signal in order to simulate time frame from the RFchannel signal.

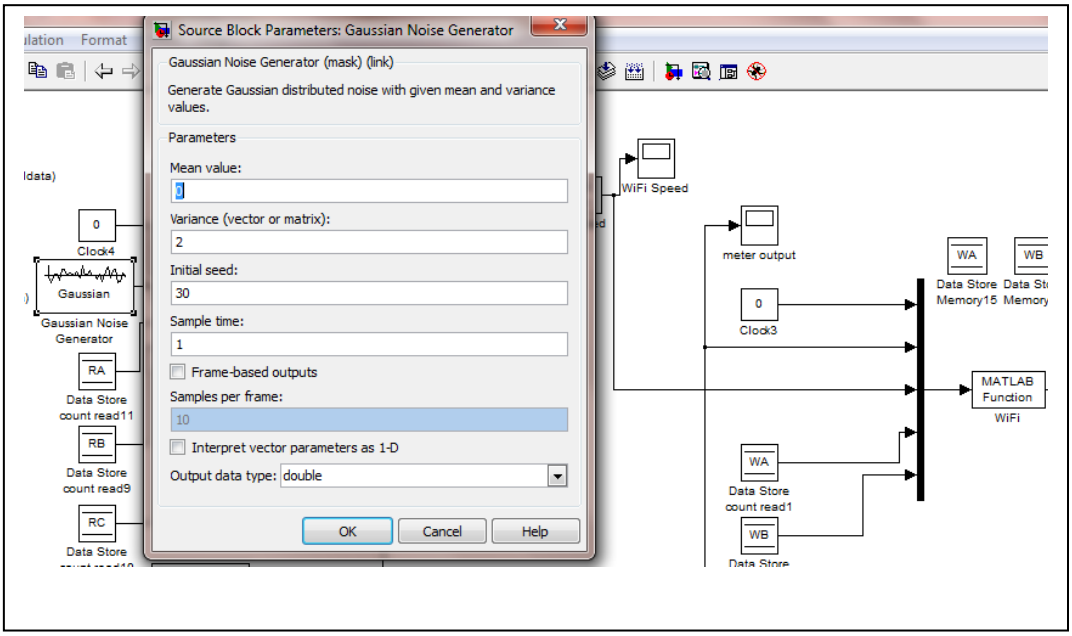


Figure 3.4.8 – Source Block for Gaussian noise generator

MATLAB Simulink program of the RF channel speed model has two inputs one output. Two inputs are channel speed signal which has normal distributed signal generator and Gaussian noise generator program with time shift function. The output is RF channel speed. The RF channel speed in MATLAB program is shown in figure 3.4.9.

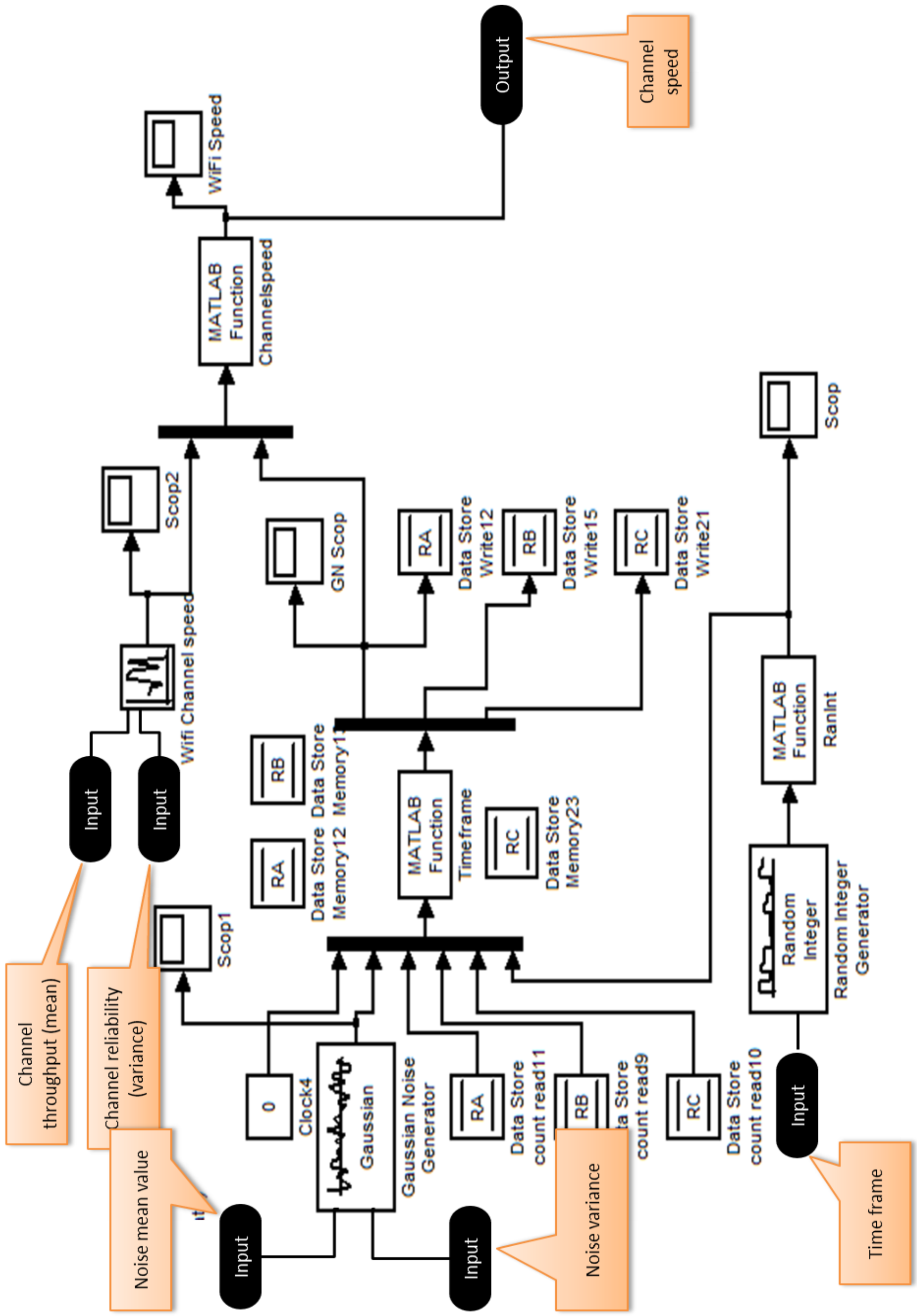


Figure 3.4.9 – RF channel speed MATLAB program

Wireless Bandwidth

Bandwidth is determined by considering the amount of useful signal range that can be modulated into the carrier signal. Bandwidth refers to the amount of spectrum available to transport information.

It is important to note that bandwidth is most often limited by resource rather than technology. That is allocation of spectrum to a particular application from limited physical capacity. The maximum physical capacity of a transmission channel can be determined by using Shannon's law which describe the relationship between the primary factors in a transmission channel, bandwidth and noise as mention in earlier. This relationship describes that more bandwidth is available, the more bits per second can be send on the channel. The more noise that is present, the fewer bits per second the channel will be able to carry. As radio signals travel through the air they lose power and encounter interference from either signals or environmental disturbances. The level of noise affects how efficiently the radio signal can be encoded at the destination. Therefore, how many bits per second can be carried on one cycle of radio bandwidth, this is referred to as bandwidth efficiency. Noise is mention by the signal to noise ratio. As the power of the signal is reduced, the signal to noise ratio degrades, and the potential for error therefore increases.

GPRS channel model

RF channel model is link with of GRPS channel speed model and data concentrator memory model as inputs and base station server as output. Data concentrator gathers information from energy meters and push through GPRS channel to the server as bulk data packets. GPRS channel model is most important part of the AMR system. GPRS channel model consists of planned duration (Dp) to varying the channel width according to data concentrator data buffer size which helps to saving the network resources. Channel speed scope is placed to the GPRS channel model to monitor wave of the channel speed and data concentrator memory scope is placed at data concentrator to monitor the memory variation with time.

The GPRS channel model block diagram is illustrated in figure 3.4.10.

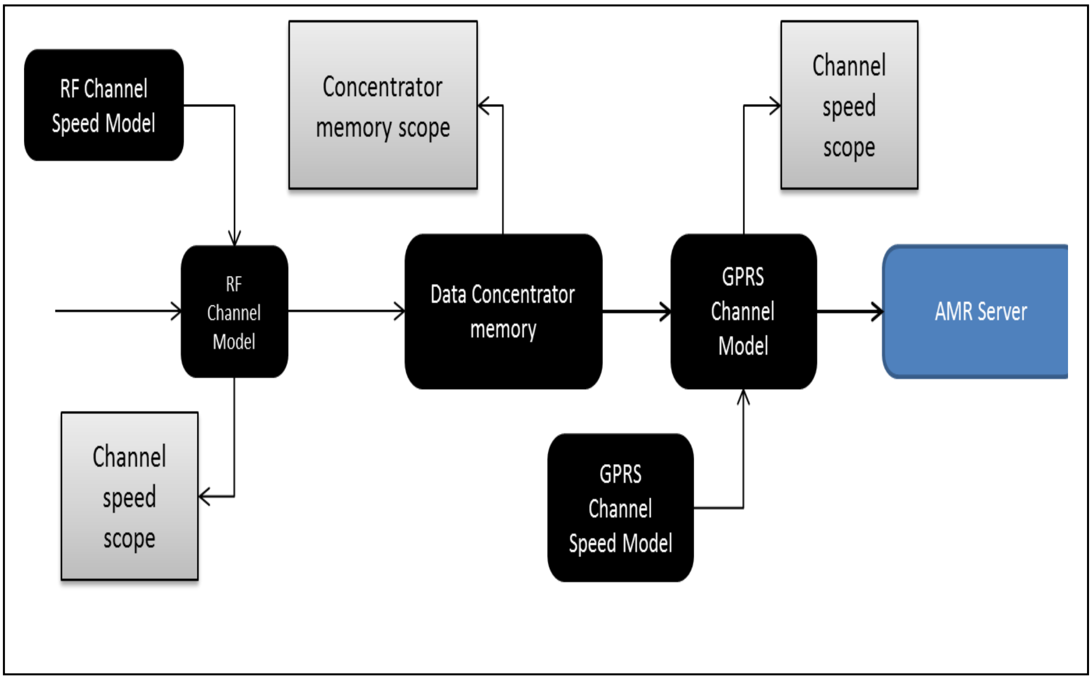


Figure 3.4.10 – GPRS channel model

There are ten inputs and seven outputs in the MATLAB Simulink function called "Channel". Inputs are simulation time frame, incoming data from data concentrator, memory variable for store previous data of feed from data concentrator, data concentrator memory, memory variable for store frequency of the GPRS channel active duty cycle, Duration channel ON (Don) , Duration of channel plan (Dp), GPRS transfer speed and memory flags for loop functions. Outputs are memory variables for storing previous data, data concentrator memory, Dp and memory flags for program loop function. There are seven memory variables to store parameter values temporally during the iterating the program. The MATLAB Simulink program is illustrated in the figure 3.4.11.

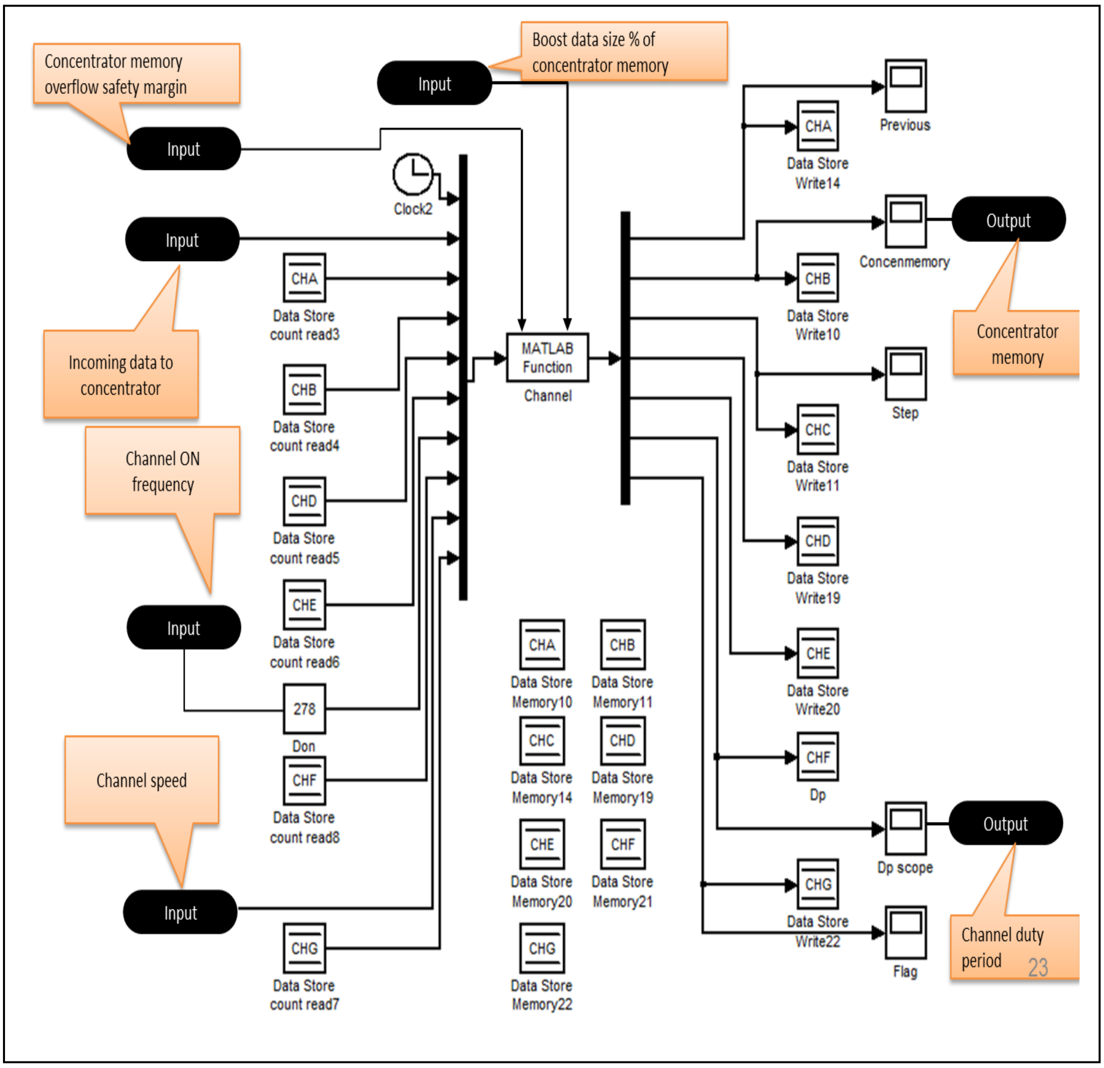


Figure 3.4.11– GPRS channel Simulink program

Concentrator memory program is developed with self-memory controlling algorithm which explains in next section. This program is also developed inside the" channel" codes. Output of the data concentrator memory is monitored by memory scope attached to concentrator memory variable. The duration channel plan (Dp) is monitored by another scope attached to the variable Dp.

Data concentrator memory management algorithm

Data concentrator memory is a main componentofimplementation of data concentrator based AMR system. Data concentrator memory has cross relationship between the GPRS channel throughput and planned duration (Dp).When GPRS channel has more data throughput then data concentrator consume less memory. However, GPRS channel throughput has limitation according to the particular telecommunication infrastructure resources and cost sensitive. If GPRS channel throughput is reduced then data concentrator buffer size is increased which also costly. Therefore data concentrator memory management is a critical factor to consider when implementation the data concentrator base AMR system.

As this research objective is identification of correct specifications for main three components of the data concentrator based AMR system it is necessary to find out equilibrium point where the GPRS channel throughput data concentrator memory size is technically viable. The flow chart of the algorithm developed to achieve above objective is illustrated in figure 3.4.12.

Planned duration (Dp) is dynamically changed with the filling of data concentrator memory. This leads to change the GPRS throughput and control the data concentrator buffer size. When higher the memory level of the data concentrator, the planned duration is reduced and allows lowering the throughput of the channel. When concentrator memory buffer size is increasingthen the planned duration is increased and allow to increase the channel throughput. If the data concentrator memory is less than the overflow safety margin which is 80% of the data concentrator installed capacity thenDpis calculated as 50% of the set value. If the data concentrator memory is more than the overflow safety margin then, 100% of the data concentrator installed memory then Dp is dynamically increased into full stretch. Planned duration (Dp) is changedin every Don period as describe above and relatively GPRS channel throughput is dynamically varied.

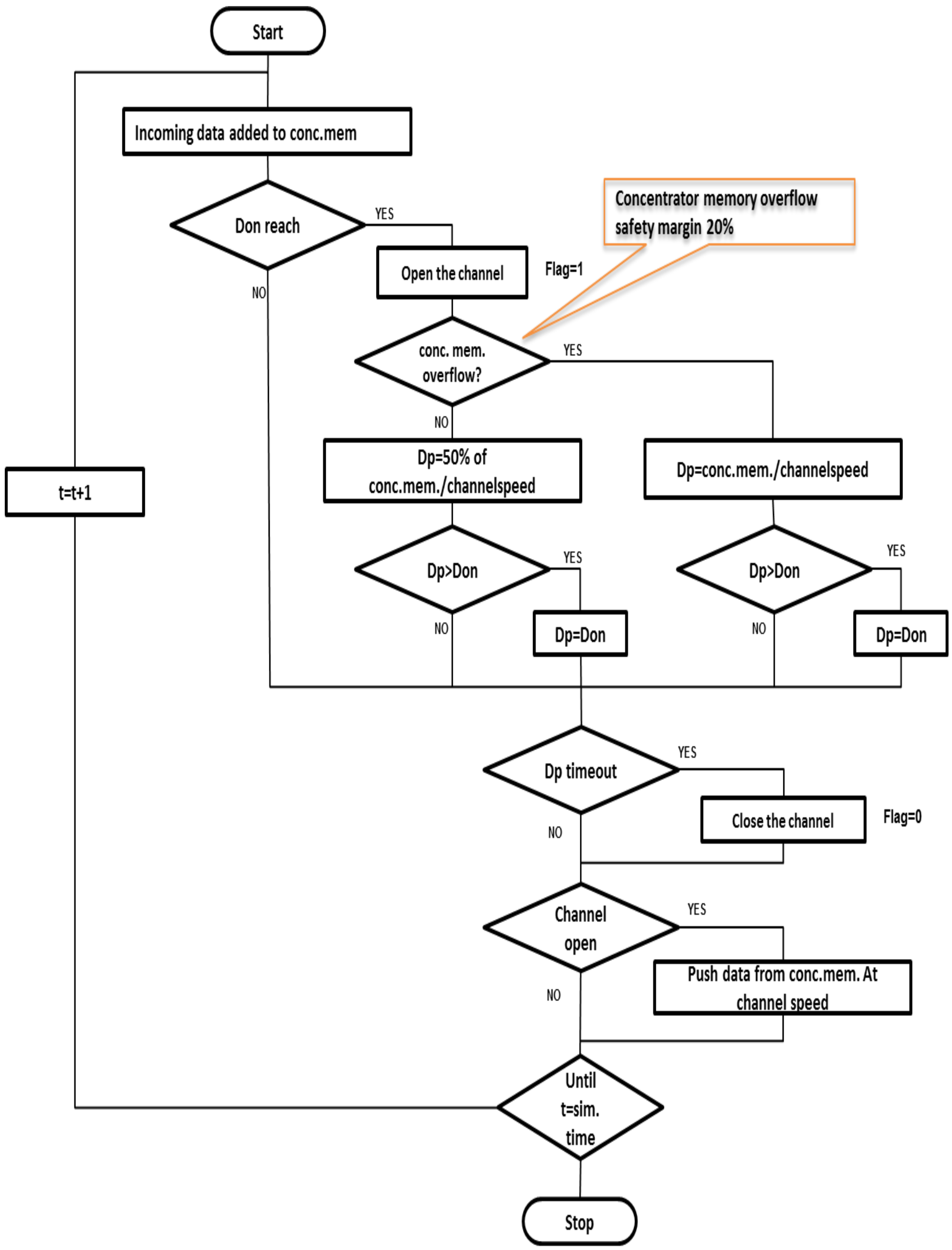


Figure 3.4.12–Concentrator memory algorithm

GPRS channel speed model

GPRS is a strongly established protocol and suitable for transmission of bulk data packet compared to transmitting small data packets of individual meter.

While considering the GPRS channel speed model,same mathematical equationis used as RF channel model to implement in MATLAB model.That is Shannon equation is used to model GPRS channel speed in this research. GPRS channel speed model is illustrated as figure 3.4.13 which is very similar to the RF channel speed model.

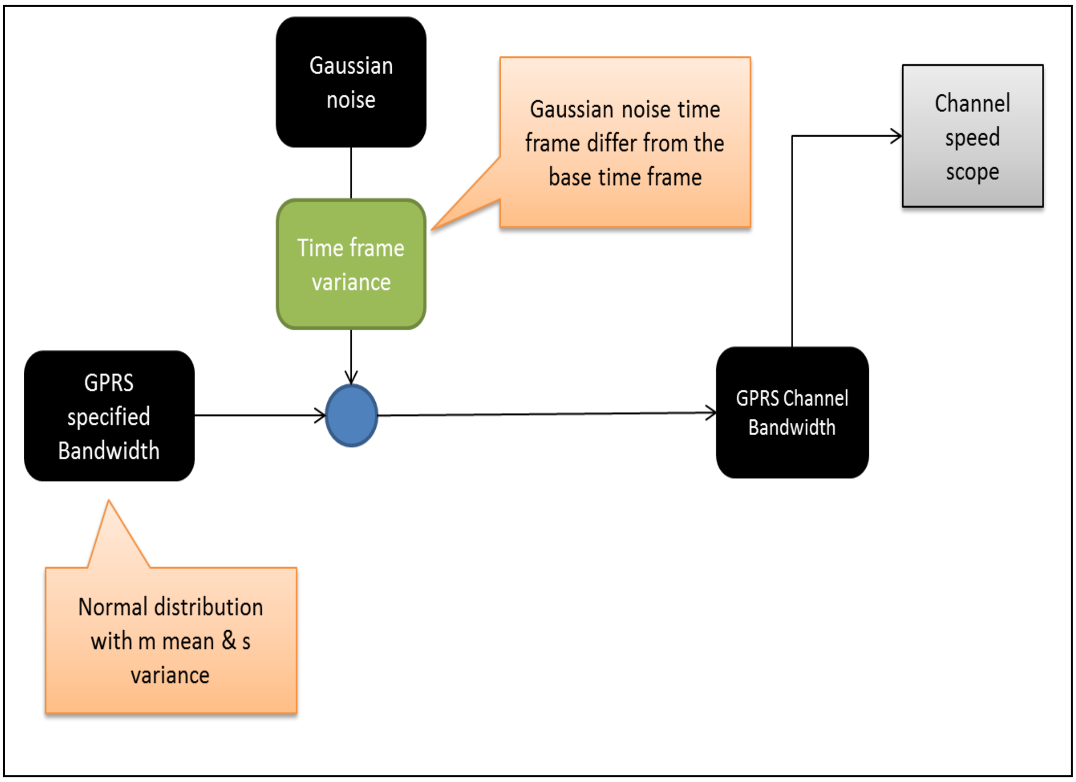


Figure 3.4.13–GPRS channel speed model

GPRS channel speed is mathematically modelled as normal distributed phenomena since random variates with unknown distributions are often assumed to be normal, as earlier consideration.

In this model, mean of the normal distributed function is the throughput of the GPRS channel and variance is the reliability of the GPRS channel. In MATLAB there is a source block function whichgenerates normally distributed signal called Gaussian Noise Generator. It has parameters of mean and variance to adjust throughput and reliability of the GPRS signal. Therefore to simulate noise in the model Gaussian noise generator it is used. Different time frame function is used to shifting noise time frame from GPRS channel signal time frame.

In MATLABSimulink program GPRS channel speed function has two inputs and one output. Two inputs are channel speed signal which having normal distributed signal generator and Gaussian noise generator program with time shift function (Figure 3.4.14).

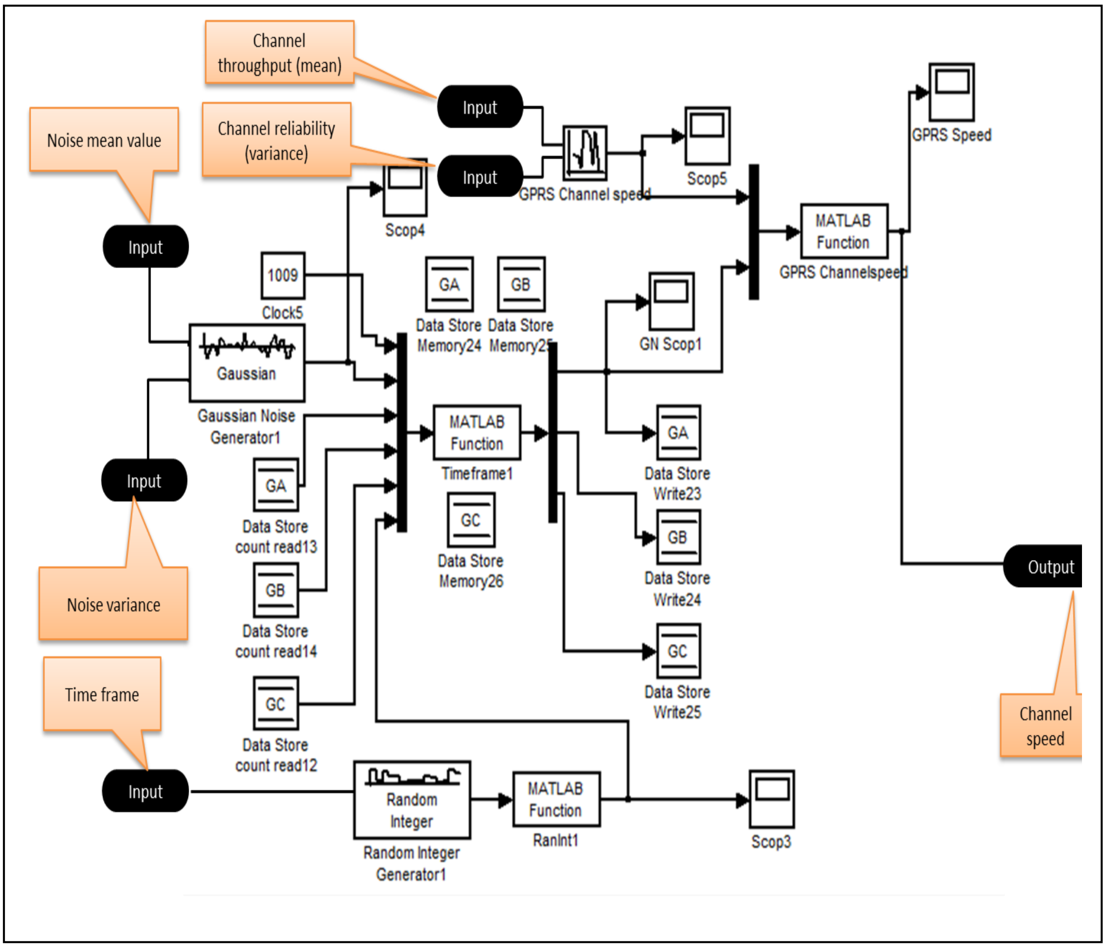


Figure 3.4.14 – Simulink GPRS channel speed program

3.5 Integrated simulation model

In the above section MATLAB Simulink programs are described in detail and finally all the models are connectedwith each other in order to implement the final integrated simulation model program. Figure 3.5.1 shows the integrated MATLAB Simulink program. This MATLAB Simulink program has facilities to vary parameters at each sub model such as energy meter level, RF channel model level, RF channel speed model level, concentrator memory level, GPRS channel model level and GPRS channel speed model level. This facility leads to repeating the program with various parameters and obtaining the results. This is the computational algorithm to apply Monte Carlo method thatis usedto repeat theinput variables to obtain various numerical results in telecommunication problem.

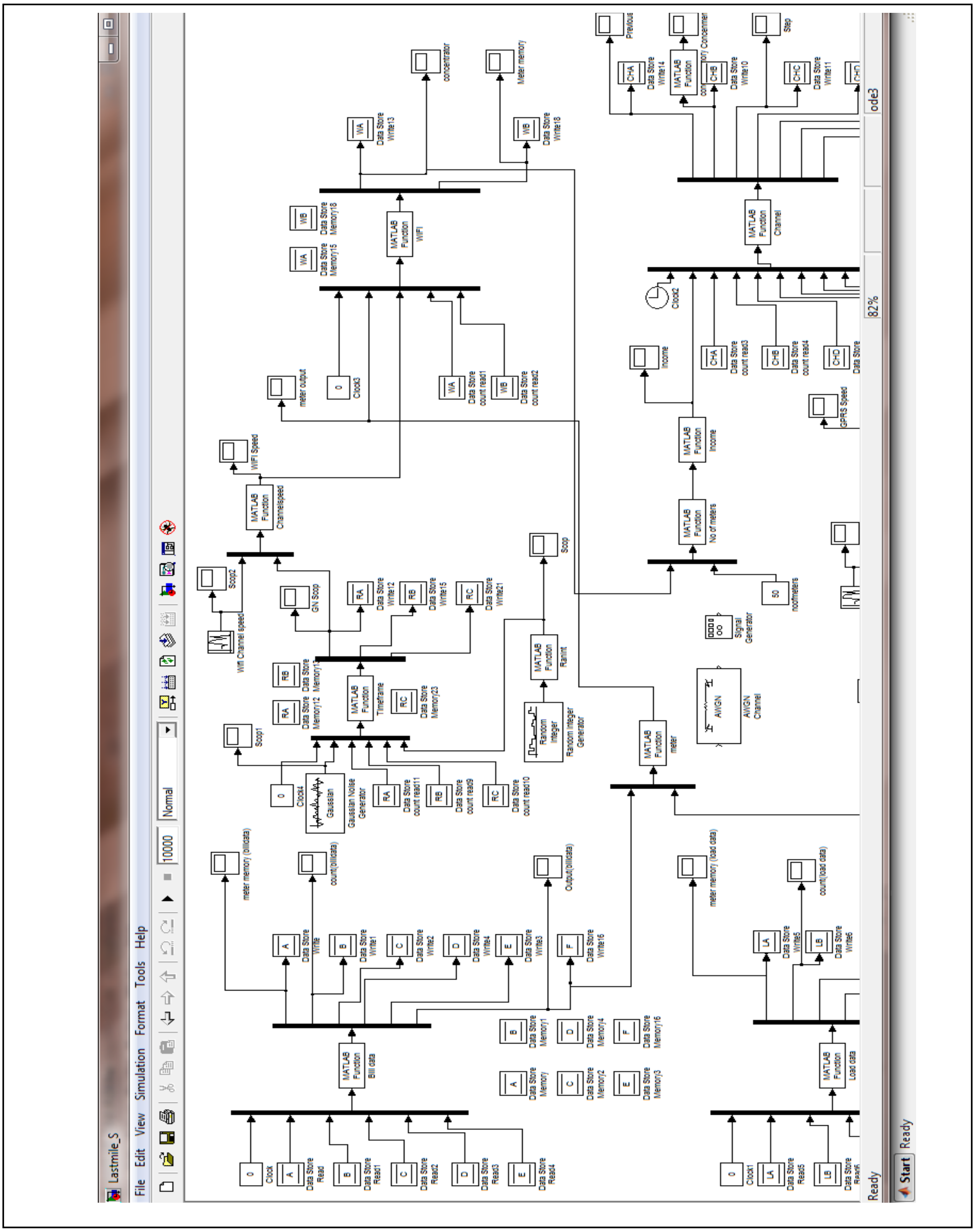


Figure 3.5.1 – Integrated MATLABSimulink program

Chapter4

Simulation results and analysis

Backbone channel speed

The integrated MATLAB Simulinkprogram is executed with suitable simulation time units and gets the results through wave form scope. Backbone channel speed is graph against the time to generatetheBackbone channel speed variations (Figure 4.1). Backbone or the GPRS speed model has normal distributed phenomenal with mean and variance subjected to white Gaussian noise at different time frames. In this case the Backbone channel speed is 244 kbps. Gaussian noise has mean of unit and variance of 2 units.

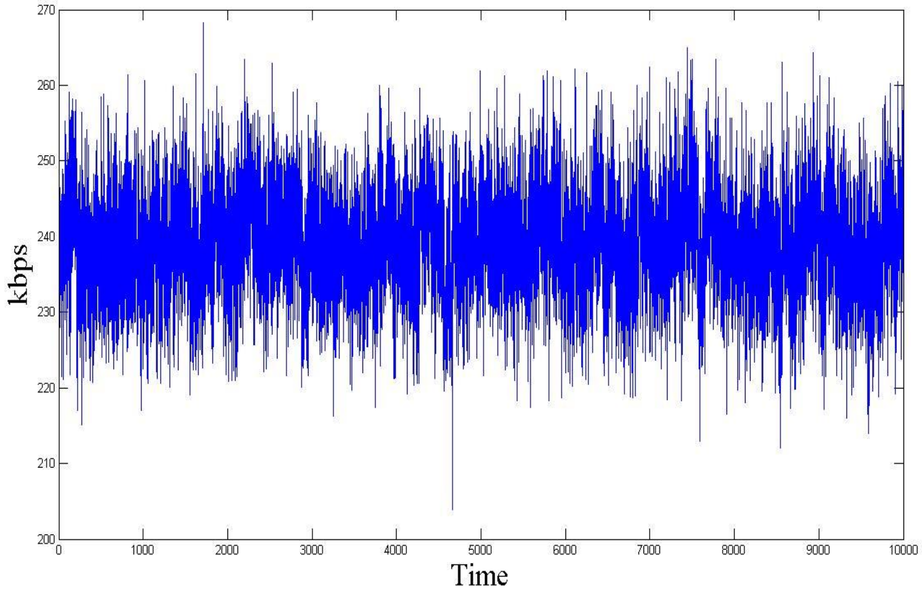


Figure 4.1 – Backbone channel speed graph

RF channel speed

RF channel speed variation is captured through the scope placed within the Simulink program and shown as figure 4.2. The channel speed is varying according to normal distribution pattern and subjected to white Gaussian noise as described earlier sections. In this case the RF channel speed is 4.5 kbps

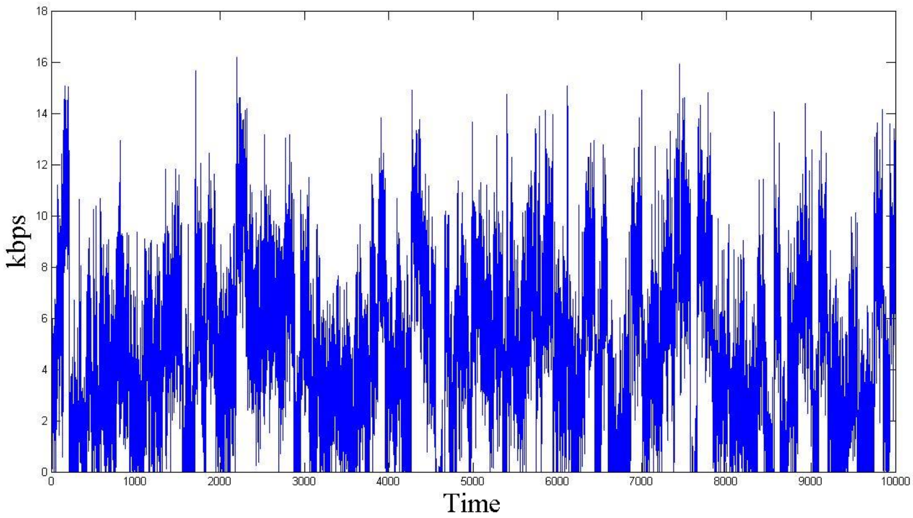


Figure 4.2– RF channel speed graph

Data concentrator memory

Concentrator memory is varied with the Backbone channel speed and planned duration (Dp) of the Backbone channel when last mile data is retrieving data at given rate. Following result is obtained for concentrator memory when Backbone channel speed is at 244 kbps (figure 4.3). Concentrator memory is limited to 100% of defined memory capacity.Memory capacity is set to 100 KB. But when data capacity reaches 80% of the defined memory capacity, that is the safety margin of the memory, the data concentrator program is shifted to boost mode and increase the Dp to double. Then the data in the memory drastically decrease and shifted to normal mode.

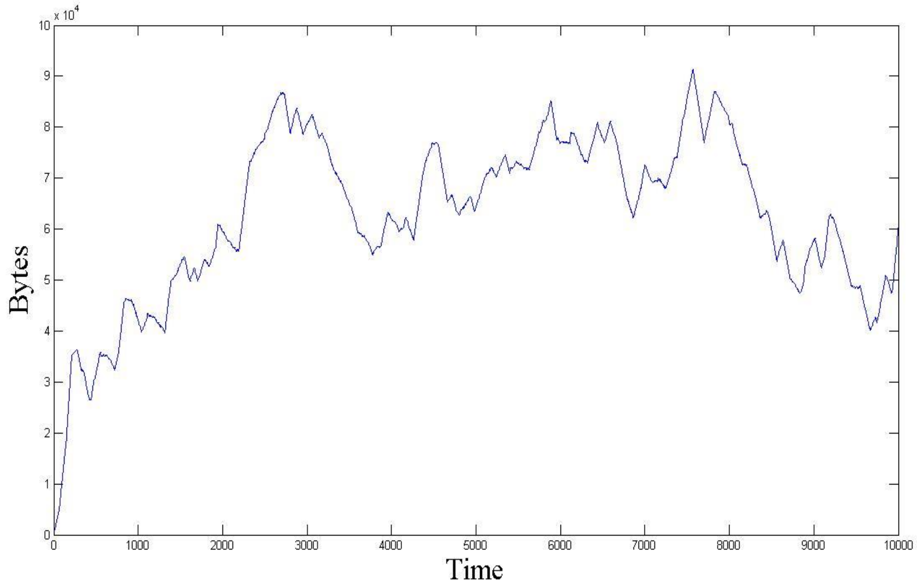


Figure 4.3– Concentrator memory graph

In this case the Backbone channel speed is 244kbps (mean is 110 units per iteration time frame and has variance of 10 units). Gaussian noise has mean of unit and variance of 2 units. RF channel speed is 4.5 kbps (mean is 2.1 units per iteration time frame and has variance of 1 unit). 50 No. of meters are sending bill data of 74 bytes at one hour frequency and load data of 737 bytes at 15 minutes frequency. Data concentrator memory capacity is 100KB. In this graph shown that when present data capacity of the concentrator is reach to 80% of the its fullest capacity enable the data boost operation and try to reduce the memory level.

Data concentrator memory behavior

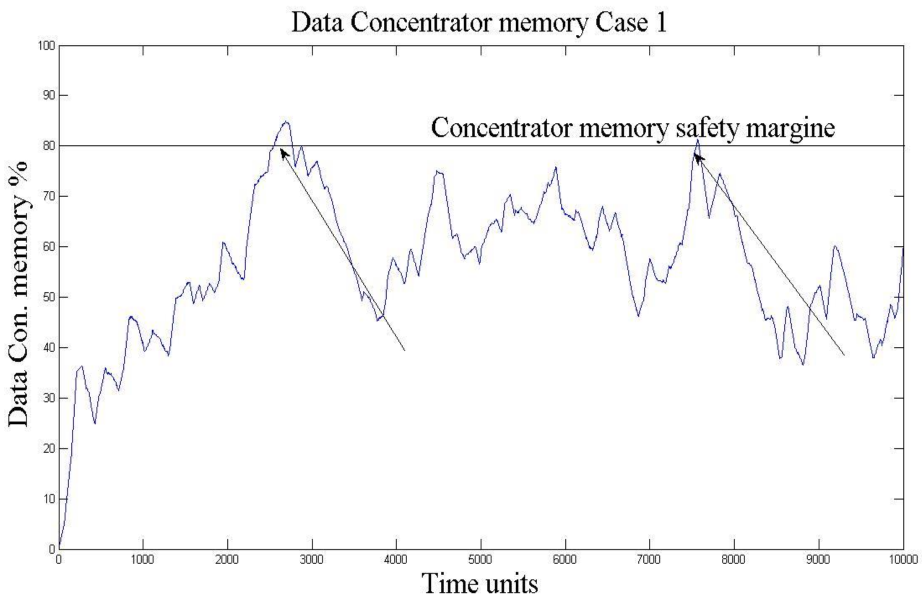
Data concentrator memory and planned duration behavior is observed with different throughput of the Backbone channel and RF channel. Planned duration Dp of Backbone channel is program as variable which is dynamically vary with the channel speed and control the data amount of the concentrator memory. Following cases are studied to analysis the Dp and concentrator memory behavior with various

Backbone channel speed. Further increase the no. of meters in the RF network and analysis the cross relationship between the main components.

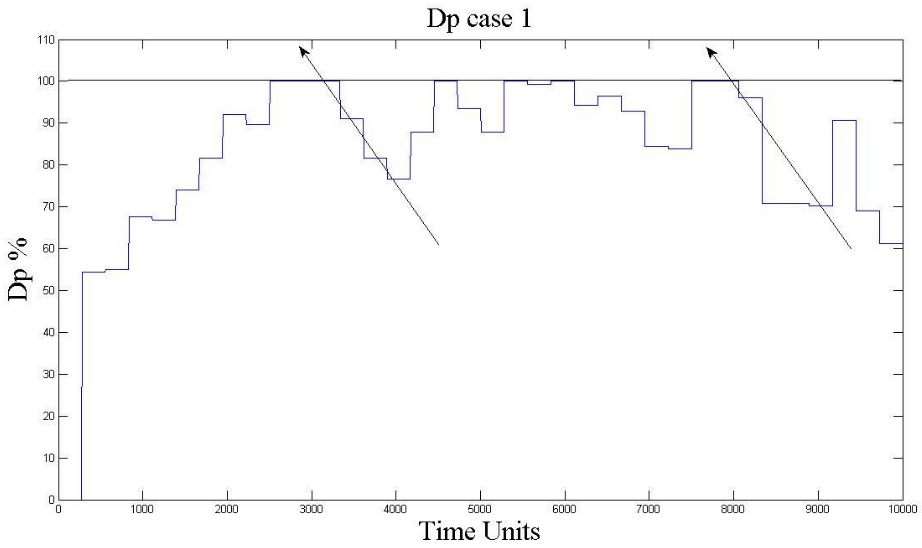
Case 1

- Backbone channel throughput is 267 kbps
- Backbone reliability factor is 10
- 50 No. of Meters
- RF channel throughput is 4.5 kbps
- Concentrator memory capacity is 100KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case concentrator memory and Backbone channel speed is tuned each other to optimize the both parameters. Whenever concentrator memory overflow the Dp factor dynamically increase to boost the Backbonedata transmission and control the dataconcentrator memory to kept behind the memory safety margin (Figure 4.4).



(a)



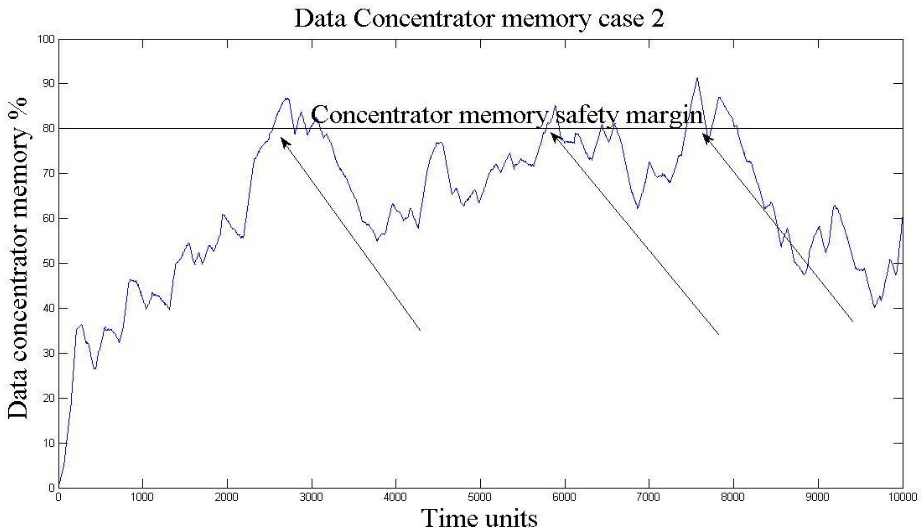
(b)

Figure 4.4 – Case 1: Concentrator memory (a)vsDp (b)

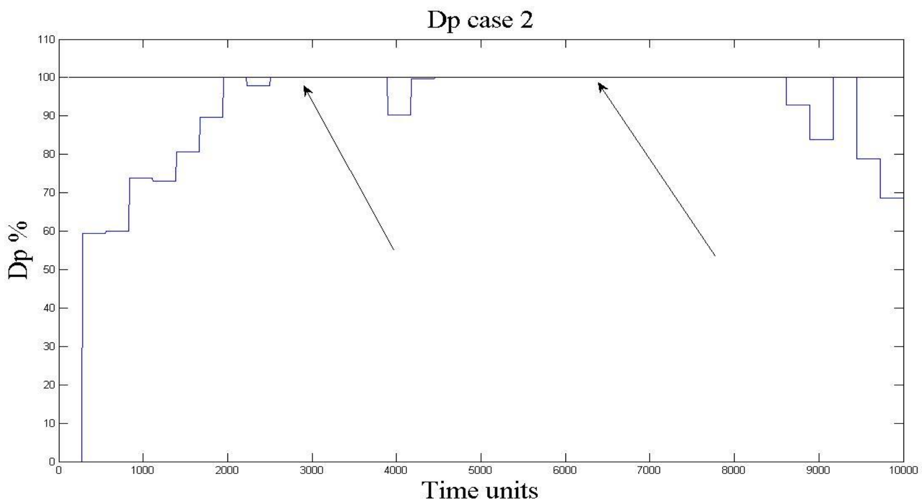
Case 2

- Backbone channel throughput is 244 kbps
- Backbone reliability factor is 10
- 50 No. of Meters
- RF channel throughput is 4.5 kbps
- Concentrator memory capacity is 100KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case lower the Backbone speed and simulate the model and the results are observed. Concentrator memory overflowsa couple of times and the Dp factor increased into its maximum limit and kept on in-order to lower the concentrator memory (Figure 4.5).



(a)



(b)

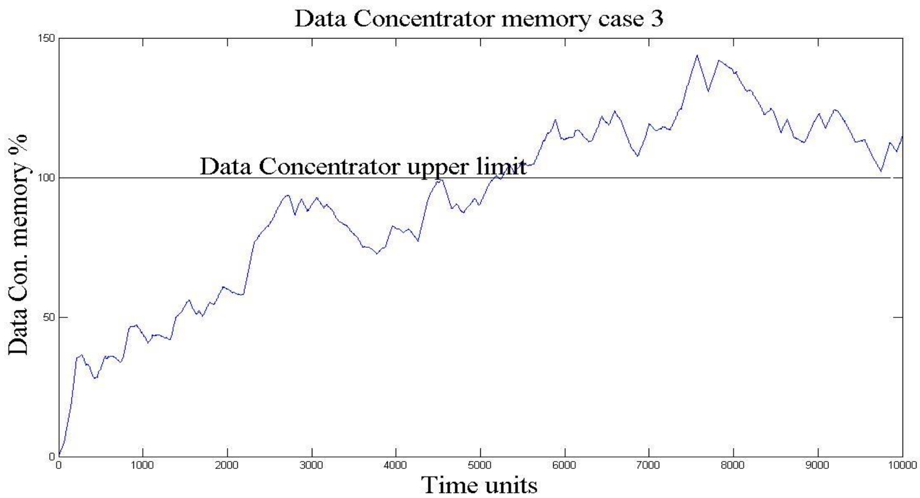
Figure 4.5 – Case 2: Concentrator memory (a) vsDp (b)

Case 3

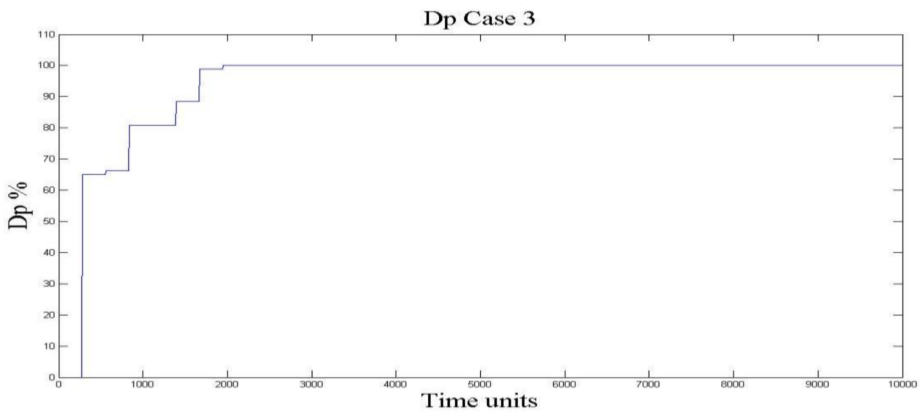
- Backbone channel throughput is 222 kbps
- Backbone reliability factor is 10
- 50 No. of Meters
- RF channel throughput is 4.5 kbps

- Concentrator memory capacity is 100KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case the Backbone channel speed is lowered further and the model is simulated. Concentrator memory is overflown and has no control to limit within the safety limit. The Dp factor has changed in dynamically to full stretch over the time and the Backbone channel opens continuously and tries to avoid overflow (Figure 4.6).



(a)



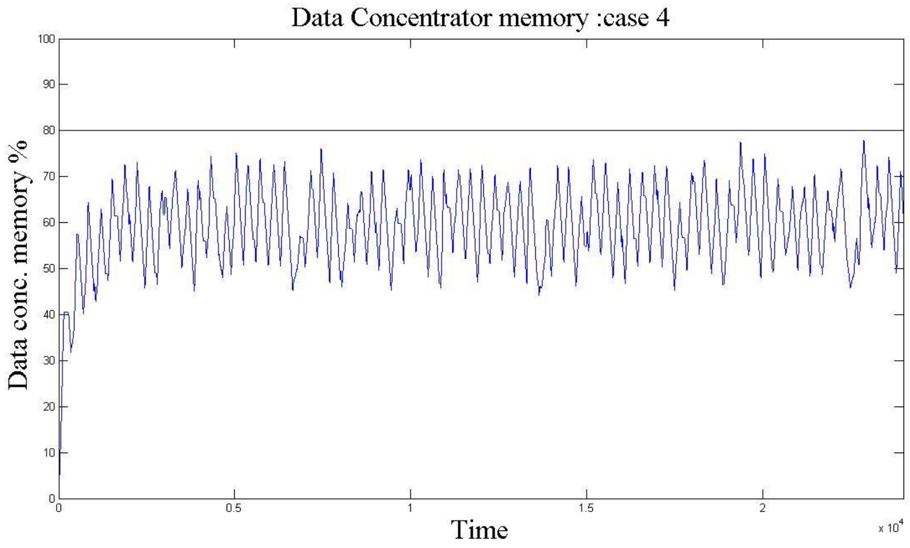
(b)

Figure 4.6 – Case 3: Concentrator memory (a) vsDp (b)

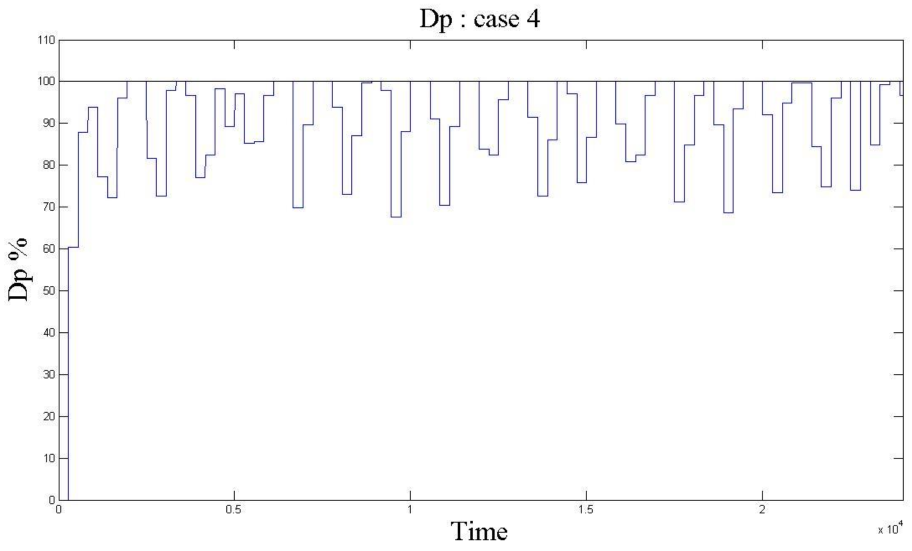
Case 4

- Backbone channel throughput is 267 kbps
- Backbone reliability factor is 10
- 50 No. of Meters
- RF channel throughput is 11.6 kbps
- Concentrator memory capacity is 100KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case the Backbone channel speed is set to 267 kbps and increase the RF channel throughput to 11.6 kbps. Throughput in a Zigbee network can be vary by a number of variables, including number of hops, security enable/disable, sleeping end devices. However testing shows that the throughput of Zigbee network is varying between 4,5 kbps to 19 kbps. 11.6 kbps is average value of these 2 value. The other parameters are unchanged. Concentrator memory is operating within the safety limit. The Dp factor has changed in dynamically to keep the data concentrator memory with in the limit (Figure 4.7).



(a)



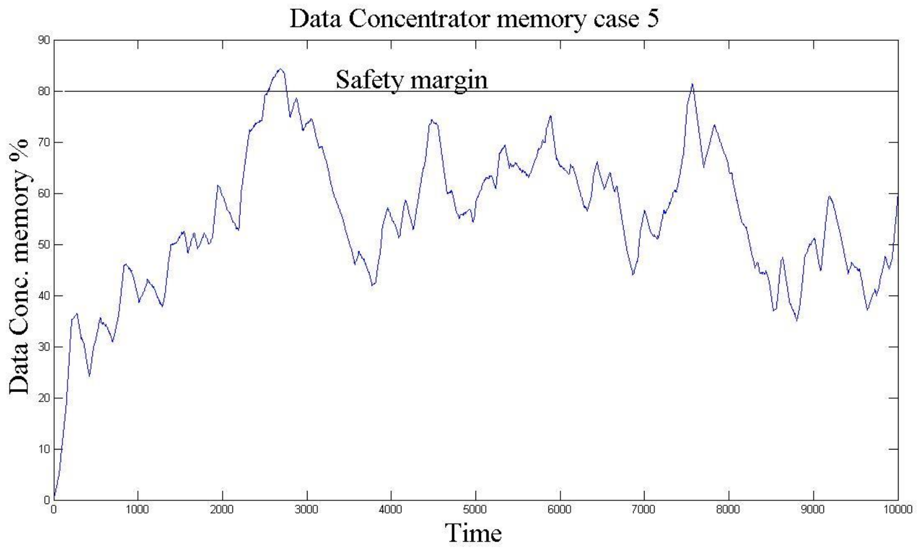
(b)

Figure 4.7 – Case 4: Concentrator memory (a) vs Dp (b)

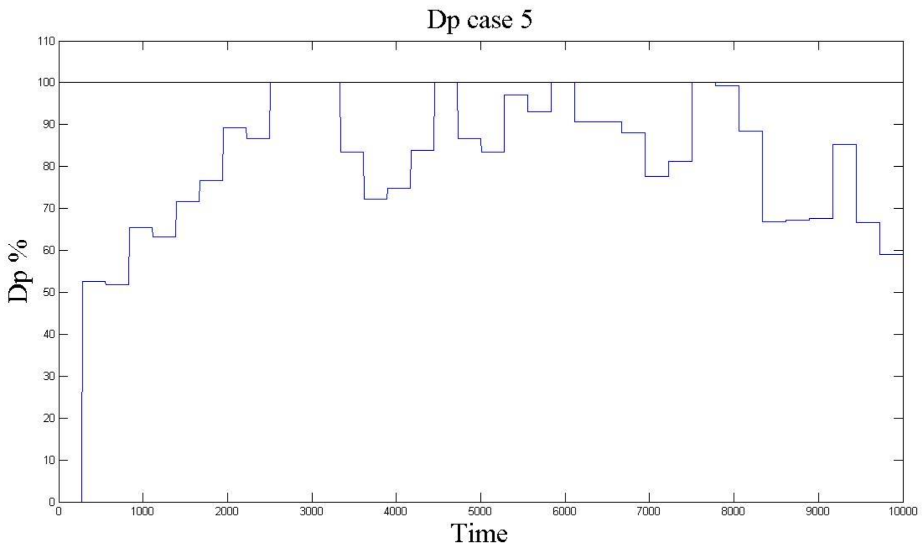
Case 5

- 100 No. of Meters
- Backbone channel throughput is 556 kbps
- Backbone reliability factor is 10
- RF channel throughput is 4.5 kbps
- Concentrator memory capacity is 200KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case increase the no. of meters to 100 and Backbone channel speed is set to 556 kbps and the model is simulated. Concentrator memory capacity is 200KB. Concentrator memory is operating within the safety limit. The Dp factor has changed in dynamically to keep the data concentrator memory with in the limit (Figure 4.8).



(a)



(b)

Figure 4.8 – Case 5: Concentrator memory (a) vsDp (b)

Case 6

- 100 No. of Meters
- Backbone channel throughput is 556 kbps
- Backbone reliability factor is 10

- RF channel throughput is 11.6 kbps
- Concentrator memory capacity is 200KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case increase the RF channel speed to11.6 kbps and the model is simulated. Concentrator memory capacity is 200KB. Concentrator memory is operating within the safety limit. The Dp factor has changed in dynamically to keep the data concentrator memory with in the limit (Figure 4.9).

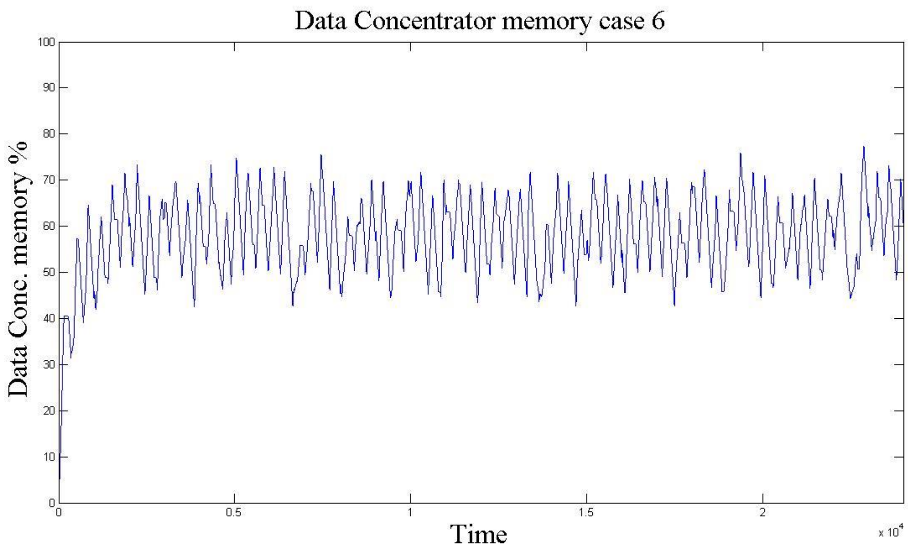


Figure 4.9 – Case 6: Concentrator memory

Case 7

- 200 No. of Meters
- Backbone channel throughput is 1.0 Mbps
- Backbone reliability factor is 10
- RF channel throughput is 11.6 kbps
- Concentrator memory capacity is 400KB
- Bill data 74 bytes at one hour frequency
- Load data 737 bytes at 15 minutes frequency

In this case increase the no. of meters to 200 and set the RF channel speed to11.6 kbps and backbone channel speed to 1.0 Mbps.. Concentrator memory capacity is 400KB. Concentrator memory is operating within the safety limit (Figure 4.10).

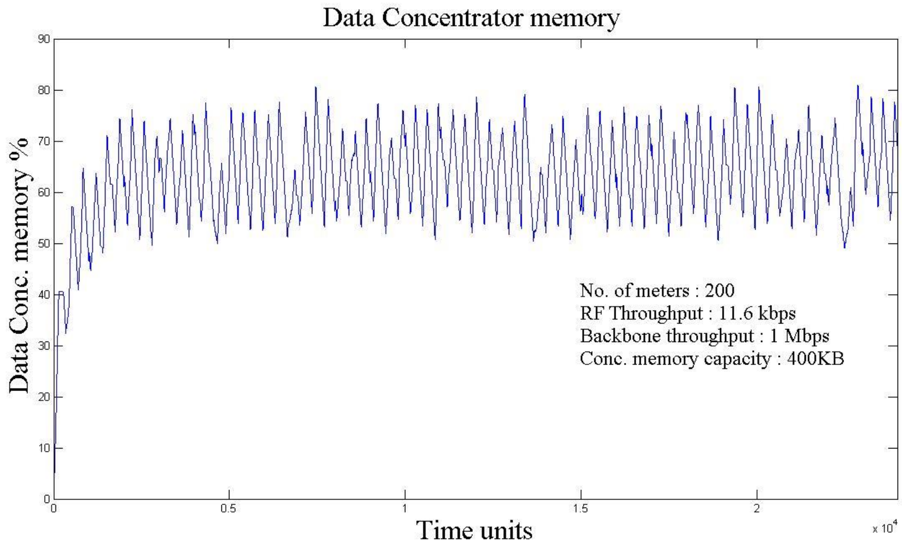


Figure 4.10 – Case 7: Concentrator memory

Summary of the Simulation Results

Memory capacity behavior of the data concentrator memory is analysis with various parameters such as RF network data throughput, backbone channel throughput, no. of meters and installed memory capacity of the data concentrator. Table 4.1 shows the summary of the results. In case 1 which is simulated with 50 no. of meters shown good data concentrator memory behavior and this rely on good inter relationship between main components of the concentrator based AMR. In case 5 which is simulated with 100 no. of meters shown good data concentrator memory behavior. Observation of the case 7 is shown good results for 200 meters configuration.

Table 4.1–Summary of the simulation results

Parameters	**Units**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**
No. of Meters	Nos.	50	50	50	50	100	100	200
Bill Data Size	Bytes	74	74	74	74	74	74	74
Load Data Size	Bytes	737	737	737	737	737	737	737
Bill Data Frequency	min	60	60	60	60	60	60	60
Load Data Frequency	min	15	15	15	15	15	15	15
RF network throughput	kbps	4.5	4.5	4.5	11.6	4.5	11.6	11.6
Backbone channel throughput	kbps	267	244	222	267	556	556	1000
Concentrator memory	KB	100	100	100	100	200	200	400
Cross relationship		**OK**			**OK**	**OK**	**OK**	**OK**

Table 4.1 shows that the main components of a AMR network that is last mile RF network, data concentrator and backbone channel has inter relationship which have to match each other to put a AMR system into integration. When increasing the no. of meters backbone channel throughput and data concentrator memory capacity has to increase simultaneously. The MATLAB Simulink program has to be used to solve this problem havingmany degree of freedom, significant uncertainty in input and wide variety of scenarios. Data concentrator memory behavior is the factor to identification of the correct specification and cross relationship od main components of the concentrator based AMR system.

Chapter5

Development of AMR

5.1 Zigbee solution for last mile in AMR

With improving capabilities of networking, automation and information technology, automatic meter reading systems and industrial sensor networks have been adapting various communication media for their purposes. Wireless data collection is mainly established using Global System for Mobile Communication (GSM) and specialized services such as Circuit Switched Data (CSD) or General Packet Radio Service (GPRS). In most cases, this scenario means that one GSM reading device is attached to every energy meter. In case of using CSD, the meter is identified by its phone number. While working in GPRS, the device most commonly acts as a data server, so it is convenient to have a fixed IP address of each device. This is realized by using private Access Point Names (APNs). Using separate GSM devices, with its own SIM card each, suits well industrial consumers due to their relatively small number in comparison with household consumers and their distribution over a very large area. In addition, the costs of GSM module and SIM card maintenance are insignificant within used energy costs. As for small consumer market, the costs of installation and maintenance of automatic meter infrastructure should be matched to actual energy usage. Having very well prospering GSM AMR systems, it is a very natural idea to divide the costs over a larger number of consumers grouped in area, or blocks of flats and utilize smart grid concept. In this scenario one GSM device acts as a router or data collector for a number of meters identified by particular phone number or IP address. In some cases, when smart metering infrastructure is taken into account during area development and design stage, it is possible to connect energy meters with GSM module using wired technologies such as RS485 bus, current loop (CLO) or Local Area Network (LAN). However, in most cases if such solution is even possible, it generates significant costs related to integration with existing infrastructure. Local communication can also be easily realized using power line communication technology (PLC). PLC technology, especially based on FSK (Frequency Shift Keying) or BPSK (Binary Phase Shift Keying), is well known and widely used in many AMR systems but it suffers from very low data-rate (<2400 bps) and vulnerability to external environment. On the other hand, OFDM (Orthogonal Frequency Division Multiplexing) technologies are relatively expensive or range limited. Complex computation of number of channels simultaneously requires sophisticated processor requirements. Moreover, high power transceiver amplifiers are required to achieve sufficient range, what significantly increases device costs, size and power demands.

IEEE 802.15.4 ZigBee is a new and proven wireless network technology with low cost and low power characteristics. With its speed of up to 250 Kbps and ranges from 50 m to even 1 km, depending on transmit power and urbanization rate, ZigBee is a candidate for another communication medium to be used interchangeably with others, depending on local area characteristics.

One of the first approach of adapting, implementing and improving ZigBee technology for Automatic Meter Reading is to use ZigBee to read data from energy meters and collect it using personal computer (PC). Ethernet connection is used to further data distribution. The next step isreplacing PC with embedded data collector or concentrator with incorporated wireless data modules.

5.2 Zigbee Implementation

The first step in designing ZigBee network is to utilize its free UART (universal asynchronous receiver/transmitter) port available on expansion connector. ZigBee expansion board (Figure 5.2.1) contains Xbee 802.15.4 module (Figure 5.2.2), power supply and indicator LEDs such as status LED or Received Strength Signal Indicator (RSSI). The main benefit of this devices is their on-module technology with on-board antenna connector. Such approach minimizes radio certification issues and shortens time-to-market factor. The manufacturer provides only 2.4 GHz ZigBee modules for now, but 868 MHz devices are soon to be released and designed expansion board allows for easily replacement of radio modules. Xbee module offers very sophisticated set of user commands and can be programmed with two alternative AT and API firmwares by software X-CTU (Figure 5.2.3). The first one is suitable for transparent communication with local AT commands configuration. As the expansion board acts as network coordinator, full access to network resources is needed. Using API frames Xbee module can access, configure and communicate with every router and end device in the network.

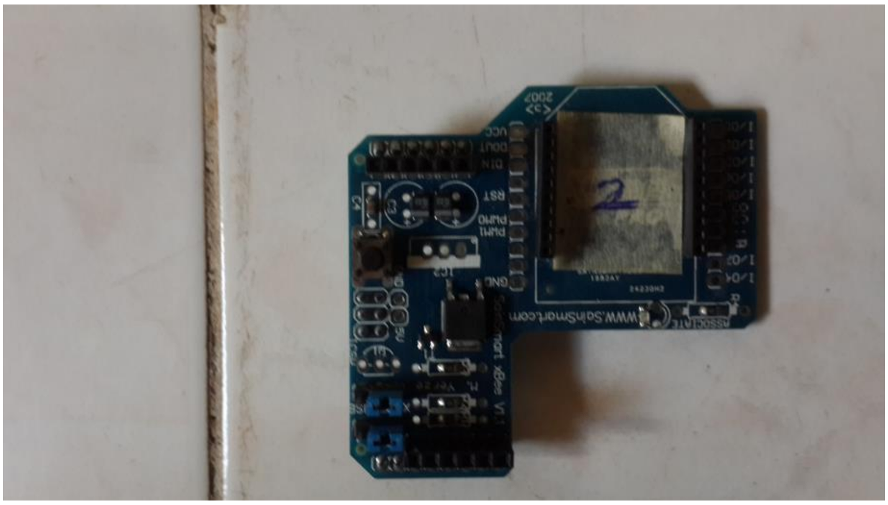


Figure 5.2.1–Zigbee expansion module

Figure 5.2.2 – Xbee module

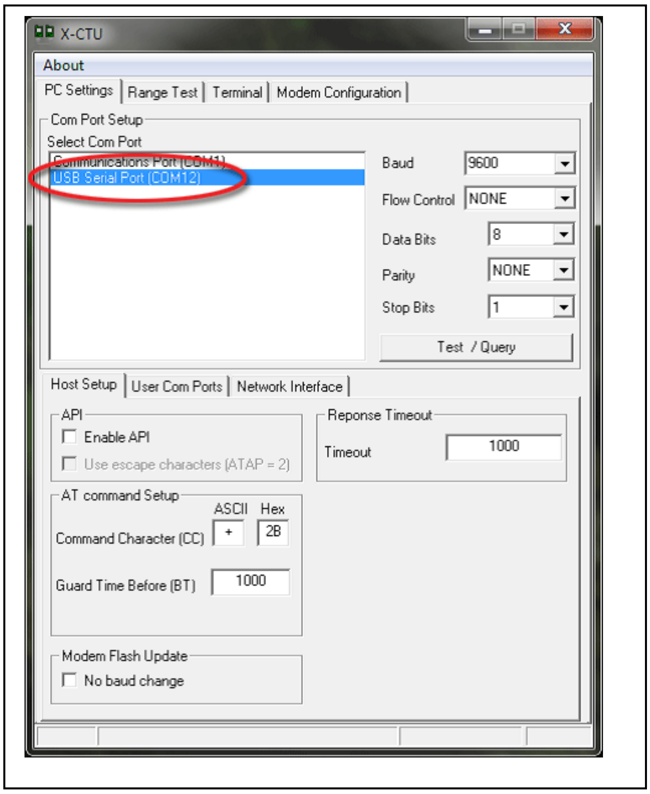


Figure 5.2.3 – X-CTU software

AT Command frames, needed to set network ID, enables AES128 and write encryption key to local ZigBee module, and Remote AT Command Request frames are passed to the application layer. This provides access to every node in the network without interfering with existing Zigbee firmware and configuration. Communication baud rate is implicitly set to 57600 bps. Much higher UART baud rate then communication link, which is usually set between 1200 to 9600 bps, ensures short time of frame collection and longer inter-frames time spaces to parse incoming frame.

Xbee USB adapter used to connect the Xbee to PC for configuration (Figure 5.2.4). Xbee communicates as serial device with the PC. Two Xbee modules are used to implement simple data communication channel. One end an Xbee device is attached to a Arduino Mega 2560 module (Figure 5.2.5) through an adapter which program as energy meter. Arduino module reads the current through a CT which is connected to analog pin of the module. The program reads the CT measurement through analog pin and calculates the energy as assuming the voltage is as constant. The program at Arduino is shown in figure 5.2.6. The other Xbee module is connected to the PC through the USB adaptor and read the serial port data through software called Processing 2.0b and display as a graph (Figure 5.3.7).

The energy calculated by this remote device which can be considered as simple energy meter data transmittedbyZigbeeRF wireless channel to the PC (Figure 5.3.8).

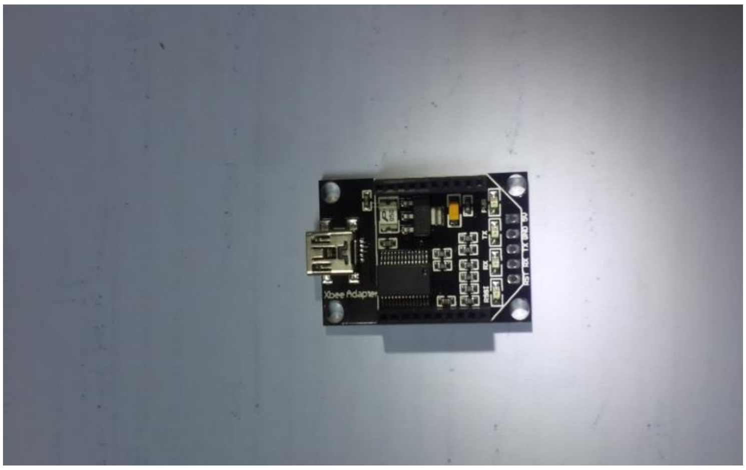


Figure 5.2.4 – Xbee USB adaptor

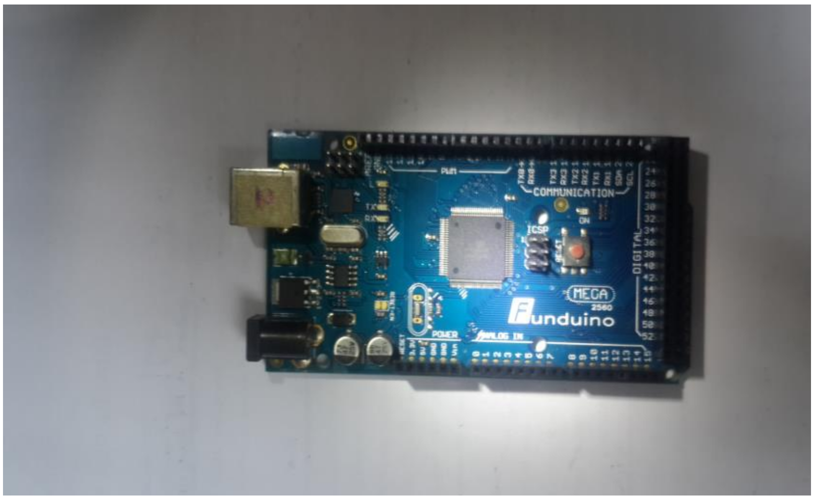


Figure 5.2.5 – Arduino Mega 2560

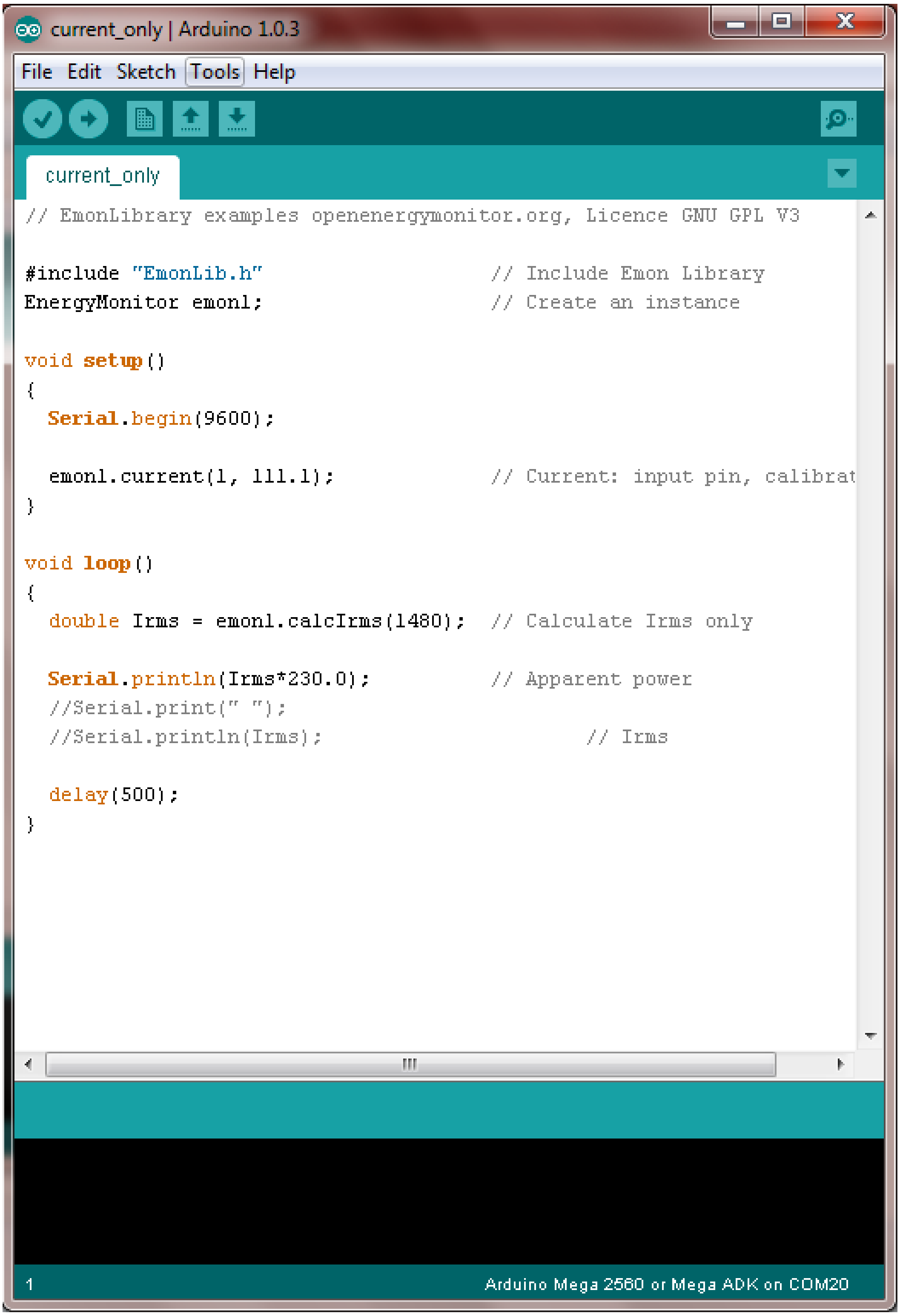
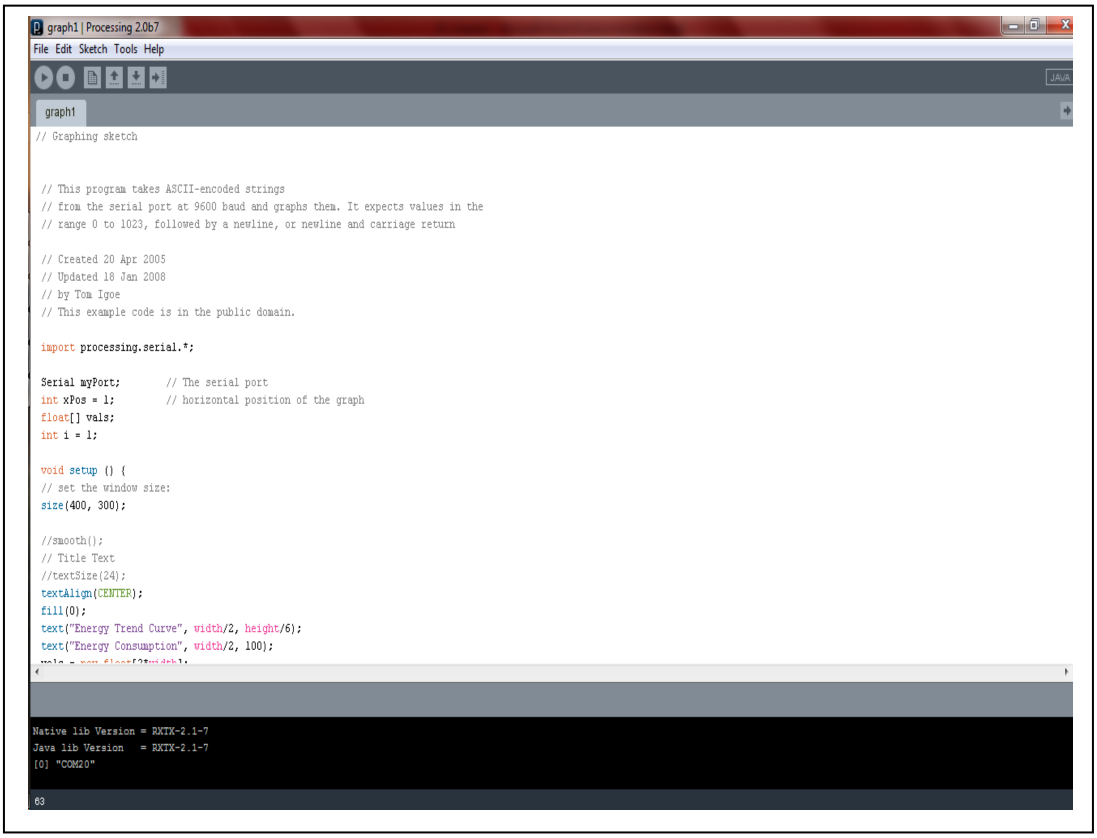


Figure 5.2.6 – Arduino program



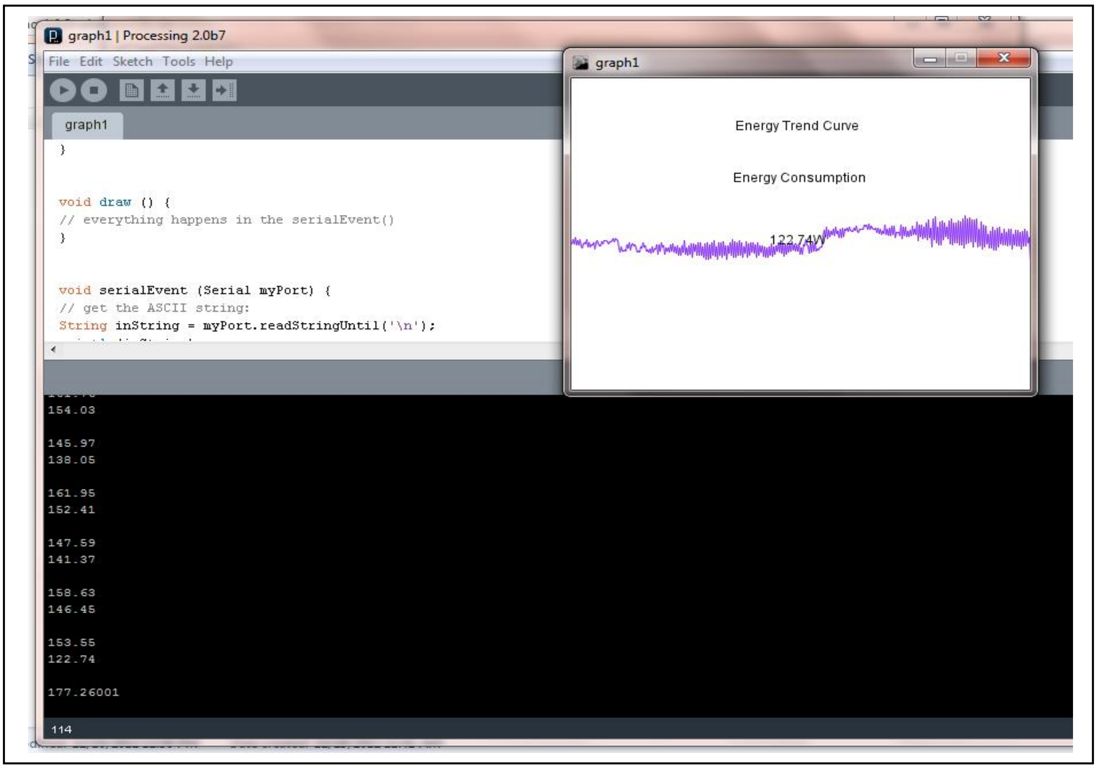


Figure 5.2.7 – Processing program & energy graph

Figure 5.2.8 – Simple Xbee data connection project

The other task is to write ZigBee communication driver. By using one of available Direct Memory Access (DMA) channels, all received characters are stored in specified memory space. After full frame reception, it is sent to appropriate application layer depending on the frame type. After receiving ZigBee Receive Packet frame, it is sent to GSM transmit FIFO while working in transparent mode or stored in internal memory while performing buffered readout. On the other hand, all the data sent with local communication port is encoded with ZigBee Transmit Request frames and sent to the module. Every Transmit Request Frame is followed by a Transmit Status frame from the Xbee module. This mechanism is used to ensure successful data delivery and perform retransmission if necessary.

ZigBee adapter is designed as a standalone device with various interface options as RS232, RS485 or USB connection useful during configuration and installation process. Additionally, digital input and output are designed for future purposes and utilizes smart grid concept. All interfaces and power outputs are galvanic isolated from the ZigBee module in case of installation or external devices failures. The default baud rate of energy meters is 9600 bps. Transparent communication between ZigBee router and coordinator is available through AT firmware, so no additional application processor is required decreasing device hardware and software costs as long as its size. Network Watchdog Timeout is set to periodically check for the presence of network coordinator. Besides LED indication of network association, this feature is used for easy coordinator replacement. The first step is to prepare another coordinator with the same network ID and link encryption password as original network. The most probable scenario is that existing network and the new coordinator will work on different channel so they will not communicate. Nevertheless, after a particular time of coordinator absence all remaining nodes will perform scan over all channels and join the new coordinator. Destination address for all modules is set to network coordinator address by default. Despite mesh topology and possible peer-to-peer connection, all communication is performed in tree-like structure, where packets are routed down the tree to the destination node and up to the coordinator.

Each energy meter has unique identification number and responds only when receiving command containing that address. Another feature of energy meter system using IEC protocol is that great majority of data is sent from meter to concentrator. That is the reason why broadcast messages from coordinator to energy meters are used. Broadcasts are less reliable and energy efficient from unicast transmission but they can be retransmitted when necessary. Moreover, they are used only on the beginning of the transmission. Sent command travels to all routers and all energy meters as a result. Only the addressed energy meter will respond, so there is only one router from which the coordinator will receive unicast data (Figure 5.2.9. After the first response using start baud rate and broadcast address, received frame contains the address of ZigBee router that the particular energy meter is connected to. Concentrator can now use unicast Remote AT Command Request frame to change adapter speed, to adjust it to meter requirements, and continue communication only with addressed node. This mechanism can be used to create database of ZigBee modules existing in the network. List of energy meters connected to each module can also be easily recovered. Usage of such database is useful in further network extending, improving routing protocol and network maintenance. There are following three main routing protocols.

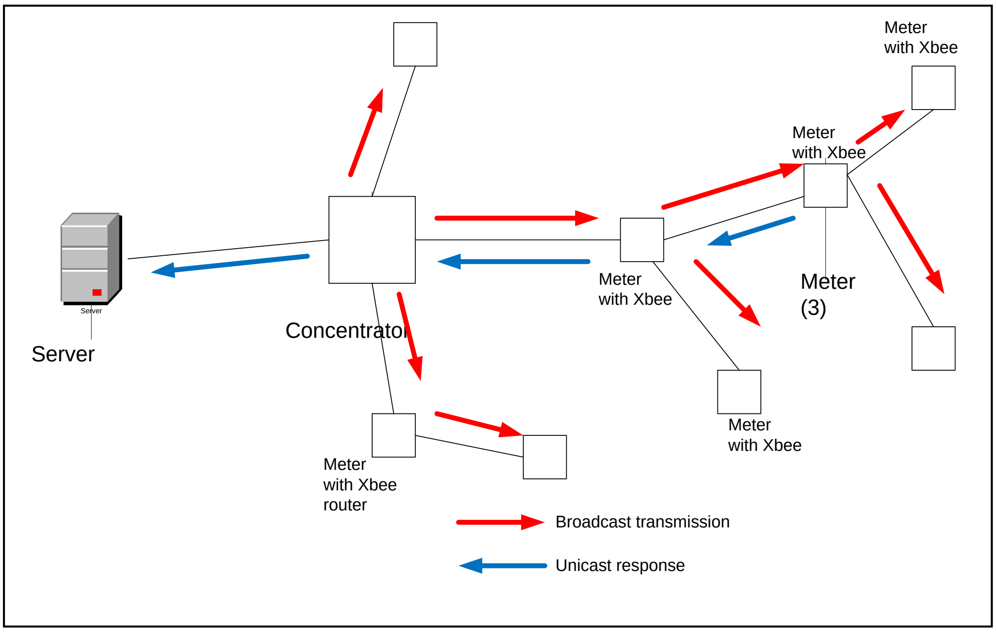


Figure 5.2.9 – Zigbee touting schema

AODV

Ad hoc On-demand Distance Vector (AODV) Mesh Routing is suitable for network not bigger than 40 nodes. In this schema, each node stores the next hop address to reach the destination node. If there is no entry for particular node, route discovery must take place in order to find a communication path. Since only a limited number of routes can be stored on a module, route discovery will take place more often on a large network with communication between many different nodes and cause large packet overhead.

Many-to-one

In cases where many devices send data to a data collector Many-to-One routing protocol removes necessity of route discover. Setting Aggregate Routing Notification parameter in the data concentrator makes it to send periodical route request broadcast message transmission. While travelling through the network, each node appends its own address to that packet and retransmits it again. As a result, each node knows the exact path to the data concentrator.

Source Routing

Source Routing is the most complex routing schema, which can be exploited only by nodes with API firmware. It enables the full control of packet transmission route and is useful when a device such as data collector communicates with many nodes. After enabling Many-to-One routing by setting Aggregate Routing Notification, each data frame from a remote node is proceeded with Route Record Indicator frame, which contains addresses of all nodes participating in transmission. Data collector should store all received Route Record Indicator frames in its own application space and use Create Source Route frame to send packet to particular node. This routing scheme is left for future work.

In described case, the first two methods are very similar. Using AODV will not cause route discover packets to flood, because all nodes need to store routing path only to the coordinator.

5.3 Industrial implementation

Following pilot projects are carried out based on this research with LECO staff as industrial implementation.

- Madiwella housing scheme Radio network pilot project
- Boralesgamuwa area Radio network pilot project and planning to expand over Maharagama and Nugegoda area.
- Negombo area Radio network pilot project

In Negombo, Seeduwa area a pilot project wasimplemented with wireless radio network using Zigbee modules and GPRS network (Appendix B).

The Zigbee network topology is Adhoc mesh topology network and having hundred nodes. The concentrator or the coordinator of the network is location at a pole closed to the center of the hundred nodes cluster (Figure 5.3.2). Energy meters at each node consist of modem, zigbee interfacing module and zigbee module (Figure 5.3.1). The concentrator consist of a zigbee module, zigbee intercaing module, GPRS module, GPRS interfacing module and arduino module which integrates all components via serial communication program module.

Figure 5.3.1 –Energy meter with Zigbee Module

Figure 5.3.2 –Concentrator

Each node of the network is configured as router devices and one device program as coordinator to establish the network. Routers are hopping the data through adjacent devices and transfer the data to the concentrator. X CTU software is used to configuration the zigbee devices and analysis the mesh network. X CTU can scan the radio modules in the network and illustrate as mesh network with the network links. In figure 5.3.3 shows that there are 30 modules in the network but only 4 nos. of radio devices are connected to concentrator and others are pushing data to the concentrator via data hopping protocol. It is necessary to estimate the link quality of the each link in the mesh wireless zigbee network. There are two parameters called RSSI (Received Signal Strength Indicator) and LQI (Link quality Indicator) to estimate the link quality. X CTU software has facility to carry out Radio Range Test which results in the real RF range and link quality between two radio modules in the same network (i.e RSSI in dBm) and also display the success of the link in percentage (Figure 5.3.4).

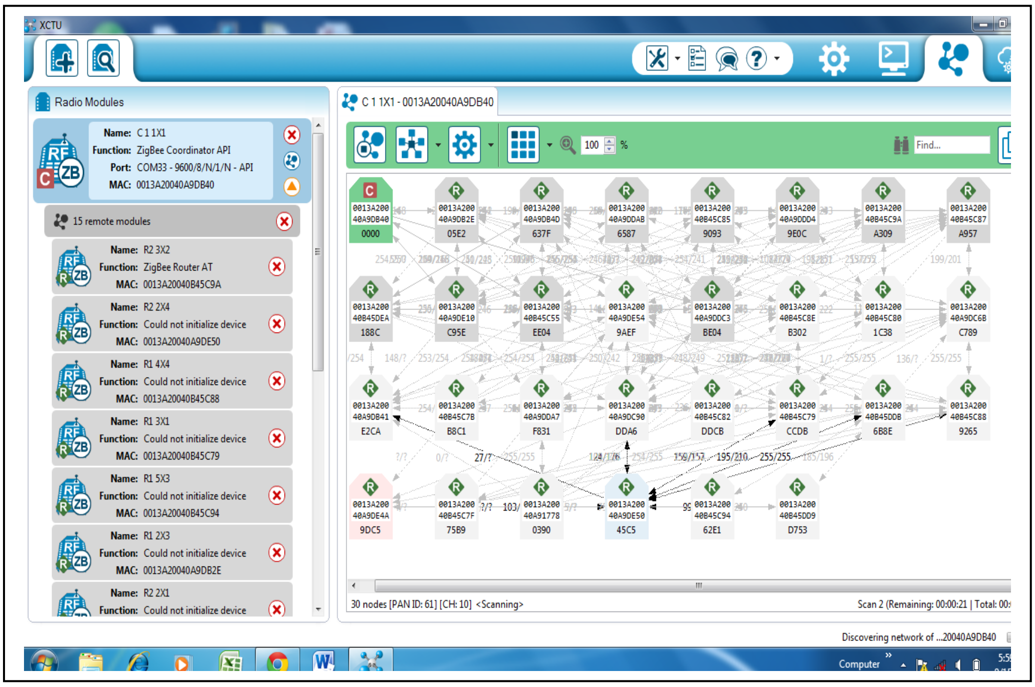


Figure 5.3.3 –Mesh network of the Zigbee radio network

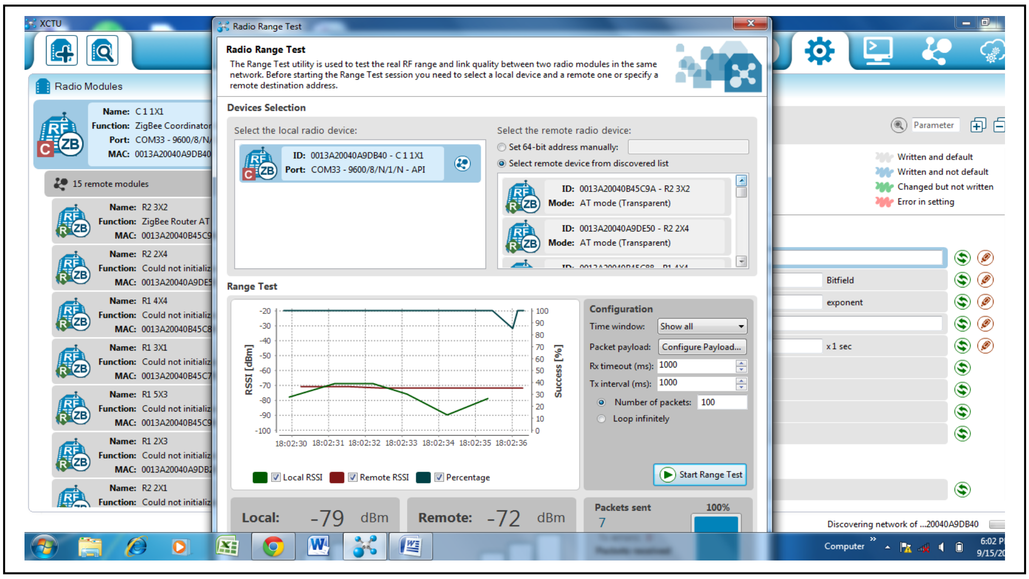


Figure 5.3.4 – Radio Range Test of the Zigbee Network

Radio Island

Radio island is the RF wireless sensor network of the particular electricity distribution network. In this case distribution area is Negombo Seeduwa primary substation and there are 100 of energy meters having Zigbee RF wireless communication modules. Each energy meters GPS locations are captured and carried out the range test to measure the RSSI value (Appendix B). Each RSSI values are graphical represented as height with the XY nodes points which are derived from GPS locations to map a 3D surface and plottedas contours in order to identify the link quality between RF devices as figure 5.3.5. Geographically distribution of the RSSI value of each node is illustrated in this map and has almost flat surface having an average of 60%-90% of RSSI. This results that the RF sensor network which has ad-hoc protocol maintains good link quality or good reliability.

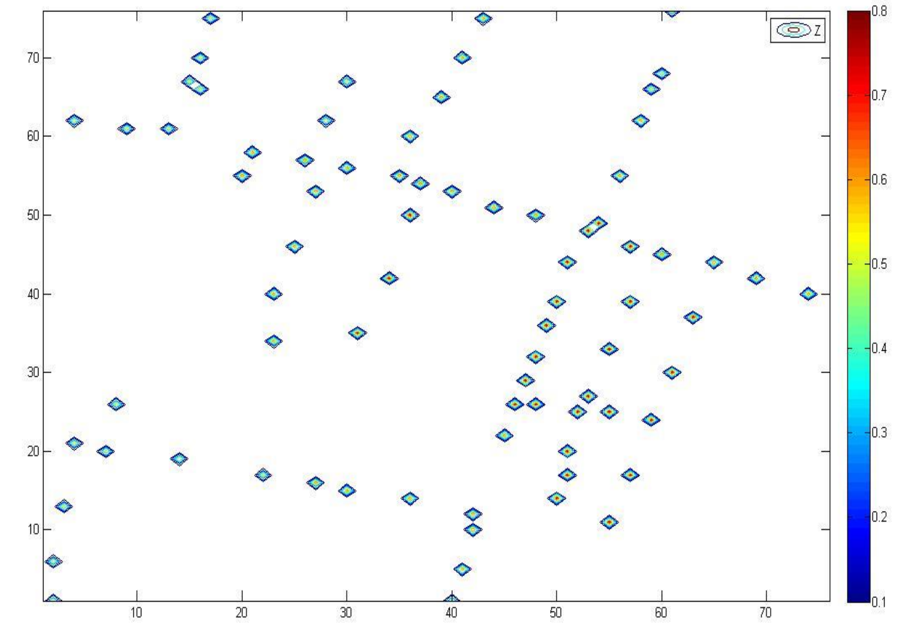


Figure 5.3.5 – Radio Island

Simulation results Vs implementation results

Results of the simulation such as throughput of the RF network and backbone channel, data concentrator capacities are compared with the actual implemented concentrator base AMR system in Seeduwa area. Seeduwa area project has 100 meters RF network aggregated data into the concentrator which is geographically located after identification the best throughput and link quality point. These parameters can be determined by carrying out the radio range test and the throughput test. Table 5.3.1 shows the comparison simulation results of case 6 discussed in chapter 4 and actual implementation results.

Table 5.3.1–Simulation results Vs actual implementation results

Parameters	**Simulation results : case 6**	**Actual implementation results**
No. of Meters	100	100
Load data	737 @ 15 min interval	737 @ 15 min interval
Billing data	45 @ 60 min interval	45 @ 60 min interval
RF network throughput	11.6 kbps	9.6 kbps
Concentrator memory	200 KB	256 KB
Backbone channel throughput	556 kbps	1Mbps

Software of the data concentrator shows data concentrator memory is operated under the 20 % safety margin of memory.

Cost Analysis

Cost of the point to point AMR system and data concentrator base AMR system is compared in detail as table 5.3.2. Capital cost and 15 years operation cost including the energy cost is considered for cost analysis. Both calculations are done for 200 meters and the concentrator base AMR system calculation is done for Xbee Pro 2 RF network and backbone data link which is having 2.5 MB downlink capacity and 1Mbps throughput with 256 capacity data concentrator memory device.

Table 5.3.2–Cost analysis

Cost Components	**Point to Point method**			**Concentrator base method**		
	Cost in US$	Qty	Total Cost in US$	Cost in US$	Qty	Total Cost in US$
Capital cost						
Modem	35.00	200	7,000.00	100.00	1	100.00
Zigbee module		-	-	55.00	200	11,000.00
Sheild		-	-	6.00	200	1,200.00
Chip set & 256DM		-	-	30.00	1	30.00
Power supply unit		-	-	50.00	1	50.00
Enclosure		-	-	20.00	1	20.00
Operational cost						
Connection chargers	180.00	200	36,000.00	900.00	1	900.00
Energy Cost						
Modem	2.85	200	570.24	2.85	1	2.85
Zigbee				1.43	200	285.12
Total			**43,570.24**			**13,587.97**

This cast analysis shows that the proposed data concentrator based AMR system is economically viable.

Chapter6

Conclusions

6.1 Conclusions and discussion

Energy meters are generating various tiny data packets at various frequencies which used to calculate energy consumption to produce the bill, study the power quality and fault identification. In AMR, these data were pushed into the base station automatically in various technologies and topologies such as Power line Carrier network, Message over GSM network, Telephone line network and Short range radio frequency network.

When transmitting this small data packet via a wireless channel it needs to establish a point to point channel in between meter and base station. When consideringthe large number of energy meters in a particular electricity distribution area, it is needed to have separate telecommunication link for each and every meter. This will cause an unnecessary telecommunication infrastructure resources utilization. Cost of 'Establishment of a telecommunication link' is, purely the cost of providing network infrastructure resources. AnElectricity service provider has to have large telecommunication infrastructure resources to push this tiny amount of data from energy meter to base station. This is same as establishing within an 'electricity service providing company' another 'in-house telecommunication company'.

Also, it takes approximately two minutes to read out a single meter and when considering the five million subscribers it is unfeasible to read real time data from meters.

Data concentrator model is the most dominating AMR model which is still under ongoing research. In this model small data packets which are transmitted by the energy meters are aggregated into a data concentrator via a data aggregating protocol. Data concentrator pushes stored data into the base station as bulk data packets. In this AMR model it is not necessary to establish point to point telecommunication link. This leads to save telecommunication infrastructure resources which are costly.

There are three main components in this model namely last mile data network which aggregates small energy meter data, data concentrator which having data storage memory capacity and backbone telecommunication channel which push bulk data packets into the base station.

In this research last mile data network is designby the ad-hoc data hopping protocol. Each energy meter consists of RF data transmitting and receiving device called Zigbee which can communicate wirelessly. This device has facilities to configure as end device or router. Ad-hoc data hopping protocol is used aggregating data into the data concentrator. Data concentrator is acting as coordinator of the wireless network which consists of Zigbee device that configured as coordinator. Also Data concentrator has data storage facility to store aggregated data. Data concentrator has data pushing algorithm to push stored data as demanding by the base station. Backbone channel is a data transmitting channel which provided by particular telecommunication service provider who intended agreement with electricity service provider.

The object of the research is to analyzing thespecifications and cross relationship between each components of this AMR network model and integrated them into mathematical model. Then arrive into a scientific conclusion to design and implementation of successful AMR network in utility wide.

Successfulness of the last mile data network is highly depending on the reliability of the ad-hoc network infrastructure and network protocol which cost sensitive. Data concentrator is required correct memory buffer size which is depend on the technology and cost. Backbone data network is highly depending on the telecommunication network infrastructure resources of the associated telecommunication network provider which is very high cost sensitive.

Analysis the energy meter data at elementary level is done by using Microsoft network protocol analysis software and mathematically model the energy meter by using MATLAB Simulink software. Last mile data transmission network is model as RF channel and RF channel speed model using MATLAB Simulink as normal distributed phenomena and added noise to the channel at a different time frame. Data concentrator is model by programing MATLAB Simulink and added special featuressuch as data booting function to avoid memory overflow of the data concentrator. Backbone data transmission channel is mathematically model as GPRS channel and GPRS channel speed model using the MATLAB Simulink and added noise signals.

These modelsare integrated with MATLAB Simulink program and end up with a computational algorithm that can input repeated random sampling of various parameters to the each component and iterating the simulation. Then various results related to various inputs are analysis to arrive into conclusion.

According to the above results the backbone channel capacity and memory capacity of the concentrator is inversely related. Concentrator memory capacity has limitation on hardware technologies and cost wise. On the other hand backbone data channel also has technological restrictions which rely on the particular telecommunication service provider. The relationship between backbone and concentrator memory capacity is illustrated in chapter four.

Last mile data network capacity is mathematically rely on number of energy meters and transmitting data packet capacity of the single energy meterthat present in the RF network. Data concentrator memory buffer sizeis directly link to the above parameters and the mathematical relationship is illustrated as in chapter four. Therefore, such a last mile radio island or the data cluster has limitation on number node to have in order to implement a successful AMR system.

Therefore, as establish in chapter threeand four last mile data network capacity, data concentrator memory buffer size and backbone channel capacity can be set up only as integrated model. And there are definite figures for the specification of the above components.There are cross relationship between above componentsthat cannot analysis individual components to establish a utility wide AMR system.

Specifications of the each component are the network resources requirement which is the objective of this research.

Industrial implementation and data validation is described in chapter five in detail. The results of the actual implementation of AMR system is used to tune the simulation to increase accuracy of the simulation results. The simple cost analysis in chapter five determined that the data concentrator based AMR system is economically viable than the conventional wireless point to point AMR system.

6.2 Future developments

Techno economic study

In this research economic consideration is for last mile data channel speed, data concentrator memory and backbone data channel capacity is not taken into account. Final optimal designshall base on the economicsof these three components.

Last mile data communication link capacity is predominatelyprotocol based. Higher data speeds and advanceddata protocol embedded devicesare highly resource reliant components. Therefore such protocol integrated devices are very costly.

Memory at concentrator, having the class of reliability required are also cost intensive. On the other hand the backbone channel capacity price is based on the respective telecommunication service provider. Thereforea techno-economic study has to be carried out to cost these three components in order to arrive at a final solution. Developing of such a cost intensive mechanism is connected with a proposed resources based calculated model developed in the chapter three; which will lead to the utilities to carry out a financially viable AMR system. Such techno economic study also provides solutions for various AMR problems.

Graphical User Interface

Graphical User Interface for Network resources identification for the AMR Software called Network Resource Planner for AMR has been partially developed. As a future work, this GUI has to be completed (Figure 5.2.1). This software has facilities to input various parameters related to last mile data network, data concentrator memory and backbone channel capacity. By inputting various sampling data into the interface the algorithm can be repeated to find out the best solutions.

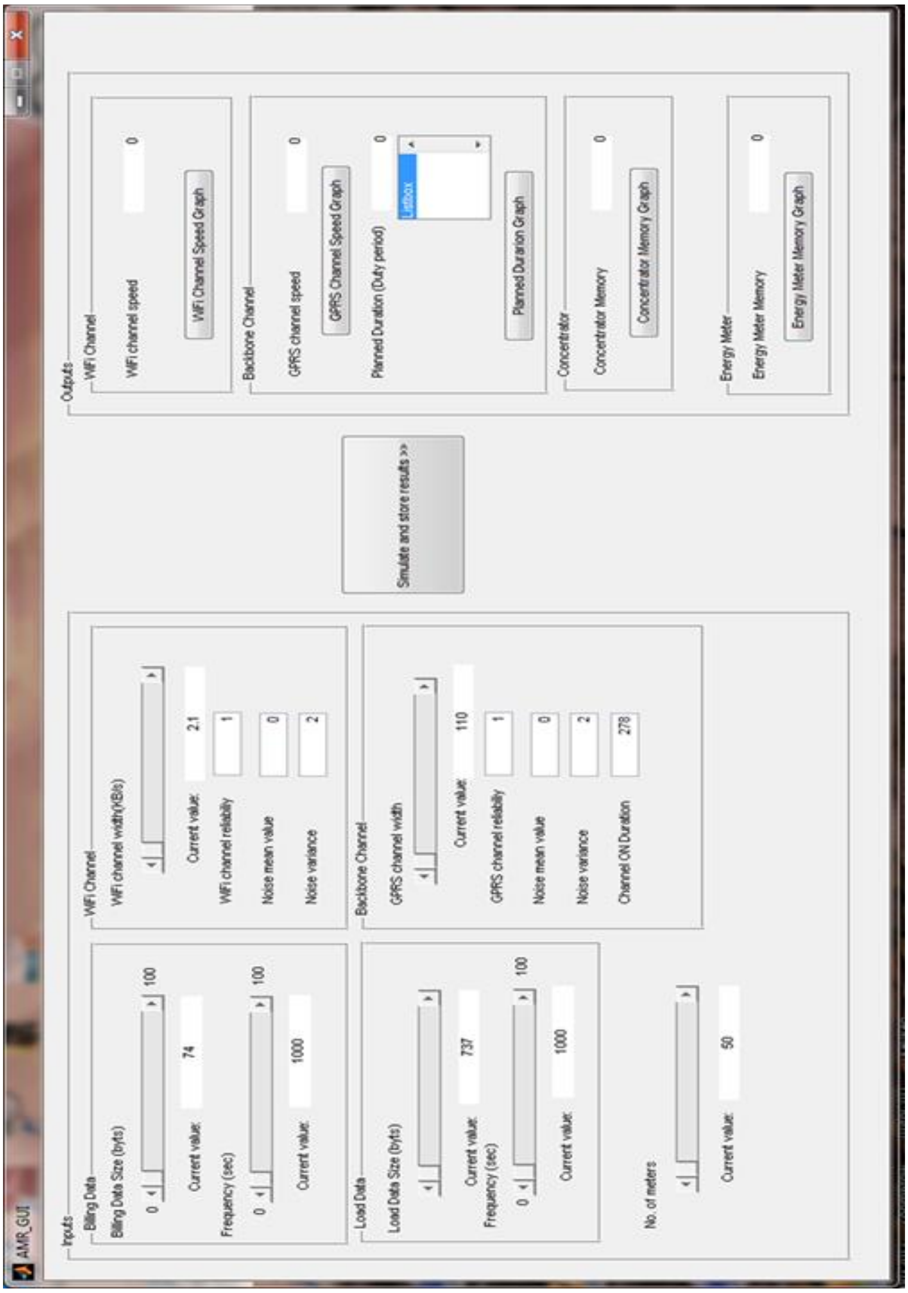


Figure 6.2.1– GUI

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Appendix A

Appendix B

Appendix C