Altahadi University Faculty of Engineering Department of Electrical Engineering

Communication Network Design of GMRWUA* Central Region (Sirte).

M.Sc. Thesis

As a partial fulfillment for a Master of Science requirements in communications engineering.

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^{*} Great Man Made River Water Utilization Authority

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تصميم شبكة اتصالات لمنظومة النهر الصناعي العظيم بالمنطقة الوسطى - سرت

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Abstract

GMRWUA has some sites that are in need to be connected together to operate as one system, so this requires to design communication network between these sites.

Private network is a communication network which is partially or fully owned and operated by a private organization. Implementation of private networks has many advantages such as, guaranteed quality of voice and data services, fixed call charges, improved security, instantaneous call connection, full control of the network and less dependent on other networks.

Communication has become a major part of any process control automation system. Before one can consider how to implement a communication system, one has to consider what is the final objective, what is the importance of data, what is the volume of data to be transferred and how often the data is required?

In this research a design of an algorithm is carried out. It handles routing of the calculated digital traffic, that include digitized voice, data and video to some locations as data between well defined nodes to establish a network of the said nodes. The algorithm is based on the Forward Search Algorithm. Each node in the formed network is assumed to serve number of stations. The algorithm computes the least-cost route between any pair of nodes and to repeat this process until completion of all nodes. The resulted final configuration is to meet the requirements of minimum cost and sufficient reliability. Following the results final configuration has been proposed (chosen) for transmission media. Finally some concluding remarks and recommendations are given.

تصميم شبكة اتصالات لمنظومة النهر الصناعي بالمنطقة الوسطى، سرت (دراسة تطبيقات الصوت ، والبيانات ، والتحكم ومراقبة البيانات المجمعة)

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ملخص البحث

هذاك بعض المواقع التشغيلية بجهاز استثمار مياه النهر الصناعى العظيم بمنطقة سرت والتى تؤدي أغلبها وظيفة واحدة وهى توزيع الاحتياجات المائية للمشاريع الزراعيسة والاحياء السكنية المحيظة، حتى يتم المحافظة على استقرار العملية التشغيلية (المحافظة على تدفق وضغط المياه بالخط) الذلك فإن هذا الامر يتطلب تصميم شبكة اتصسالات بين المدواقع المختلفة لكى تتم المراقبة الدقيقة لجميع المرافق.

تكون الشبكات الخاصة مملوكة كليا او جزئيا من قبل هيئة او منظمة خاصة، ولها عدة مزايا والتى منها ضمان نوعية خدمات البيانات والصوت، وثبات معرالمكالمة، وضمانة جيدة ولاتعتمد على شبكات أخرى. تعتبر الاتصالات العمود الفقرى في أى نظام تحكم، وقبل تنفيذ أى نظام الصالات من الواجب معرفة الهدف الرئيسي من التصميم وما هي المعلومات المهمة المطلوب نقلها وما هو حجمها وزمن نقل تلك البيانات.

في هذا البحث ثم تصميم خوارزمية مبنية على تحديد مسار الحركة الرقمية والتي تتضمن الصوت والبيانات والصورة لبعض المواقع كبيانات أو معلومات للمواقع المراد ربطها مع بعضها بشبكة اتصال واحدة. والخوارزمية مبنية على البحث الامامي للمسار المطلوب، وكل موقع في الشبكة المقترح تشكيلها يعتمد على خدمة عدد من المحطات. يتم حساب أقل تكلفة مساريين موقعين عن طريق هذه الخوارزمية، ويتم تكرار هذه العملية حتى الانتهاء من جميع المواقع. يلبي الشكل النهائي الناتج متطلبات التصميم وهي التكلفة الأقل والوصول الى الموثوقية الكافية. وبعد الحصول على الشكل النهائي للشبكة، تم اقتراح وسائط الارسال المناسبة للربط بين المواقع. وفي النهاية تم استنتاج بعض من الملاحظات وتقديم التوصيات بالخصوص.

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Abbreviations

ADSS: All-Dielectric Self-Supporting

AGPS: Al Gardabiya Pump Station

ALs: Access Links

BER: Bit-Error-Rate

BHR: Busy Hour

CDMA: Code Division Multiple Access

CPE: Customer Premise Equipment

CS: Circuit Switching

CSMA: Carrier-Sense-Multi-access

CVSDM: Continuously Variable slope DM

DL: Directed Link

DM: Delta Modulation

ECD: Expected Call Duration

EMD: Expected Message Duration

EPA: Enhanced Performance Architecture

FCC: Federal Communications Commission

FDMA: Frequency Division Multiple Access

FDM: Frequency Division Multiplexing

GAGPS: Grand Al Gardabiya Pump Station

GMRWUA: Great Man Made River Water Utilization Authority

GMRA: Great Man Made River Authority

GOS: Grade-of-Service

GPTC: General Post and Telecommunication Company

Human Machine Interface

IED: Intelligent Electronic Device

IP: Internet Protocol

LAN: Local Area Network

MARS: Multiple Address Radio Systems

MD: Multidrop

MM1: Man Machine Interface

MS: Message Switching

MST: Minimal Spanning Tree

MTBF: Mean Time Between Failure

MTU: Master Terminal Unit

NMC: Network Management and Control

OSI: Open System Interconnection

OS&M: Operation, Service and Maintenance

OPGW: Optical Power Ground Wire

PBX: Private Branch Exchange

PCS: Personal Communication System

PCM: Pulse Code Modulation

PCCS: Permanent Control and Communication System

PLCs: Programmable Logic Controllers

PLC: Power Line Carrier

PS: Packet Switching

PSN: Public Switched Network (PSN)

PTO: Public Telecommunication Operator

PTP: Point-To-Point

PTM: Point-To-Multipoint

PVC: Polyvinyl Chloride

QOS: Quality of Service

RCC: Regional Control Centre

RTU: Remote Terminal Unit

SCADA: Supervisory Control and Data Acquisition

SDM: Space Division Multiplexing

TCAs: Time Consistent Averages

TDMA: Time Division Multiple Access

TDM: Time Division Multiplexing

TKs: Trunks

UHF: Ultra High Frequency

VSAT: Very Small Aperture Terminal

VHF: Very High Frequency

WAN: Wide Area Network

WOC: Wrapped Optical Cable

WWPS: Western Wadis Pump Station

CHAPTER I

Introduction

Chapter I: Introduction

1.1 General

Public and private networks are based on similar technical principles, but differ in scale and complexity. Private networks cater for much lighter traffic, but more specialized service and features are needed; such as inter-switching signaling system, where the private branch exchanges (PBXs) in different office buildings are interconnected by circuits between them more details in [2,3]. The (PBXs) and other customer apparatus may be owned by a private company, or leased from the public telecommunication operator (PTO). The wiring in each office normally belongs to the private company, the circuits that interconnect the different PBXs in different buildings are most leased from the PTO, and some are wholly owned by the company.

The main issue and most critical part in the network design is the backbone links, which carry the main traffic between the nodes. Problems on this backbone will affect severely the network performance. The selection of appropriate transmission media between different nodes is not an easy process. The network designers are always confronted with different attractive alternatives. The selection process depends on a set of parameters, some of them depend on technology and media characteristics, and the others depend on sites and physical route and terrain between them.

1.2 Motivation

The water distribution of GMRWUA system covers a large area which contains several locations (Pumps, Irrigation Machines, Tanks, and Workshops). The problem is how to operate this system efficiently, in case there are defects in

the system, they will have effects on the operation (system blockage), e.g. if there is leakage in the pipeline with pressure about 9 bar (operating pressure of the system), or in the tanks (15.4 million cubic meter, water capacity of Grand Algardabia Reservoir), it will cause a big problem to the environment.

So from the above the suggested solution is to establish a network through the design of a control and a communication system with a headquarter that can control and monitor the sites of the whole system clearly.

In the design of communication networks one of the fundamental consideration is the reliability and availability of communication paths between all terminals. Together, these form the network system reliability. The other important aspect is

the layout of paths to minimize cost.

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The overall objective is to supply and maintain the water allocation for the GMRWUA central zone facilities in the sirte area, while maintaining the flow within limits between supplier and user. In order to achieve this objective Permanent control and Communication System is needed to provide the means of controlling and monitoring the various elements of GMRWUA facilities. Therefore our aim is to design an optimum communication and control network to meet the overall objective, Hence, a search algorithm to optimize the design of network overall objective.

1.5 Description of Chapters

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The thesis is divided into six chapters. Chapter one introduces the motive of the research and scope of the work. Chapter two present SCADA system and the reasons of its implementations. It also contains SCADA protocols and transmission media that needed to connect SCADA components. Chapter three presents the

concept of networking and the properties that define the network architecture, since there are several topologies. This chapter also, shows the concept of traffic in communication networks. Chapter four contains input data of the case under study that are collected from the site and needed to design enterprise communication network. Chapter five discusses the scenarios of communication network design and criteria of selection to get the optimum design for GMRWUA facilities. Chapter six discusses results and given conclusion of this design.

CHAPTER II Supervisory Control and Data Acquisition (SCADA) System

Chapter II: Supervisory Control and Data Acquisition System

2.1 Introduction to SCADA

SCADA systems are used to monitor and control a plant or equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining and transportation. These systems encompass the transfer of data between a SCADA central host computer and a number of Remote Terminal Units (RTUs) and/or Programmable Logic Controllers (PLCs), and the central host and the operator terminals. A SCADA system gathers information (such as where a leak on a pipeline has occurred), transfers the information back to a central site, then alerts the home station that a leak has occurred, carrying out necessary analysis and control, such as determining if the leak is critical, and displaying the information in a logical and organized fashion. These systems can be relatively simple, such as one that monitors environmental conditions of a small office building, or very complex, such as a system that monitors all activities in a nuclear power plant or the activity of a municipal water system. Traditionally, SCADA systems have made use of the Public Switched Network (PSN) for monitoring purposes.

Today many systems are monitored using the infrastructure of the corporate Local Area Network (LAN)/ Wide Area Network (WAN). Wireless technologies are now being widely deployed for purposes of monitoring.

A SCADA system means a system consisting of a number of RTUs collecting field data transmitted back to a master station via a communication system. The master station displays the acquired data and also allows the operator to perform remote control tasks, as shown in Fig (2.1).

The accurate and timely data (normally real-time) allows for optimization of the operation of the plant and process. A further benefit is more efficient, reliable and

most importantly, safer operations. All these result in a lower cost of operation compared to earlier non-automated systems.

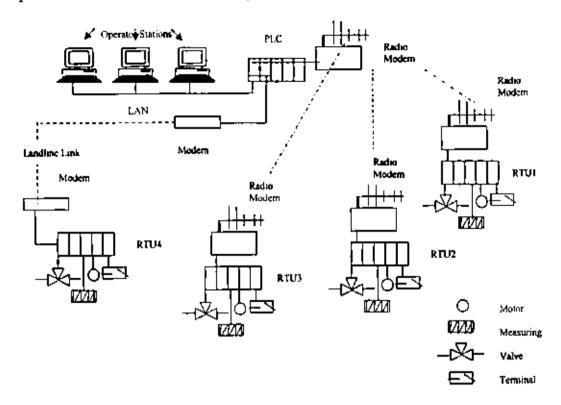


Figure (2.1) Diagram of a typical SCADA system

2.1.1 Reasons for implementing a SCADA

Obviously, a SCADA system's initial cost has to be justified. A few typical reasons for implementing a SCADA system are:

- Improved operation of the plant or process resulting in saving due to optimization of the system operation.
- · Increased productivity of the personnel
- · Improved safety of the system due to better information and improved control
- Protection of the plant equipment
- · Safe guarding the environment as a result of any possible system failure
- · Improved energy saving due to optimization of the plant

- Improved and quicker receipt of data so that clients can be invoiced more quickly and accurately
- Government regulations for safety and metering are met.

2.1.2 Components of SCADA

Components of SCADA system are composed of the following:

- Field level instrumentation and control devices, usually RTUs, or PLCs, which interface to field sensing devices and local control switchboxes and valve actuators. The RTU provides an interface to the field analog and digital signals situated at each remote site.
- A communication system used to transfer data between field data interface
 devices and control units and the computers in the SCADA central host. The
 system can be radio, telephone, cable, satellite, or any combination of these.
 Specific protocols and error detection philosophies are used for efficient and
 optimum transfer of data.
- A central host computer server or servers (sometimes called a SCADA Center, master station, or Master Terminal Unit (MTU)). The master station (and submasters) gather data from the various RTUs and generally provide an operator interface for display of information and control of the remote sites. In large telemetry systems, submaster sites gather information from remote sites and act as a relay back to the control master station.
- The commercial data processing department computer system. A collection of standard and/or custom software [sometimes called Human Machine Interface (HMI) software or Man Machine Interface (MMI) software] systems used to provide the SCADA central host and operator terminal application, support the communications system, and monitor and control remotely located field

data interface devices. Specific protocols and error detection philosophies are used for efficient and optimum transfer of data [5]. Figure (2.2) gives an example of a SCADA system showing the above mentioned components.

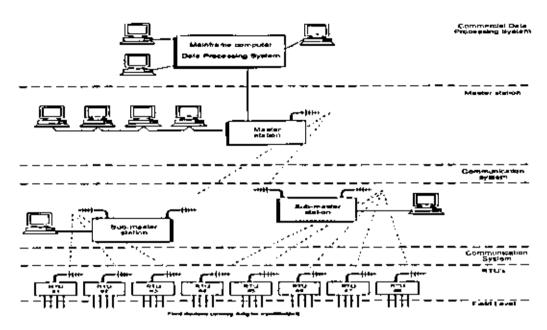


Figure (2.2) SCADA system

2.2 SCADA Architectures

SCADA systems have evolved in parallel with the growth and sophistication of modern computing and communication technology. The following sections will provide a description of three generations of SCADA systems:

- First Generation Monolithic
- Second Generation Distributed
- Third Generation Networked

2.2.1 Monolithic SCADA Systems

When SCADA systems were first developed, the concept of computing in general is centered on "mainframe" systems. Networks were generally non-existent, and

each centralized system stood alone. As a result, SCADA systems were standalone systems with virtually no connectivity to other systems.

WANs that were implemented to communicate with RTUs were designed with a single purpose in mind that of communicating with RTUs in the field, and nothing else. In addition, WAN protocols in use today were largely unknown at the time. The communication protocols in use on SCADA networks were developed by vendors of RTU equipment and were often proprietary. In addition, these protocols were generally very "lean", supporting virtually no functionality beyond that required scanning and controlling points within the remote device. Also, it was generally not feasible to intermingle other types of data traffic with RTU communications on the network. Connectivity to the SCADA master station itself was very limited by the system vendor.

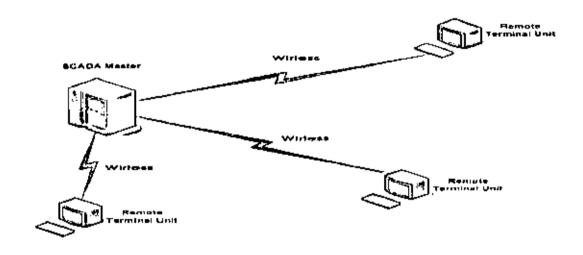


Figure (2.3) First Generation SCADA Architecture

Connections to the master typically were done at the bus level via a proprietary adapter or controller plugged into the CPU backplane. Redundancy in these first generation systems was accomplished by the use of two identically equipped

mainframe systems, a primary and a backup, connected at the bus level. The standby system's primary function was to monitor the primary and take over in the event of a detected failure. This type of standby operation meant that little or no processing was done on the standby system. Figure (2.3) shows a typical first generation SCADA architecture.

2.2.2 Distributed SCADA Systems

The second generation of SCADA systems took advantage of development and improvement in system miniaturization and LAN technology to distribute the processing across multiple systems. Multiple stations, each with a specific function, were connected to a LAN and shared information with each other in real-time. These stations were typically of the mini-computer class, smaller and less expensive than their first generation processors.

Some of these distributed stations served as communications processors, primarily communicating with field devices such as RTUs. Some served as operator interfaces, providing the HMI for system operators. Still others served as calculation processors or database servers. The distribution of individual SCADA system functions across multiple systems provided more processing power for the system as a whole than would have been available in a single processor. The networks that connect these individual systems were generally based on LAN protocols and were not capable of reaching beyond the limits of the local environment.

Some of the LAN protocols that were used were of a proprietary nature, where the vendor created its own network protocol or version thereof rather than pulling an existing one off the shelf. This allowed a vendor to optimize its LAN protocol for real-time traffic, but it limited (or effectively eliminated) the connection of network from other vendors to the SCADA LAN. Figure (2.4) depicts typical second generation SCADA architecture.

Distribution of system functionality across network-connected systems served not only to increase processing power, but also to improve the redundancy and reliability of the system as a whole.

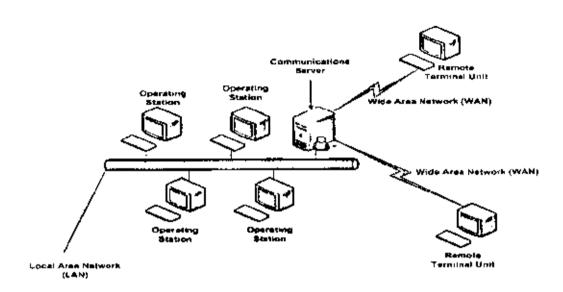


Figure (2.4) Second Generation SCADA Architecture

Rather than the simple primary/standby failover scheme that was utilized in many first generation systems, the distributed architecture often kept all stations on the LAN in an online state all of the time. For example, if an HMI station were to fail, another HMI station could be used to operate the system, without waiting for failover from the primary system to the secondary.

The WAN used to communicate with devices in the field were largely unchanged by the development of LAN connectivity between local stations at the SCADA master. These external communications networks were still limited to RTU protocols and were not available for other types of network traffic. As was the case with the first generation of systems, the second generation of SCADA systems was also limited to hardware, software, and peripheral devices that were provided or at least selected by the vendor.

2.2.3 Networked SCADA Systems

The third generation of SCADA master station architecture is closely related to that of the second generation, with the primary difference being that of open system architecture rather than a vendor controlled, proprietary environment. There are still multiple networked systems, sharing master station functions. There are still RTUs utilizing protocols that are vendor-proprietary. The major improvement in this generation is that of opening the system architecture, utilizing open standards and protocols and making it possible to distribute SCADA functionality across a WAN and not just a LAN. Open standards climinate a number of the limitations of previous generations of SCADA systems. The utilization of off-the-shelf systems makes it easier for the user to connect third party peripheral devices (such as monitors, printers, disk drives, tape drives) to the system and/or the network.

The major improvement in third generation SCADA systems comes from the use of WAN protocols such as the Internet Protocol (IP) for communication between the master station and communications equipment. This allows the portion of the master station that is responsible for communications with the field devices to be separated from the master station "proper" across a WAN. Vendors are now producing RTUs that can communicate with the master station using an Ethernet connection. Figure (2.5) represents a networked SCADA system. Another advantage brought about by the distribution of SCADA functionality over a WAN is that of disaster survivability.

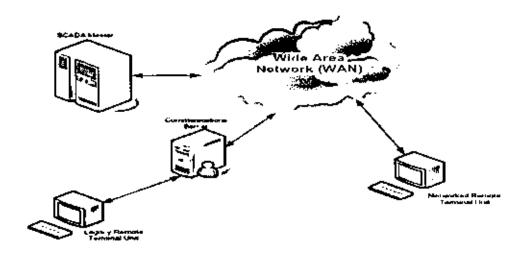


Figure (2.5): Third Generation SCADA System

The distribution of SCADA processing across a LAN in second-generation systems improves reliability, but in the event of a total loss of the facility housing the SCADA master, the entire system could be lost as well. By distributing the processing across physically separate locations, it becomes possible to build a SCADA system that can survive a total loss of any one location. For some organizations that see SCADA as a super-critical function, this is a real benefit.

2.3 SCADA Protocols.

In a SCADA system, the RTU accepts commands to operate control points, sets analog output levels, and responds to requests. It provides status, analog and accumulated data to the SCADA master station. The data representations sent are not identified in any fashion other than by unique addressing. The addressing is designed to correlate with the SCADA master station database. The RTU has no knowledge of which unique parameters it is monitoring in the real world. It simply monitors certain points and stores the information in a local addressing scheme.

Each protocol consists of two message sets or pairs. One set forms the master protocol, containing the valid statements for master station initiation or response,

and the other set is the RTU protocol, containing the valid statements RTU can initiate and respond to. In most but not all cases, these pairs can be considered a poll or request for information or action and a confirming response.

The SCADA protocol between master and RTU forms a viable model for RTU-to-Intelligent Electronic Device (IED) communications. In industry, there are several different protocols in use. The most popular are International Electrotechnical Commission (IEC) 60870-5 series, specifically IEC 60870-5-101 (commonly referred to as 101) and Distributed Network Protocol version 3 (DNP3) [5].

2.3.1 IEC 60870-5-101

It specifies a number of frame formats and services that may be provided at different layers. It is based on a three-layer Enhanced Performance Architecture (EPA) reference model (see Figure 2.6) for efficient implementation within RTUs, meters, relays, and other IEDs. Additionally, IEC 60870-5 defines basic application functionality for a user layer, which is situated between the Open System Interconnection (OSI) application layer and the application program. This user layer adds interoperability for such functions as clock synchronization and file transfers. The following descriptions provide the basic scope of each of the five documents in the base IEC 60870-5 telecontrol transmission protocol specification set. Standard profiles are necessary for uniform application of the IEC 60870-5 standards [6]. A profile is a set of parameters defining the way a device acts. Such profiles have been and are being created. The 101 profile is described in the following details:

 1EC 60870-5-1 (1990-02) specifies the basic requirements for services to be provided by the data link and physical layers for telecontrol applications. In particular, it specifies standards on coding and synchronizing data frames of variable and fixed lengths that meet specified data integrity requirements.

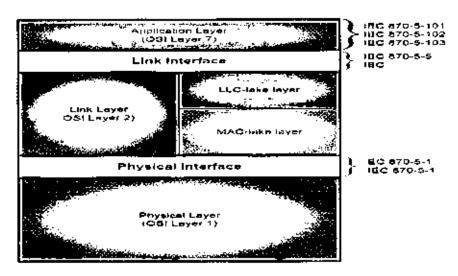


Figure (2.6): Enhanced Performance Architecture

- IEC 60870-5-1 (1990-02) specifies the basic requirements for services to be provided by the data link and physical layers for telecontrol applications. In particular, it specifies standards on coding, formatting, and synchronizing data frames of variable and fixed lengths that meet specified data integrity requirements.
- IEC-60870-5-2 (1992-04) offers a selection of link transmission procedures using a control field and optional address field; the address field is optional because some point-to-point topologies do not require either source or destination addressing.
- IEC 60870-5-3 (1992-09) specifies rules for structuring application data units in transmission frames of telecontrol systems. These rules are presented as generic standards that may be used to support a great variety of present and future telecontrol applications. This section of IEC 60870-5 describes the general structure of 17 application data and basic rules to specify application data units without specifying details about information fields and their contents.

- IEC 60870-5-4 (1993-08) provides rules for defining information data elements and a common set of information elements, particularly digital and analog process variables that are frequently used in telecontrol applications.
- IEC 60870-5-5 (1995-06) defines basic application functions that perform standard procedures for telecontrol systems, which are procedures that reside beyond layer 7 (application layer) of the ISO reference model. These utilize standard services of the application layer. Its specifications serve as basic standards for application profiles that are then created in detail for specific telecontrol tasks.

2.3.2 DNP3

Protocols define the rules by which devices talk with each other, and DNP3 is a protocol for transmission of data from point A to point B using serial communications. The DNP3 is specifically developed for inter-device communication involving SCADA RTUs, and provides for both RTU-to-IED and master-to-RTU/IED. It is based on the three-layer EPA model contained in the IEC 60870- 5 standards, with some alterations to meet additional requirements of a variety of users in the electric utility industry.

DNP3 was developed with the following goals:

- High data integrity. The DNP3 data link layer uses a variation of the IEC 60870-5-1 (1990-02) frame format FT3. Both data link layer frames and application layer messages may be transmitted using confirmed service.
- Flexible structure. The DNP3 application layer is object-based, with a structure that allows a range of implementations while retaining interoperability.
- · Multiple applications. DNP3 can be used in several modes, including:
 - Polled only
 - Polled report-by-exception

- Unsolicited report-by-exception (quiescent mode)
- Mixture of modes.

It can also be used with several physical layers, and as a layered protocol is suitable for operation over local and some wide area networks.

- Minimized overhead. DNP3 was designed for existing wire-pair data links with operating bit rates as low as 1200 bit/s and attempts to use a minimum of overhead while retaining flexibility. Selection of a data reporting method, such as report-by- exception, further reduces overhead.
- Open standard. DNP3 is a non-proprietary, evolving standard controlled by a
 users group whose members include RTU, IED, and master station vendors, and
 representatives of the electric utility and system consulting community.

A typical organization may have a centralized operations center that monitors the state of all the equipments in each of its substations. In the operations center, a computer stores all of the incoming data and displays the system for the human operators. Substations have many devices that need monitoring for example circuit breakers opened or closed, current sensors and voltage transducers. The operations personnel often need to switch sections of the power grid into or out of service. One or more computers are situated in the substation to collect the data for transmission to the master station in the operations center. The substation computers are also called upon to energize or de-energize the breakers and voltage regulators.

DNP3 provides the rules for substation computers and master station computers to communicate data and control commands. DNP3 is a non-proprietary protocol that is available to anyone, see Figure (2.7).

The substation computer gathers data for transmission to the master such as:

- Binary input data that is useful to monitor two-state devices. For example, a
 circuit breaker is closed or tripped, or a pipeline pressure alarm shows normal
 or excessive.
- Analog input data that conveys voltages, currents, power, reservoir water levels and temperatures.
- Count input data that reports kilowatt hours of energy.
- · Files that contain configuration data.

The master station issues control commands that take the form of:

- · Close or trip a circuit breaker, raise or lower a gate, and open or close a valve.
- Analog output values to set a regulated pressure or set a desired voltage level.

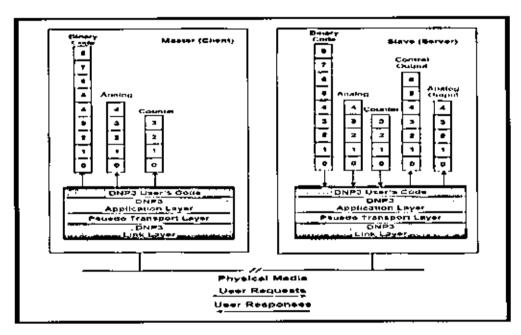


Figure (2.7): DNP3 Layers

2.4 Deploying SCADA Systems

There are many different ways in which SCADA systems can be implemented. Before a SCADA or any other system is rolled out, one needs to determine what function the system will perform. Depending on whether customers are a utility company or a telecommunications provider, you have a number of options in creating SCADA systems. There may be a need to employ different methods that are complimentary to each other. The way in which SCADA systems are connected can range from fiber optic cable to the use of satellite systems. The following sections will present some of the common ways in which SCADA systems are deployed. We will also look at their advantages and disadvantages.

2.4.1 Twisted-Pair Metallic Cable

Twisted-pair telecommunication cable is the most popular medium used by utilities and has existed in its present form for many years. The cables are essentially the same as those used by the telephone Companies and contain a number of pairs of conductor. Aerial cables would be more appropriate for installation in the utility's service area since the utility may own a large number of distribution poles from which the cables could be suspended. The smallest aerial cables can be self-supporting, whereas large aerial cables have to be attached to supporting wires (messengers) by lashing wire. Table (2.1) shows the Twisted-Pair Cable advantages and disadvantages.

Table (2.1) Twisted pair advantages and disadvantages

Advantages	Disadvantages	
No licensing, fewer approvals	• Right-of-way clearance required for	
Existing pole Infrastructure	buried cable	
• Economical for short distances	Subject to breakage and water ingress	
Relatively high channel capacity (up	Subject to ground potential rise due to	
to 1.54 MHz) for short distances	power faults and lightning	
	 Failures may be difficult to pinpoint 	
	Inflexible Network Configuration	

2.4.2 Coaxial Metallic Cable

Coaxial cable is constructed of a center copper conductor, polyvinyl chloride (PVC) insulation, a braided or extruded copper shield surrounding the center conductor and PVC insulation, and a plastic jacket cover. Coaxial cable can transmit high frequency signals up to several MHz with low attenuation compared to twisted pair wires used for telephone service. Methods of installation used for existing systems in Europe and USA are underground, direct buried, overhead, and on existing power line structures.

Services usually supported are voice, data, and interoffice trunking. Table(2.2) shows the Coaxial Cable advantages and disadvantages.

Table (2.2) Coaxial Cable advantages and disadvantages

Advantages	Disadvantages	
 No licensing, fewer approvals Existing pole Infrastructure Economical for short distances Higher channel capacity than Twisted pair More immune to radio Frequency noise interference than the twisted pair 	 Right-of-way clearance required for buried cable Subject to breakage and water ingress Subject to ground potential rise due to power faults and lightning Failures may be difficult to pinpoint Inflexible Network Configuration 	

2.4.3 Fiber Optic Cable

Fiber optic technology has improved considerably since its inception in 1970. The technology has improved to the point where commercially available fibers have losses less than 0.3 db/km. Losses of this magnitude, as well as the

development of suitable lasers and optical detectors, allow designers to consider fiber optic technologies for systems of 140 km or more without repeaters[5].

Optical fibers consist of an inner core and cladding of silica glass and a plastic jacket that physically protects the fiber.

Two types of fibers are usually considered: multi-mode graded index and single-mode step index fiber. Single-mode fiber supports higher signaling speeds than the multi-mode fiber due to its smaller diameter and mode of light propagation. Communication services usually supported by optical fiber include voice, data (low speed), SCADA, protective relaying, telemetering, video conferencing, high-speed data, and telephone switched tie trunks. Optical fiber cables have similar characteristics to twisted-pair communications cables in that aluminum tape or steel-wire armors and polyethylene outer jackets can protect them. However, the inner core is constructed to accommodate the mechanical characteristics of the fibers.

Typically, the fibers are placed loosely in semi-rigid tubes, which take the mechanical stress. Special types of fiber optic cables have been developed for the power industry. One type of fiber cable is the Optical Power Ground Wire (OPGW) that is an optical fiber core within the ground or shield wire suspended above transmission lines. Another type of optical fiber cable is the All-Dielectric Self-Supporting (ADSS) cable that is a long-span of all dielectric cables designed to be fastened to high voltage transmission line towers underneath the power conductors. A Wrapped Optical Cable (WOC) is also available that is usually wrapped around the phase conductor or existing ground/earth wire of the transmission or distribution line. In the Utility's case, aerial fiber optic cable can be fastened to the distribution poles under the power lines. Table (2.3) shows the Fiber Optic Cable advantages and disadvantages.

Table (2.3) Fiber Optic Cable advantages and disadvantages

Advantages	Disadvantages	
 No licensing requirement 	 Novel technology, i.e. new skills must be 	
Immune to electromagnetic	learned	
interference	Cable subject to breakage and water	
• Immune to ground potential rise	ingress	
 Low operating cost 	Expensive test equipment	
High channel capacity	Inflexible Network Configuration	

2.4.4- Power Line Carrier (PLC)

PLC was one of the first reliable communications media available to electric utilities for critical communications channels that could not be subjected to the intolerance and unreliability of leased (common carrier) telephone circuits. PLC uses the power transmission lines to transmit radio frequency signals in the range of 30 kHz to 500 kHz. The physical security of this communications is very high since the power line carrier equipment is located within the substations. PLC systems are used to provide voice, telemetry, SCADA, and relaying communications on portions of the 220/230 kV, 110/115 kV, or 66 kV interconnected power transmission network [5].

Digital PLC technology is a relatively new technology. Power lines and their associated networks are not designed for communications use. They are hostile environments that make the accurate propagation of communication signals difficult. Two of the biggest problems faced in using power lines for communications are excessive noise levels and cable attenuation. Noise levels are often excessive, and cable attenuation at the frequencies of interest is often very large. Digital PLC can be increased from one channel to three channels within the same RF bandwidth. Table 2.4 shows PLC advantages and disadvantages.

Table (2.4) PLC advantages and disadvantages.

Advantages	Disadvantages	
Located where the circuit are required	Not independent of the power distribution	
Equipment installed in utility owned	system	
land or structures	Carrier frequencies often not protected on a	
Economically attractive for low	primary basis	
number of channels extending over	Inherently few channels available	
long distances	Will not propagate through open	
Digital PLC has capacity for three to	disconnects	
four channels (e.g., two voice and one	Expensive on a per channel basis compared	
high speed data)	to microwave (normally, over four	
Analog PLC has capacity for two	channels)	
channels (one voice and one "speech		
plus" low speed data)		

2.4.5 Satellites

The use of satellites has been investigated for many years. The satellites are positioned in geo-stationary orbits above the earth's equator and thus offer continuous coverage over a particular area of the earth. Satellites contain a number of radio transponders which receive and retransmit frequencies to ground stations within its "footprint," or coverage, on the earth's surface. A network facility on the ground tracks and controls the satellite. Earth stations are comprised of an antenna pointing at the satellite, a radio transceiver with a low-noise amplifier, and baseband equipment. Satellites use both the C-band and the Ku-band. Very Small Aperture Terminal (VSAT) technology has advanced to the point where a much smaller antenna (down to about one meter) can be used for Ku-band communications. This has resulted in the Ku-band being preferred for sites with

modest communications requirements. VSAT technology is advancing steadily, and the capital costs have dropped substantially [5]. Continual time-of-use charges must be considered in the use of satellite communications. Development in this area should be investigated when making a decision on the use of this technology. Table (2.5) shows the Satellite system advantages and disadvantages.

Table (2,5) Satellite system advantages and disadvantages

Advantages	Disadvantages	
Wide area coverage	Total dependency on a remote facility	
Easy Access to remote sites	 Less control over transmission 	
Costs independent of distance	Transmission time delay	
• Low error rates	Reduced transmission during solar	
Adaptable to changing network	equinox	
patierns	Continual leasing costs	

2.4.6 Very High Frequency Radio (VHF)

VHF band extends from 30 to 300 MHz and is usually used by utilities for mobile radio, although point-to-point links have been implemented in this band. Advances in data transmission on mobile radios have been made, particularly for joint voice and data use, such as in taxi and police dispatching systems. Such systems could be used for maintenance vehicle dispatching. SCADA systems can use adapted VHF radios for communications; however a SCADA system would need exclusive use of the frequencies. Frequency assignments in this band are usually reserved for mobile services. Table (2.6) shows the VHF Radio advantages and disadvantages.

Table (2.6) VHF Radio advantages and disadvantages

Advantages	Disadvantages
 Frequency assignments available Propagation over non line of sight paths Low cost radios compared to microwave Less stringent waveguide and antenna requirements Not dependent on power lines and common carriers Greater field strength coverage patterns than UHF band 	 Low channel capacity Low digital data bit rate Limited transmission techniques available

2.4.7 Ultra High Frequency Radio (UHF)

UHF band extends from 300 to 3000 MHz. The bands typically considered for UHF radio are in the 400 MHz and 900 MHz range. Most of the suitable radio products for SCADA applications available in U.S. operate in the 900 MHz frequency range. In U.S., the Federal Communications Commission (FCC) regulates the use of radio frequencies and has designated the 928 to 952 MHz range specifically for use by utilities for data communication applications. These UHF systems can be Point-To-Point (PTP), Point-To-Multipoint (PTM), Trunked Mobile Radio, or spread spectrum systems. The PTM systems are also referred to as Multiple Address Radio Systems (MARS). Spread spectrum systems are the basis for many wireless applications including 802.11 a/b/g networks. These types of UHF systems are described in the following subsections.

A. Point-to-Point

Point-to-point communications is usually used for SCADA communications from a master station or dispatch center to individual substations. Radios used in the lower frequencies of the UHF band can be expected to have greater ranges, particularly for nonline-of-sight paths. Table (2.7) shows the Point-To-Point UHF radio system advantages and disadvantages.

Table (2.7) Point to Point UHF Radio system advantages and disadvantages

Advantages	Disadvantages		
Frequency assignments available	Low channel capacity		
Propagation over non line of sight	Low digital data bit rate		
paths	Limited transmission techniques available		
Low cost radios compared to			
microwave			
Less stringent waveguide and			
antenna requirements			

B. Multiple Address Radio Systems (MARS)

A MARS Radio System generally consists of one Master Station (usually Hot Standby, full duplex) transmitting over an omni directional, gain antenna in a 360 radiation pattern to fixed station remotes or slaves (usually non Standby, half duplex) that receive the signals via a directional, gain antenna. The 400/900 MHz MARS Radio is a single channel system that communicates with each of its remotes or slaves in sequence. Services usually supported by MARS are SCADA, Telemetry/Data Reporting, and voice (on a limited basis) [5].

The security of a MARS system is high between stations, but is vulnerable at terminal stations in regard to the antenna and the terminal RF transmission lines. If security is a potential problem, the RF transmission lines can be placed in conduit,

and the antennas can be ruggedized. The components of a MARS system have a long Mean Time between Failure (MTBF) and friendly user maintenance features. The MARS system is usually configured for data transmission at 300 to 9600 band, but can be used for voice transmission during radio system maintenance by locking the data signal out while voice is being transmitted. Table (2.8) shows MARS advantages and disadvantages.

Table (2.8) MARS advantages and disadvantages

Advantages	Disadvantages	
Frequency assignments available	Low channel capacity	
Lower cost than point to point media	 Low digital data bit rate 	
Propagation possible over non line of	 Limited transmission techniques 	
sight paths	available	
Low cost radios compared to	Multi-point operation restricts data speed	
microwave	compared to Point-to-Point UHF or	
Less stringent waveguide and antenna	dedicated paths between stations	
requirements		

C. Microwave Radio

Microwave radio is a term used to describe UHF radio systems operating at frequencies above 1 GHz, although multi-channel radio systems operating below 1 GHz are sometimes referred to as microwave systems. These systems have high channel capacities and data rates, and they are available in either analog or digital transmission technologies.

Analog transmission was the first microwave technology available. It is the most mature method of transmission. There have been a number of developments, which have affected the traditional balance between digital and analog technologies. On the analog side, direct-to-baseband analog channel units have been developed to ease the addition of channels to existing multiplexer equipment and to reduce the

complexity of modifying the channel plan. On the digital side, products such as digital cross-connects and direct first order hierarchical level access to Private Branch Exchange (PBXs) have reduced costs further and added flexibility. There is also a growing demand for circuits with very high data rates, which can be transported much easier on the digital systems. New protocols and standards are being introduced for utility data communications that are more easily accommodated by digital carrier systems. Therefore, even for light communication traffic routes, digital is judged to be the more appropriate technology for new installations. Services usually supported by microwave communications include voice, data (low speed and high speed), SCADA, compressed video, protective relaying, telemetering, frame relay, Broadband Integrated Services Digital Network (B-ISDN), and fractional T1.

In the lower part of the frequency range, microwave radios are designed in both point-to-point and point-to-multipoint configurations. Point-to-multipoint radios operate like a local area network with a number of shared channels, which are used on a demand basis. Point-to-multipoint radios can operate in several modes:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

TDMA and CDMA are more suitable for digital radios. Point-to-multipoint radios are more appropriate if network topology is in a star or tree configuration in which a number of terminal nodes have direct radio paths to a single central node and channel usage is not continuous. For linear configurations and continuous traffic, or bulk transmission over long distances, point-to-point radio is more appropriate. Table (2.9) shows the Microwave Radio advantages and disadvantages.

Table (2.9) Microwave Radio advantages and disadvantages

Advantages	Disadvantages
 High Channel Capacity Transport high data rates Independent from power lines and common carriers Future standardized high speed networks Low right-of way costs Simpler installation than cable technology 	 Line of sight clearance required Specialized test equipment and training required Frequency assignments sometimes unavailable in urban areas More expensive site development Limited capacity

CHAPTER III Basic Networking Concepts

3. Basic Networking Concepts

3.1. Classification of Switched Communication Networks

Switched communication system can be understood only in terms of their properties. These properties, when collectively considered, define what is known as the *network architecture* [2]. One can classify any switched communication network by the following attributes:

- Geographical coverage of the switched network.
- Method of accessing the switched network.
- Network topology.
- Transmission and multiplexing techniques employed to synthesize a switched network.
- Network management and control (NMC) techniques.

These techniques are involved with the way intelligence is distributed throughout the network and how it is employed to switch / route traffic, control congestion and manage day-to-day operations.

3.1.1- Geographical coverage

There are four types of networks, characterized by their geographical coverage:

- A. Local Area Networks (LANs): where about 60 percent of all networks fall into this category that span one or more building over a campus.
- B. Metropolitan Area Networks (MANs):where about 20 percent of all networks cover distances of about 80 km and fall into this category.
- C. Wide Area Networks (WANs): where about 15 percent of all networks fall into this category. WANs covering a distance of about 800 km account for 9 percent, and those covering longer distance account for 6 percent.

D. Global Area Networks (GANs): About 5 percent of all networks fall into this category, which is bound to grow due to the global nature of many corporations. These networks present a unique design challenge due to the presence of many national boundaries and public policies.

3.1.2- Method of Accessing

Each subscriber node must be designed to access the switched network for service. Similarly, each network node must be designed to offer the advertised services to any qualified subscriber. Basically, there are three distinct access methods:

- a. Demand Access: It's generally employed in most voice and data communication networks. According to this interrupt-based technique, the subscriber goes off-hook to demand service. The service node provides a dial tone immediately after discovering the off-hook condition. The dial tone is an invitation for a further dialogue that ultimately results in a switched path between the calling and the called subscribers.
- b. Polled Access: This is another popular method for allowing the computercontrolled switching node to interrogate each subscriber regarding the need for data interchange with another subscriber. The polled access method generally provides a very controlled environment, but only at the cost of a high overhead.
- c. Multiaccess: The multiaccess technique is primarily employed by data LANs. A large fraction of data LANs employ the carrier-sense-multiaccess (CSMA) technique whereby each node senses the carrier on the shared bus before sending the message or packet. Many newer LANs employ the token access whereby a node can only transmit when it grabs a free token. Collisions are therefore prevented altogether since the need for a token is analogous to the poll. A few WANs employ the ALOHA multiaccess technique whereby a

source node begins transmitting whenever it has a message or packet in its memory.

3.1.3 Network Topologies

Network topology defines not only the manner in which the network nodes are interconnected with one another but also the types of links employed to interconnect each pair of nodes. Generally, there is a hierarchy associated with the network nodes and/or links. One can classify the topologies that have proven useful for designing switched telecommunications networks as follows:

- Mesh topology based on either a fully connected or partially connected backbone network.
- Multidrop (MD) topology based on a minimal spanning tree(MST).
- Directed link topology based on directed graphs.
- Star topology based on either one star or many interconnected stars.
- Bus topology employing a bus shared by many stations.
- Ring topology employing a ring shared by many stations.
- Mixed topology.

Since most of the cost of a communication network is generally dictated by the cost of communication links, network topology must be optimized with great care for each application.

3.1.3.1 Mesh Topology

A fully connected mesh topology shown in Figure (3.1a), provides a direct link or path between every pair of network nodes of a given level of hierarchy. The mesh topology is economically feasible only when the number of switching nodes at a given network hierarchy is small.

A partially connected topology, Figure (3.1b), is recommended when the traffic flow between certain nodes is negligible and it can be switched on longer paths while resulting in a better economy of scale or better reliability.

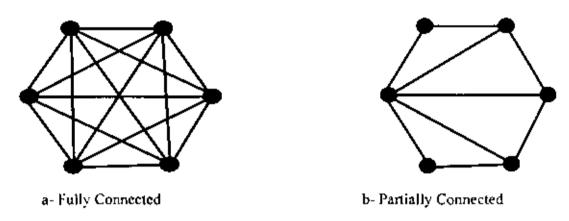


Figure 3.1 Mesh topology

3.1.3.2 MD Topology Based on MST

A MD topology based on MST is a subset of the generalized tree designed with the constraint that the sum of all link lengths in the network is minimal. Figure (3.2a) represents an MST topology. Assume that node 6 of Figure (3.2a) is a switching node. Using that information, one can create a four-level hierarchy of Figure (3.2b) according to the number of links between any pair of nodes.

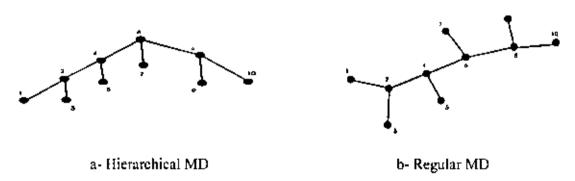


Figure (3.2) Multidrop (MD) topology.

3.1.3.3 Directed Link (DL) Topology

Figure (3.3) is an illustration of four netlinks, each based on the directed link topology.

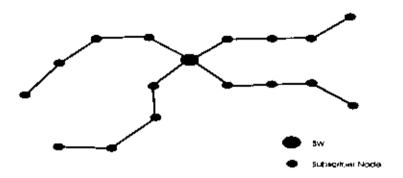


Figure (3.3) Directed link topology with four netlinks.

3.1.3.4 Star Topology

A network consisting of a single switching node and directly connected subscribers can be represented by a star topology Figure (3.4). For that case, each subscriber is connected to the switching node directly through a subscriber or user line.

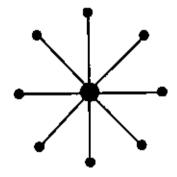


Figure (3.4) Star topology

3.1.3.5 Bus Topology

The bus topology employs a fully shared broadcast transmission facility, called a bus, for exchanging information between nodes. Such a topology as

shown in Figure (3.5) is generally the basis for a high-speed, distributed system used for interchange of information between computers and computer-controlled devices located within a building or a campus.

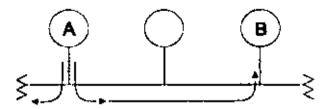


Figure (3.5) Bus Topology

The bus topology is commonly used for synthesizing high-speed LANs.

3.1.3.6 Ring Topology

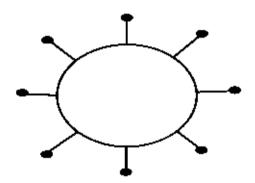


Figure (3.6) Ring topology

When the two ends of a shared transmission media of bus topology are closed to form loop, a ring topology results Figure (3.6). Whereas Figure (3.6) represents broadcast type ring topology, many popular data LAN architectures employ the ring topology using the token access.

3.1.3.7 Mixed Topologies

Many mixed topologies can be derived from the previously mentioned basic topologies through the process of superposition or interconnection. For example, the multicenter multistar topology of Figure (3.7) consists of the star and

mesh topologies. Similarly, the multicenter multidrop topology of Figure 3.8 consists of the mesh and the MST/MD topologies. This mixed topology is the basis for many SNA-based data communication networks. Such a mixed topology is finding some applications in the design of a Personal Communication System (PCS) within a metropolitan area.

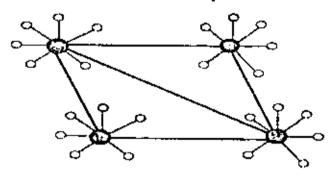


Figure 3.7 Multicenter, multistar topology.

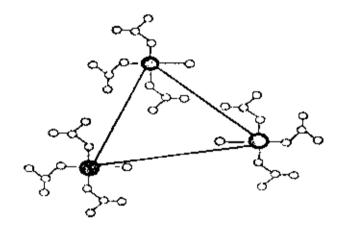


Figure 3.8 Multicenter, MD topology

3.1.4 Transmission and Multiplexing Techniques

Transmission and multiplexing techniques define the modulation, encoding, transmission/reception, and multiplexing techniques employed to synthesize links for interconnecting the various network nodes. Knowledge of the transmission and multiplexing techniques is essential. Whereas, the transmission techniques usually involve the method of encoding each basic

symbol prior to transmission over the channel, the multiplexing technique defines the way multiple streams of user and control data can be combined together to share a single physical link.

3.1.4.1 Transmission Techniques

Discrete information can be transmitted in the form of either analog or digital signals.

A. Analog Transmission Techniques

An analog signal is realized by multiplying a continuous modulating function (usually the information) with a high-frequency carrier waveform centered at f_c .

B. Digital Transmission Techniques

A digital signal is simply a base-band signal in the form of a digital pulse train that represents a coded version of the original information. Pulse code modulation (PCM) and delta modulation (DM) are two popular techniques for producing digitized voice signals. The telephone industry standard throughout the world is a PCM system with 256 quantization levels that requires a PCM bit rate of 2×4000×8=64000 bps. A new technique called the adaptive differential PCM (ADPCM) is being introduced that requires a PCM bit rate of only 32000bps. It is based on the fact that a highly correlated signal (e.g., voice) changes slowly from one Nyquist sample to another and therefore it sends only the difference. Delta modulation (DM) is another form of the sample data technique. DM requires very little hardware complexity when compared to the PCM technology. Some DM-based systems are based on the continuously variable slope DM (CVSDM) concept that is generally superior to the older DM and compares favorably with the PCM technique.

3.1.4.2 Multiplexing Techniques

Most transmission links employ some form of multiplexing of individual user and control channels for utilizing the inherent structure or bandwidth of the physical link and hence reducing the cost of per-channel transmission. Special multiplexing techniques are used for both the analog and digital transmission systems.

A Multiplexing Techniques for Analog Transmission

The first multiplexing technique employed for analog transmission was called the space division multiplexing (SDM) that implies the bundling of individual voice grade channels in a physical/spatial manner. This method allows the sharing of the common conduit and hence the cost of cable laying. Frequency Division Multiplexing (FDM) combines the spectrums of individual channels to form a large spectrum if allowed by the physical link. It requires the use of guard bands at the transmitter to separate the individual channels and the use of filters to separate the individual channels at the receiver.

B Multiplexing Techniques for Digital Transmission

Time division multiplexing (TDM) is the most popular technique for combining several digital channels into a single channel. PCM-TDM is the most popular technique for combining 24 PCM channels to create a Tl carrier rated at 1.544Mbps.

3.1.5 Network Management and Control (NMC) Techniques

Network Management and Control (NMC) technique are involved with the switching technology, traffic flow control, and methods of distributing and controlling intelligence in the network for day-to-day operation. Switching

technology employed by the network determines the manner in which the network components or facilities are shared among the subscribers.

Basic functions of NMC can be classified into four distinct categories:

- Routing of network traffic
- Database related services
- Maintenance and repair management
- Network operation services
 The following section describes each of these NMC functions in a little more detail [2, 3].

3.1.5.1 Routing of Network Traffic

Allowing the traffic to flow on alternate routes results in a better use of network facilities and a better performance to subscribers. Three methods of traffic routing are generally employed by a system with alternate routing capabilities.

- a. Deterministic Method: This is the simplest routing control involving the use of fixed primary (also called the high usage or HU) routes and a fixed number of alternate (also called the final) routes.
- b. Synoptic Method: The network management center (NMC) samples the traffic flows in the entire network frequently and, based on the information collected, it decides which path the next call or message will follow. Sometimes, routing tables are dependent upon the time of day.
- c. Adaptive Method: Each network node gathers sufficient information from the neighboring nodes on a periodic basis and decides how calls or messages are to be dynamically routed toward their destination.

3.1.5.2- Database Related Services

A properly designed NMC system must maintain a relational database that provides the following essential capabilities:

- Network directory service
- Network component inventory
- Traffic/performance statistics gathering.
- Billing

3.1.5.3 Maintenance and Repair Management Services

A properly designed NMC system should provide the following capabilities required to maintain an almost fault-free system:

- Collection of system alarms
- Converting the system alarms into trouble tickets and sending these to qualified persons
- Scheduling diagnostics and repairs
- Predicting impending failures and taking evasive actions (self-healing)

3.1.5.4 Network Operations Services

A properly designed NMC system should provide the following functions to help the corporation run a smooth operation:

- A. Scheduling training classes for the NMC-related personnel
- B. Staffing of the NMC personnel

C. Ordering new network components or retiring other components for the purpose of maintaining an optimum network design on an ongoing basis.

3.2 Traffic Engineering Techniques

Networks, whether voice or data, are designed around many different variables. Two of the most important factors that you need to consider in network design are service and cost. Service is essential for maintaining customer satisfaction. Cost is always a factor in maintaining profitability. One way that you can factor in some of the service and cost elements in network design is to optimize circuit utilization. The following points describe the different techniques you can use to engineer and properly size traffic-sensitive voice networks.

3.2.1 Basic Traffic Attributes

A network system exists primarily to provide useful services to a set of subscribers. These services involve many forms of information exchange between network service nodes and subscriber nodes. Several traffic attributes characterize such services [2]. These attributes and the underlying concepts are enumerated as follows:

- The Expected Call Duration (ECD) is defined by the duration of a single voice session. Some analysts substitute call-holding time for ECD. A message length is generally determined by the number of bits or characters in the message. Some analysts simply use the letters ECD for the expected call-holding time.
- One can also define the Expected Message Duration (EMD) as the message length divided by the link capacity denoted in terms of bits or characters per second.

- Call or Message Arrival Rate (K) defines the rate at which the calls or messages are presented to a network resource/server/system. The rate at which the calls or messages are successfully served is generally defined as the system throughput.
- The concept of *Traffic Intensity* is generally employed to derive short-term statistical utilization of network resources. Traffic intensity is also employed for computing the number of servers such as access links (ALs) and trunks (TKs), which are required to provide a desired performance level.
- Offered Traffic Intensity (A) is generally defined as the product of arrival rate, K and the expected call duration (ECD) for voice networks, or A = K × ECD Erlangs.

Traffic intensity for voice networks is measured in terms of Erlangs. The average utilization (ρ) of an AL or TK server in a voice network can be computed as the ratio of Erlangs carried by the AL/TK bundle and number of servers in the AL/TK bundle. Erlangs carried is defined as a product A (I-B) where B is the fraction of calls blocked by the server group.

Traffic intensity in data networks is generally measured in bits per second to account for the bursty nature of data traffic. One can compute its value as a product of K and EMD [= (packets per second)×(bits per packet)].

One can compute the short-term utilization (ρ) of a data trunk bundle by dividing the data traffic intensity (bps) by the total capacity of a data trunk bundle. In this case, if p is close to or larger than one, one must add ALs or trunks in order to reduce the average server utilization (ρ) below 1.0. Many experienced designers generally try to maintain the value p at about 0.667 ($\pm 2/3$) to achieve a tolerable range of system response times.

The value $N \times \rho$ can be defined as data Erlangs only if some care is employed in defining data network server utilization.

• Traffic Flow is a measure of the traffic intensity on any directed path consisting of an ordered sequence of network nodes and links. A sequence of two nodes in a path implies a single circuit bundle connecting the two nodes. A sequence of N nodes in a virtual connection implies a directed path of (N-I) intervening links, each consisting of one or more physical circuits. Most well-designed network systems provide some traffic flow control to prevent congestion that may result in system failures and performance degradation. There are many ways to achieve flow control. Access limiting and dynamic routing of traffic are two of the most popular methods.

3.2.2 Defining Time Consistent Averages (TCAs) of Traffic Intensities

Traffic plays an important factor in the network design process. The basic units of traffic intensity (TI) such as Erlang have been defined previously. If a network system already exists, one can measure the busy hour traffic intensity for each network link by reading the output of specially installed meters or commonly available call recording (e.g., Station Message Data Recording or Automated Message Recording) tapes and then deriving the system grade-of-service (GOS) in any desired form. In case the GOS is better or worse than that which is required, one may achieve cost effectiveness through better network dimensioning. If one has the resources, one may achieve additional cost effectiveness through a new optimum network design based on end-to-end traffic flows.

3.2.3 Estimating Traffic Intensities for AL Bundles in a New Network

To compute the total traffic, Tj handled by the ith AL bundle (that connects one CPE to one of the available switches. If it is a voice LAN in the form of a PABX, then the total traffic handled by the particular AL bundle is equal to 0.1 ×No. of Voice Lines served by the PABX. If it is a data LAN, the total traffic handled by the particular AL bundle is equal to BHR data rate handled by the LAN-Associated Server for wide area application.

If a CPE is a small office with a few voice lines and two or three workstations that communicate with the company host, the traffic intensity can be easily computed for voice or data or for multimedia application for dimensioning the AL bundle. The network design tool must be capable of computing the economic viability of either a leased AL or a virtual service for this small office.

3.2.4 Estimating Traffic Intensities for Trunks in a New Network

Since the exact traffic flows in a new network are not known to exactly compute the traffic on each trunk bundle, one can estimate the traffic intensities on trunk bundles by using an assumption that traffic from each source is uniformly distributed to all destinations as a function of their loadings. A symmetric traffic matrix can be defined for a backbone network if the following steps are executed:

Step 1. Compute the total traffic (TTi) handled by the ith switch node = $\sum T_k$ = sum of traffic handled by all AL bundle ($k=1, 2,...,N_{Ali}$ where N_{Ali} is equal to the number of AL bundles served the ith switch).

Step 2. Compute the grand total (GT) of all the traffic handled by all the switches, where $GT=\sum TTi$, $i=1,2,\ldots,All$ switches

Step 3. Compute the traffic (Tij) flowing on the trunk from the ith switch to the jth switch as follows:

$$Tij = [TTi \times TTj] / GT \qquad (3.1)$$

$$= Tji$$

(for a symmetric traffic matrix)

If the value *i* equals *j*, one obtains the value of intranodal traffic. The intranodal traffic implies that the source and the destination are terminated on the same backbone switch of the network node. As a result, this traffic does not influence the sizing of any trunk bundle. After computing the internodal traffic intensities for each direction of flow, the designer should then apply the most appropriate traffic analysis formula to determine the size of each trunk bundle and its length in Kilometers.

3.3 Concepts of System Performance

Performance of a network system generally deals with costs, throughputs, quality-of-service, and grade-of-service. These are described in the subsections that follow.

3.3.1 System Costs

This criterion is probably the most critical performance parameter since it determines the cost of service provided to the users. The cost of a call made on the public telephone network is a prime example of a system cost. Most system designers talk of system throughput in terms of the telephone call handling capacity as an example. Costs of a system should be divided into major components such as transmission, NMC, and hardware.

Experience shows that the transmission costs are generally the predominant part of the total cost. For most private networks, the costs related to transmission may constitute as much as 70 percent. The costs incurred on a WAN management, operations and control may be 20 percent of the total costs. The costs of NMC are also natural for a monthly exhibit. It is also easy to spread the costs of hardware for the entire life cycle of the system while considering the costs of money (e.g., interest, depreciation) and obtain an equivalent monthly cost [2].

3.3.2 System Throughput

System throughput measures the overall capability of the system in terms of the maximum number of transactions that can be handled per unit of time. The throughput of a circuit switched system is represented by the maximum number of call attempts and calls handled per average second of a busy hour by each network node and by the entire network system.

The throughput of the entire system is also determined by the maximum number of calls that can be handled concurrently during the busy hour. The latter value is affected by the call duration and the number of nodes in the call path.

The throughput of a packet switched system is represented by the number of input packets or messages that can be handled per average second of a busy hour.

Some vendors represent the throughput of their packet switch node by the maximum bit rate (input rate plus the output rate) handled during a second. Another useful measure of system throughput should be the maximum number of packets or messages handled by the entire network during a second or busy hour.

3.3.3 Quality of Service (QOS)

QOS deals with performance issues such as the transmission quality, voice quality at the receiver, length of error-free periods, average bit-error-rate (BER), system reliability as determined by such measures as mean-time-between-failures (MTBFs) for each node and link and mean-time-between-system-failures (MTBSFs), and system connectivity (a measure of capability to provide service to all subscribers during component failures).

3.3.4 Grade-of-Service (GOS)

Grade-of-Service criteria deal with the degradation in service caused by contention for critical resources when all those resources are functioning. GOS for a circuit switched system deals with the statistical distributions of the following design parameters:

- a. System response time: The clapsed time measured from the moment a user goes off-hook and the moment the user hears a dial tone.
- b. Call connection tim: The clapsed time measured between the moments the last digit is dialed and the connection is made between the calling and the called subscriber.
- e. Call set-up time: The sum of the two previous quantities and the time to dial all the digits.

GOS of a Circuit Switching (CS) system is also determined by the probability of a call loss or blockage caused by the unavailability of a path through the network during the busy hour.

GOS of a CS system can only be computed by taking into account the actual network topology and the blocking probability experienced by each network node-link bundle pair.

GOS for a packet switched system deals with the statistical distributions associated with the following design parameters:

- i. Nodal response time: The clapsed time measured from the moment the last byte of the packet is received by the node and the moment the first byte of the same packet is transmitted.
- ii. Call/session set-up time: The clapsed time between the moment the last bit or byte of the call set-up packet is transmitted and the moment the first byte of the acknowledgment packet is received by the packet mode terminal.

GOS for a message switched system deals with the statistical distributions associated with the following design parameters:

- i. Nodal response time: The elapsed time measured from the moment the last byte of the message is received by the node and the moment the first byte of the same message is transmitted by the node.
- ii. Message retention time provided by the system: The elapsed time measured from the moment the last byte of the message is received by a network node and the moment the system puts the message into a storage media requiring manual handling.

3.3.5 System Reliability

Reliability is an important factor for telecommunication networks, so reliability design is an important factor in constructing highly reliable telecommunication networks at reasonable cost. There are many occasions when it is necessary to compute the reliability of a nodal subsystem or the entire network system. In order to achieve that goal, we must define several quantities, since reliability can be expressed in several ways.

More details are given in appendix A.

System availability is defined as the percentage of time the system is available for its assigned mission.

CHAPTER IV

Input Data of the Case Under Study

4. Input Data of the Case Under Study

4.1 Area of study

The area to be covered by communication system is known as the sirte central area and covers an area of land adjacent to the sirte coast of Libya. The land area is approximately 25 km from East to West and 5 km from North to South. The main Phase 1 section of the Great Man-Made River (GMRA) pipeline conveyance runs from East to West through the area as in Figure (4.1) and Figures(C1,C2) in appendix C. Grand Al Gardabiya reservoir is fed from a conveyance turnout at the Eastern end and Al Gardabiya reservoir is fed from a conveyance turnout at the Western end.

At each reservoir there are pump stations which feed both ends of the Large and Small Farm system. The irrigation system to the Large Farm area occupies the area of land to the south of the coastal highway. The Large Farms consists of in excess of 100 circular fields, some of which are 1 km in diameter.

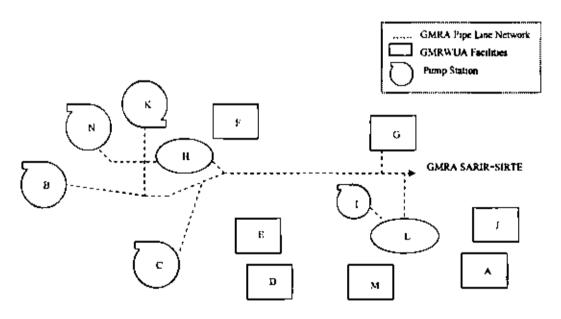


Figure (4.1) Zone facilities

The irrigation system to the small farms occupies the area of land to the North of the Coastal Highway. Additionally at Al Gardabiya there is a second pump station which feeds three irrigation systems in the Western Wadis area.

The area will be supervised from the GMRWUA Operation, Service and Maintenance (OS&M) facility located adjacent to Grand Al Gardabiya reservoir. The OS&M will house a Regional Control Centre (RCC) from where all control and communication will be supervised. The Large Farms area will be divided into three areas, (Farms A, B, and C). Each farm will have a central utility/ warehouse unit. The RCC will communicate with the Phase 3 Al Gardabiya pump station and the GMRA OS&M facility both of which are located in the vicinity of Al Gardabiya reservoir.

4.2 Node functions and description.

4.2.1 Description of facilities

A brief description of all nodes is given below; in addition Table (4.1) gives a summary information about nodes.

- Node A: GAG OS&M
 This node is the headquarter of the system as it contains RTU.
- Node B: Phase 3 Pump Station
 Includes a set of pumps used to fed GMRA phase two(at Sidada region) from phase one (at Sirte region) by a 200 kilometer pipe line.
- Node C: Future Turnout Sirte Town
 it will be connected to Pump Station to an agriculture project called aldhir, and
 a research farm.
- Node D: Farm unit A
 It contains a maintenance building to maintain the irrigation machines
- Node E: GMRA Sirte OS&M

It's an operating and maintenance system for algardabia reservoir and its network distribution.

- Node F: Dairy Complex
 - It's a dairy station consists of cow barn and laboratory to produce milk and its ingredients.
- Node G: Farm unit B
 Building contains warehouse and workshop to maintain pumps and irrigation machines.
- Node H: GAG Reservoir Turnout
 Contains this node a flow meter and valve control chamber to control the reservoir outlet.
- Node I: Grand Al Gardabiya Pump Station (GAGPS)

It consist of two independent sets of pumps within the pump station building. The pumps are centrifugal type driven by variable speed electric motors. Six pumps are provided for each set (Small Farm and Large Farms), four duty pumps, two standby pumps. Flow rate per pump to Small Farms will be 234 l/s while flow rate per pump to Large Farms will be 1280 l/s.

- Node J: Guard House

 Reservoir gate that contains drainage out control panels
- Node K: Al Gardabiya Pump Station (AGPS)

It consists of two independent sets of pumps within pump station building. The pumps are centrifugal type driven by variable speed electric motors. Six pumps are provided for each set (Small Farm and Large Farms), four duty pumps, two standby pumps. Flow rate per pump to Small Farms will be 210 l/s. Flow rate per pump to Large Farms will be 716 l/s. If Al Gardabiya reservoir is out of service, the pump station can be fed from the phase 3 Forebay tank through the Al Gardabiya reservoir bypass line.

Table (4.1) Information about nodes [10]

Nade Symbol	Description	Level (m)	Coordinates (m)	Type of service
Α .	GAG QS&M	38	X= 0.0 Y= 0.0	Scada+Voice+ Data+Video
В	Phase 3 P.S	43	X = 15833.02 Y = 1239.51	Data + Voice
С	Future Turnout(Sirte Town)	42	X= 13080.45 Y= 2458.53	Data + Voice Scada
D	Farm unit A	52	X= 14692.87 Y= 1243.77	Data + Voice
E	GMRA Sirte OS&M	45	X= 13335.73 Y= 2004.83	Data + Voice Scada
F1	Dairy Complex	37	X= 12310.55 Y= 3046.98	Data + Voice
G	Farm unit B	27	X= 2761.19 Y= 3241.1	Data + Voice
H	GAG Reservoir Turnout	38	X= 718.13 Y= 617.69	Scada+Voice+ Data+Video
ī	GAG P.S.	34.25	X= 553.43 Y= 718.81	Scada+Voice+ Data+Video
j	Guard House	36	X=358.72 Y= 724.09	Data + Voice
К	AG P.S	37.8	X= 15886.09 Y= 1946.49	Scada+Voice+ Data+Video
1.	GAG Reservoir Inlet	38	X= 695.16 Y= 703.99	Scada +Data + Voice
М	Farm Unit C	54	X=5539.51 Y= 495.60	Data + Voice+ Scada
N	W.W.F.S	37	X= 15885.10 Y= 2049.52	Scada+Voice+ Data+Video

- Node L: GAG Reservoir Inlet

It consists of flow meter and valve control chamber to control the reservoir injet.

- Node M: Farm Unit C

Area included project or owner accommodations and project management offices and headquarters of irrigation machines system.

- Node N: Western Wadis Pump Station (WWPS)

WWPS consists of three independent sets of pumps within pump station building. The Pump Station transfers water from Al Gardabiya Reservoir to a number of tanks supplying agricultural development projects in the Wadis to the west of Sirt. The water from WWPS is delivered through 3 separate pipelines to Wadi Jarif /Tamit tanks, Wadi Tilal South tank, Wadi Tilal North / Wadi Qubaybah tanks respectively. It is understood that flow rate per pump to Wadi Jarif/Tamit tanks is 590 l/s, 2 duty (2 standby) in series. The flow rate per pump to Wadi Tilal South tank is 169 l/s, 2 pumps are duty in series and one is standby.

4.2.2 Facilities Functions

Table (4.2) represents the function of each node

Table (4.2) Function of Nodes

Node	Function
A	Head Quarter to monitor the overall system
В	Information for monitoring (e.g. flow, speed, pressure and so on)
C	Information for monitoring
D	Workshop, to maintain and repair irrigation machines.
E	To keep the flow of water in the main pipeline stable.
F	A factory that produces a milk
G	Workshop
H	To fed the environment places by water
	Pumping the water to the large and small farms
1	Valve chamber control room
ĸ	Pumping the water to the large and small farms
L	Valve and flow meter chamber to fed the reservoir by water
M	Maintenance and storage building
N	Pumping the water to the Western Wadis

4.2.3 Type of Services

Table (4.3) shows the service requirements for each node.

Table (4.3) Services supported of nodes.

Nodes		SERVICES							
Α	Voice	internet	Fax	SCADA	Video				
В	Voice	Internet	Fax	SCADA					
С	Voice	Internet	Fax	SCADA					
D	Voice	Internet	Fax	1	· · · · · · · · · · · · · · · · · · ·				
E,	Voice	Internet	Fax	SCADA					
F	Voice	Internet	Fax						
G	Voice	Internet	Fax						
H	Voice	Internet	Fax	SCADA					
I	Voice	Internet	Fax	SCADA	Video				
<u>l</u>	Voice	Internet	Fax (
K	Voice	Internet	Fax	SCADA	Video				
ſ,	Voice	Internet	Fax	SCADA					
M	Voice	Internet	Fax	SCADA	Video				
N	Voice	Internet	Fax	SCADA					

4.3 Volume of data in each node

4.3.1 Uni or bi-direction flow

A. In control application case (nodes acts as RTU or MTU for SCADA system)

There are 14 nodes in the enterprise that have relationship with each other, where these relations reflected or translated from project philosophy of operation [5], these relationships determine the connectivity or topology of these nodes, as in Table (4.4). There are four types of SCADA parameters that will be collected at RTU nodes, these parameters are:-

- Digital Input
- Digital Output
- Analog Input
- Analog Output

Table (4.4)- Inter-Node Traffic Flow (Control), i.e. the relationship between nodes.

Table	A	В	C	D	E	F	G	H	1	ŢĴ	Ţ κ 1	L	М	N
From	<u> </u>		<u> </u>			<u> </u>		<u> </u>		<u> </u>	ļ		<u></u>	
^	0	×	×		×			×	×		×	×	×_	×
В	l _	0			<u> × </u>			×	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
c	×		0	<u> </u>				<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	ļ	<u> </u>
D]	0				1	<u> </u>	<u> </u>	<u> </u>	<u> </u>	↓	
Е	×	¥ _]		0		<u> </u>	×	<u> </u>	<u> </u>			<u> </u>	<u>*</u>
F	Ţ <u> </u>	ж				0					<u> </u>		<u> </u>	<u> </u>
G	i			Γ	1	Ì	0			1	<u> </u>		×	
Н	×	×	Π		×			0		×			<u> </u>	
	×							×	0	×		×	×	
1	1	×	1	<u> </u>	×				×	0	7	i _		
К	<u>-</u> .	T		T _	1					×	0		×	
L	×	1	1	1				Ţ <u></u>		Ж	×	0		
М	×	1	\top	 	_			1	×	1	×		0	
N	×	×	1	1	<u> </u>			7	1	1	×			Ö

x - There are relation between nodes, 0- No relation

B. In general application case.

There are another applications (voice, data, video, fax) which is required in enterprise network, so the node requirements of these applications is shown in Table (4.5).

Table (4.5)- Inter-Node Traffic Flow (Data and Voice)

To	A	В	C	D	Е	F	G	Н	ı	1	ĸ	L	М	И
From	6	╁╌┈	 	 	+-	╅	 	1.	╁ <u>-</u>	+	+-	1.	 	 _
В	- x	0	1	1 ×	i.	╅	 _ _	1,	1	┪ ╸	- x	1.	1.	 -
С	<u> </u>	<u> </u>	Ö	T R	×	×	,	×	r	-	×	×	-	7
D	×	┪-	<u> </u>	0	×	7	я	r r	1	и		<u></u>	*	×
Е	Ţ	ĸ	 	7	0	и	ı ı	ĸ	*	<u></u>	×	¥	Я	ж
F		×	×	¥		0	ļ -	× _	и	ĸ	×	×	ĸ	ľ
G	-		7	<u> </u>	×	ĸ	0	7	-	-		и	н	×
11	l a	1.	١,	7	<u> </u>	_ k	•	10	-	<u> </u>	j =		۱.	l K
	1 -	1	r	×	-	F		ж	0	7	F			-
<u></u>	×	-	к	Ţ.ĸ	-	u	<u> </u>	×	ĸ	0	į ×	ĸ	ĸ	ж
К	×	*	ĸ			×	ы	ж	, F	7	0	×	<u> </u>	ж
L	ļ,	r	-	,	, ,	[×		<u></u>	я	0_	×	<u> " </u>
М	ĸ	¥	×	<u> </u>	ĸ	-	ĸ	*	ĸ		×	×	0	
N	K	1.	, ,	,	\ <u>\</u>	r	1.		7	F	- K	и	,	0

So these relations will be reflected to values to calculate the traffic flow between each pair of nodes, where that relation reflected to values, as in Table (4.6) by using 5 points scale, and assign a number as shown to the degree of relation.

Table (4.6) Possible Traffic flow scores assumption

Number	ī	3	5
Degree	low	medium	high

By translating the relations that are found into Tables (4.4 and 4.5) we get relation level using Table (4.6) as given in Table (4.7).

Table (4.7)- Inter-Node Traffic Flow Scores

				ame	· · · / ·	*****	1 - 1 1 0 1	**	110		70100			
То	A	В	C	D	E	۲	G	H	1 "	J	K	1,	М	N
From)										<u> </u>	<u> </u>		
Λ	0	5	5	3	5	3	3	5 _	5	3	5	5	5	5
В	3	0	3	3	5	3	3	5 _	3	. 3	3	3	3	3
C	5	3	0	3	3	3	3	3	3	3	3	3	3	3
t)	3	3_	3	0	3	1	3	3	3	3	3	3	3	3
H,	5	5	3	3	0	3	3	5	3	3	3	3	3	5 _
F	3	5	3	3	3	1)	3	3	3	3	3	3	3	3 .
G	, 3	3	3	3	3	3	0	3	3	3	3	3	5	3
11	5	5	3	3	5	3	3	0	3	5	3	3	3	3
	5	3	3	3	3	3	3	5	0	5	3	5	5	3
1	3	5	3	3	5	3	3	3	5	Ō	3	3 _	3	3
- к	5	3	3	3	3	3	3	3	5	5	0	3_	5	3
 	5	3	3	3	3	3	3	3	3	5	5	0	3	3
М	5	3	3	3	3	1	3	3	5	3	5	3	0	3
N N	5_	5	3	3	3	3	3	3	3	3	5	3	3	0

4.3.2 Node Traffic Requirements

According to enterprise facilities which is about 14 sites, an important need for each node (site) is to determine traffic demand. Considering all such nodes in the network, we can estimate the traffic volume between any two such nodes that form a traffic volume matrix or demand volume matrix. So the assumptions mode to estimate the demand of sites are as follows:

- a. Bases of calculating no. of required telephone lines per site:
 - Function of the site.
 - Size of the site in no. of offices.
 - Future needs to be as a spare capacity.

- b. Bases of calculating number of the required Fax lines per site:
 - Need of a dedicated Fax per site.
- c. Bases of estimating Internet (data) demand per each site:
 - Need to exchange data between sites.
 - Need to access Web sites of internet.
 - Common practice in each site of defined data.
- d. Bases of estimating Video demand per site:
 - Function of the site.
- e. Bases of estimating SCADA demand per each site:
 - Function of the site.
 - Size of field level instrumentation and control devices.

Table (4.8) illustrates the requirements of nodes that depend on the previous assumptions. SCADA parameters are collected at each node by site survey and recorded as in appendix D.

Table (4.8) Node Requirements

		No. of		<u></u>	1		SCA	DA		
Nodes	No. of users	No. of servers	Fax	Video	Analog		Digital		To	tal
					I/P	O/P	T/P	O/P	T/P	O/P
, A	103	60	Yes	Yes	201	72	300	284	501	356
В	5	2	Yes		<u> </u>			·	·)	<u> </u>
С	5	l	Yes		11	32	40	10	51	42
D	5	2	Yes		<u> </u>			<u>.</u>		<u> </u>
E	5	2	Yes		11		52	27	63	27
F	10	4	Yes	i			_		-	
G	5	2	Yes		-	<u> </u>	-	<u> - </u>	<u> </u>	-
[1]	5	2	Yes		60	10	55	43	115	53
<u>1</u>	20	4	Yes	Yes _	83	12	569	51	652	63
J	5	Ī	Yes		· ·	-	-	<u>. </u>		<u> </u>
K	20	3	Yes	Yes	77	12	418	45	495	57_
1.	5	1	Yes		26	6	126	34	152	40
M	30	10	Yes	Yes	150	<u>-</u>	200		350	
N	10	3	Yes		33	- <u>-</u>	266	74	299	74

61

This table reflects site or node requirements, since column one shows node names and in the next column appears some numbers that are coming from node description as given in Table (C.2)

4.4 Transmission media characteristics

The main issue and most critical part in the network design is the backbone links, which carry the main traffic between the nodes. Problems on this backbone will affect severely the performance of the network. The selection of an appropriate transmission media between different nodes is not an easy process. The network designers are always confronted with different attractive alternatives. The selection process depends on a set of parameters some of them depend on technology and media characteristics, and the others depend on the sites and the physical route and terrain between them. Table (4.9) gives evaluation parameters and their assigned numerical value according to 10 points scale.

4.4.1-Evaluation parameters that depend on the actual physical links

a. Cost

The cost is varied with distance and capacity of the link, e.g. MW links can provide an excellent choice of an alternative access to long distance networks, where the right of way for an underground fiber links is unavailable or too expensive, as the digging and civil work are the dominant in the fiber links cost.

b. Operation and Maintenance Requirements

O&M mainly depend upon test equipment requirement, flexibility of elements maintenance, degree of service continuity while maintaining, quality of service and MTTR.

Table (4.9) Possible Evaluation Scores [8]

Evaluation parameters\score	9	7	5	3	1
Cost	low	Below average	average	High	Very high
Operation & maintenance requirement	simple	Below moderate	moderate	High	Very high
Spectrum availability	Very high	High	аустаде	Below average	Low
Implementation Requirement	Simple	Below moderate	moderate	High	Very high
Terrain characteristic	Simple	Below moderate	moderate	difficult	Very difficult
Interference & environment effect	Low	Below average	average	high	Very high
Execution time	Very short	Short	medium	long	Very long
Availability of equipment	Very high	· High ·	average	Below average	Low
Capacity &up grading flexibility	Very high	High	ачетаде	Below average	I.ow
Interfacability Requirements	Simple	Below moderate	moderate	Involved	Very involved
Reconfiguration flexibility	Simple	Below moderate	moderate	High	Very high
Design& link engineering requirement	Simple	Below moderate	moderate	High	Very high
Technology life time	Very long	long	moderate	Short	Very short
State of the art technology	Very advanced	Advanced	Partially advanced	medium	Below medium
Security of information	Very high	High	average	Below average	Low

c. Spectrum Availability

Unavailability of spectrum can limit the number of alternatives on selecting the transmission media or eliminate the capacity upgrading. Also the licenses in some transmission media are required for using spectrum.

d. Implementation requirements

The implementation requirements such as tools requirements which can be very costly and administration process such as premises, transportation, accommodations right of way.

e. Terrain characteristic

Some transmission media can not be implemented due to terrain difficulty, where laying fiber optic cable may need long time delay and cost is more than expected.

f. Interference and Environment effect

The fiber optic has very high immunity against electromagnetic wave interference and less affected by temperature changes, while microwave transmission is not.

g. Execution time

For some situations where the execution time is a main factor, satellite earth station e.g. (VSAT) can be installed within a day or two while MW link may require much more time for installation.

4.4.2 Evaluation parameters depending on technology and media characteristics

a. Availability of equipment

The availability of the equipment on the market, spare parts and operation equipments and spare stock are very important. Also software upgrading can affect the availability of the older software versions equipments.

b. Capacity and upgrading equipments

For certain distance and capacity some transmission media can not be used or become un practical such as pair gain for long distance, and capacity greater than 8Mbps, on other hand capacity upgrading may not be possible in some situations due to requirements of new equipments for new operating band or due to transmission media itself.

d. Inefaceability Requirements

Its requirements are different from transmission media to another in complexity and cost. For example using 2 Mbps connection between PBX and MW links is economical, because no conversion process is needed.

e. Reconfiguration Flexibility

Network reconfiguration is needed by adding new sites or company moves from one site to other. For example satellite network is very flexible while fiber optic network reconfiguration can be very costly and time consuming.

f. Design and Link Engineering Requirements

The design of links vary from simple to complex and also the required tools vary from simple tools to other costly tools.

g. Technology Life Time

An example of this is the coaxial cables for long distance digital transmission is of limited use due to the use of fiber optic cables. Also technology life time can be related to operating software and its upgradeability.

h. State of the art technology

The state of the art technology can be different from transmission media to another, e.g. fiber optic link against coaxial cable link.

i. Security of information

The security of information is an important parameter for Business Company and military, fibre optic links can be considered as one of the highest secure transmission media.

CHAPTER V

Design and Analysis of Node Requirements

5. Design and Analysis of Node Requirements

5.1 Distance Matrix

Longitude and latitude for each site where used to determine the distance matrix as shown in Table (5.1) where the unit is in km...

5.1.1 Nodes with SCADA function

According to the functionality of the nodes which illustrate the relationship between sites (nodes) as in Table (4.4), and because only nine nodes has SCADA application by point to multipoint (master and slave), as shown in Figure (5.1).

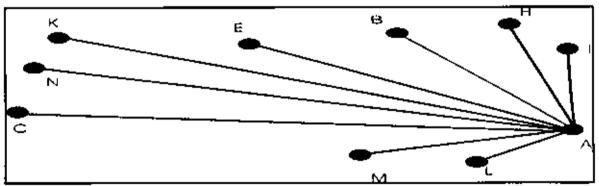


Figure (5.1) Nodes interconnection for SCADA application

5.1.2 Nodes with other applications

With reference to Table (4.5), one can notice the relationship between sites, since if

Table (5.1) Sites Distance Matrix in (km)

1				abic (.	_					(:- -				
Nodes	A	В	С	1)	E	P P	G	H	!	/	K	<u>. Լ.</u>	М	N
A]	0	15.9	13.3	14.7	13.5	12.7	4.3	09	0.9	0.8	16.0	1.0	5.5	16.0
В	15.9	0	3.0	1.4	2.6	4.0	13.2	15.1	15.3	15.5	0.7	15.3	104	0.7
c	13.3	3.0	0	2.0_	0.5	0.9	10.3	12.5	12.6	12.8	2.9	12.8	7.9	2.9
D	14.7	1.4	2.0	0	1.6	3.0	12.1	14.0	[4,1]	_14.3	1.4	14.1_	9.2	1.2
F.	13.5	2.6	0.5	1.6	0	1.4	10.6	12.7	12.8	13.0	2.6	12.9	8.0	2.6
F	12.7	4.0	1.0	3.0	1.4	0	9.6	[].8_	12.0	12.2	3.7	12.2	7.4	3.7
C	4.2	13.2	10.3	12.1	10.6	9.6	0	3.3	3.3	3.5	13.2	4.4	4.3	13.2
11	0.9	15.1	12.5	14.0	12,7	11.8	3.3_	0	0.2	0.4	15.2	1.3	4.9	15.2
_	0.9	15.3	12.6	14.1	12.8	12.0	3.3	0.2	0	0.2	15.4	1.4	5.0	15.4
1	0.8	15.4	12.8	14.3	13.0	12.2	3.5	0.4	0.2	0	15.2	1.5	5.2	15.6
К	16.0	0.7	2.9	1.4	2.6	3.7	13.2	15.2	15.4	15.6	0	15.4	10.5	0.03
L	1.0	15.3	12.8	14.1	12.9	12.2	4.4	1.3	1.4	1.5	15.4	0	5.0	15.4
M	5.5	10.4	7.9	9.2	8.0	7.4	4.3	49	5.0	5.2	10.5	4.9	0	10.5
N	16.0	0.7	2.9	1.2	2.6	3.7	13.2	15.2	15.3	15.6	0.03	1 15.4	10.5	0

one draws the logical connections, will get a huge number of intersections between nodes that arrives up to 91 links.

5.2 Traffic Requirement Analysis

GMRWUA facilities need many of traffic e.g voice, data, internet and control, so the following points discuss all types of traffic that needs in GMRWUA network.

5.2.1 Traffic in Telephone Networks (Voice Traffic)

An important aspect about the telephone network is that when you place a call and you are connected through the network, the voice circuit is dedicated to you until you hang up due to the circuit switching functionality. In other words, the circuits along your connection path are not released for use by another person until you are done. To make this simple, we will assume temporarily that call arrives in a deterministic fashion and that we are considering only a single voice circuit. Suppose that a call arrives at the start of an hour and the user talk exactly for an hour. Thus, this user occupies the circuit for an hour and no one else can use it. Now suppose the user talks only for 10 minutes and then hangs up. The circuit is free for others to use for the rest of the hour. In fact, if another user arrives at that instant and occupies the circuit for, say 10 more minutes, then a third user can start using the circuits 20 minutes into the hour. Thus, if we slice the length of the calls to fixed 10 minute window, we can accommodate six calls; this means we can have six arrivals per hour (using 10 minutes each) as opposed to one arrival per user (using for the full hour for talking) while in either case we just needed one circuit.

Thus the determination of the traffic demand in the telephone network needs more than the average call arrival rate. From the example of 10 minutes each as opposed to an hour-long call, it is clear that the traffic demand somehow also needs to take into account the (average) duration of the call. So a good way to capture the demand volume is to consider the product of call duration and average call arrival rate.

In our design we measure the call duration and found it equals 3.6 minutes, this value came from a questionnaire answered by GMRWUA management site for a one month period as shown in appendix C, Table (C.1).

To estimate traffic for each node, we must know some parameters such as number of calls per day per office (N), observation time (T), grade of service assumed equal 1%, average call duration (H) and busy hour factor (BF assumed 33%)

For example traffic in node B where Number of user (Nu) =5, T=7 hours and H measured and found it equals 3.6 minutes (from Table (C.1)), equal to 0.515 Erlang. To know the number of lines or circuits that are needed to carry the offered traffic which resulted at node B, we use Erlang B Table (C.3). B (M, 0.515) at a probability of blocking =0.01. Thus the number of lines = 4.

By the same way we can calculate the traffic and number of circuits for the other nodes. The results are summyed as in table (5.2).

Table (5.2) Voice traffic calculation, at H=3.6min, B=0.01, T=7hrs, N=9

		Va	ice Traffic	
Node	No of users	Erlang	No of Lines	VOIP BW in Kbps
Λ	103	10.61	19	1824
В		0.515	4	384
С	5	0.515	4	384
D	5.	0.515	4	384
E	5	0.515	4	384
F	10	1.03	5	480
G	5	0.515	4	384
Н	5	0.515	4	384
ī	20	2.06	7	672
	5	0.515	4	384
[К	20	2.06	7	672
L	5	0.515	4	384
M	30	3,09	. 8	768
N	10	2.06	7	672

Because VolP traffic uses Real-time Transport Protocol (RTP) to transport voice traffic, one can use the same principles to define the bandwidth on network links.

There are some factors consider to define the BW and their effect on the BW of voice networks. As some of the defined BW could be allocated to, voice codec, number of samples per packet, voice activity detection and RTP header compression.

So our assumption is based on G.711 voice codec (13) with specifications of packet duration 10 ms and 80 bytes per sample and a call with only one sample per packet. So the VOIP bandwidth = 96 kbps per call. By the same procedures we get the values that are shown in Table (5.2).

5.2.2 Traffic of Internet Networks (Data Traffic)

When a user employs applications such as email, the generated message is broken down into smaller data packets for transporting over the internet. A large portion of the internet applications uses the TCP/IP (Transmission control protocol / Internet Protocol) stack. The end computers are responsible for breaking application's messages (e.g., web pages, email) into smaller packets on one end, and then reassembling them in the right order at the other end before handing it over to the application; in the process, the two end computers are needed to insure that if a packet is by chance lost somewhere, they need to work together to insure notification of the lost packet and retransmission so that the message content is correctly delivered to the application.

So we need to know the average packet size which is assumed to be 500 bytes per packet for medium size and 40 bytes for small size [1], and the average packet arrival rate is 20 packets per second.

Thus, by the above assumptions we get the up and download data rate of 6.4 and 80 Kbps respectively.

For the data management traffic which is needed for all sites, we must know the expected message length which is determined by site survey. The average message length = 87 kbits, then the management data traffic equal to 0.05 Kbps per server, where observation time =7hrs, number of messages per day per server = 10 and busy hour factor (BF assumed 33%). For example data traffic generated by node M = 0.5 kbps. By the same way we get the results for other nodes, as in Table (5.3).

Table (5.3) Data traffic estimation

		Data Traffic
Node	No of Servers *	Data Management Traffic kbps
A	60	3
i!	2	0.1
c	1	0.05
D	2	0.1
E	2	0.1
F	4	0.2
G	2	0.1
H		0.1
Ī	4	0.2
		0.05
K	3	0.15
١, "	I	0.05
M	[0	0.5
N	3	0.15

^{*} Assumed as one server per office (Table C.2)

5.2.3 Traffic generated by SCADA system

In SCADA system there are four types of parameters that determine the amount of data at each remote site, so the data to be gathered can be as a little as one status point or as much as several hundred status and alarm points as well as several dozen meter totalizer points and several dozen analog values.

To communicate, each status or alarm point requires one or two bits of data. Since each meter or analog point will be transcribed to a binary word, each point requires about sixteen bits.

For simplicity as well as for safety reasons, it is better to select the largest RTU when evaluating points. Multiply this point count by the total number of RTUs to count of all data coming back from all RTUs. Because a conversation is usually a transfer of data in both directions, it is important to include the time taken for the MTU to talk to each RTU. This will include both the time for MTU to ask the RTU for information and the time for the MTU to give other instructions to each RTU.

SCADA Parameters Nodes Analog Digital Total SCADA Traffic Kbps I/P O/P I/P OΦ IJР O/P Input Output 201 300 284 501 356 320 228 72 В Ĉ 42 32.8 11 32 40 51 27.2 10 D E 11 52 27 63 40 17.6 17 115 10 55 43 73.633.6 Н **6**0 ī 83 12 569 51 652 417.6 57 12 418 495 316.8 36.6 45 97.6 26 126 152 40 L 25.6

Table (5.4) SCADA traffic estimation

At the design stage, the best way to take these two times (i.e. MTU and RTU) into account is to evaluate what this point count is for the largest outgoing message and then multiply by the number of RTUs.

74

350

299

74

224

192

48

 $2\overline{00}$

266

М

150

33

This should provide a conservative result because the messages from MTU to RTU are usually shorter than the messages from RTU to MTU. But in the design of GMRWAU SCADA system, we evaluate each RTU individually. To estimate the

traffic for SCADA nodes, we start from field device and apply IEEE C37. 10 protocol to take the overhead into account [4]

From the above the average message duration equals 80 bits per packet and average arrival rate = 8 packet per second, then we can calculate traffic which is generated by SCADA components, as in Table (5.4).

5.3 Demand Volume Matrix

Traffic volume between any two nodes which form traffic volume matrix or a demand volume matrix must be determined. So we will start by collecting or integrating the overall traffic application for each node The results are summyed in Table (5.5).

Table (5.5) Traffic Node Integration

				Traff	fic Integrat	lon		
Node	Voice	Data	SCA Traffic		Internet	traffic kbps	Total Tra	iffic kbps
	Traffic kbps	Traffic kbps	I/P	I/P O/P Upload		Download	Up	Down
Λ	1824	3	320	228	6.4	80	2061.4	2227
В	384	0.1		<u> </u>	6.4	80	390,5	464.1
C	384	0.05	32.8	27.2	6.4	80	417.7	496.9
D	384	0.1	<u> </u>	<u> </u>	6.4	80	390.5	464.1
E	384	0.1	40	17.6	6.4	80	408.1	504.L
F	480	0.2		-	6.4	80	486.6	560.2
G	384	0.1		-	6.4	80	390.5	464.1
H	384	0,1	73.6	33.6	6.4	80	424.1	537.7
	672	0.2	417.6	40	6.4	80	718,6	1169.8
	384	0.05	-	<u>-</u>	6.4	80	390.45	464.1
K	672	0.15	316.8	36.6	6.4	80	715.2	1069
. L	384	0.05	97.6	25.6	6.4	80	416.1	561.7
M	768	0.5	224	<u> </u>	6.4	80	775	1072.5
N	672	0.15	192	48	6.4	80	726.6	944.2

With reference to Table (4.7) that shows the relation between nodes which are reflected to points (1, 3, 5), in the 5 points scale since these points are to determine the traffic flow between nodes and because GMRWUA nodes has symmetrical function, so we use two points 3 and 5 to determine the traffic flow.

Table (5.6) Traffic Flow Estimation

	Total Traf	fie kbps	Total		Traffic Flow in kbps						
Nodes			points	Up		Down					
	Up	Down		3	5	3	5				
۸	2061.4	2227	55	112.4	187.4	121.5	202.5				
В	390.5	464.1	43	27.2	45.4	32.4	54				
C	417.7	496.9	41	30.6	51	36.3	60.6				
D	390.5 464.1 408.1 504.1		39	30	50.1	35.7	59.5				
- 15	408.1	504.1	47	26	43.4	32.2	53.6				
F	486.6	560.2	41	35.6	59.3	41	68.3				
G	390.5	464.1	41	28.6	47.6	34	56.6				
H	424.1	537.7	47	27	45,1	34.3	57.2				
I	718.6	!169.8	49	44	73.3	71.6	119.4				
J	390.45	464.1	45	26	43.4	31	51.6				
K	715.2	1069	47	45.7	76	68.2	113.7				
t.	416.1	561.7	45	27.9	46.2	37.6	62.3				
М	775	1072.5	45	52	86	71.9	119				
Ŋ	726.6	944.2	45	48.7	80.7	63.3	104.8				

Because there are three types of node requirements that are voice, data and SCADA, and all nodes need voice and data requirements, whereas, not all nodes need SCADA as in Tables (4.4) and (4.5), the relation between nodes is taken3 when only voice and data are needed, and 5 means all requirements are needed, using Table (4.7), which shows the points distribution for each node, the traffic for each node is determined as in Table (5.6). Traffic flow is a measure of the traffic intensity on any directed path consisting of an ordered sequence of

network nodes and links, the traffic matrix is illustrated in table (5.7), where the unit is Mbps. The upper half of the matrix is Upload, where as the lower half is Download as in Table (5.7).

Table (5.7) Traffic Matrix (kb/s)

7.	187,4	212	306	8	43.4	35.6	386	z	7	જ	45.7	672	બ	¢
K	187.4	27.2	306	30	92	35.6	47.6	Ħ	73.3	Ä	Ж	672	0	71.9
-2	187.4	27.2	3n6	30	38	356	386	27	73.3	33	45.7	0	37.6	37.6
ĸ	187.4	272	336	30	3%	35.6	386	27	#	36	0	1137	1137	113.7
ı	1124	272	306	30	25.	35.6	386	45.1	73.3	0	51.6	51.6	31	31
-	1124	272	30.6	30	3%	35.6	æ	22	O	71.6	119.4	71.6	119.4	71.6
=	1124	454	306	æ	43.4	356	386	0	57.2	34.3	34.3	343	343	34.3
ט	1124	272	306	æ	સ	35.6	0	燕	8.	£	¥	д	콨	8
н	1124	272	30.6	œ	35.	0	41	11"	4]	41	lt	7	41	41
E.	ν τ ι1	VSV	900	ιέ	0	ਹਕ	ट क	צוני	7a:	ગહ	202	272	za:	231
ด	1124	212	306	0	238	45£	258	5 %	4 %	232	35.7	35.7	35.7	35.7
٥	ν Z ΙΙ	242	0	£9£	363	€%€	£79£	363	595	£9£	EW	£9£	£9£	590
si	1124	0	13 .4	12.	54	*	72,	572	ğ	£	Ŕ	ង្ក	ğ	¥
*	0	121,5	20E	\$,(2)	305	1215	5121	इत्र	sæ	\$121	इत्रह	325	Sax	รสะ
lo lo	٧	Ħ	С	Q	2	Ъ,	ט	Ŧ	L		Ж	T	Σ	Z

Download Traffic

5.4 Location and Network Configuration

An important part of network design is to find the best way to layout the components (nodes and links) to minimize cost while meeting a performance criterion such as transmission delay and reliability. The communication network topology should be at least a spanning tree technique to connect N sites (each site connected network configuration to its nearest node), and each site is to be connected by one or more links. The overall configuration has been spanning tree and no loop cycles with (N-1) number of links.

MST provides minimum construction cost for non existing infrastructure such as ducting, towers, building. For existing infrastructure it might be better to use minimum distance to node A (HQ).

Using an algorithm to design minimum spanning tree network with number of nodes 14, as illustrated in the following steps:

- Start out with all unconnected (or isolated) nodes and no clusters as in Figure (5.2a).
- Consider the closest node to an unconnected node. If the closest node is also unconnected, make the connection between the two nodes. This step when repeated for all isolated nodes will yield either isolated nodes or clusters of connected nodes as in Figure (5.2b).
- 3. Connect every isolated node to the closest cluster by the shortest connection.
- Connect the two closest clusters by the shortest connection as in Figure (5.2c).
- 5. Repeat the preceding steps until only a single cluster (network) is formed as in Figure (5.2d).

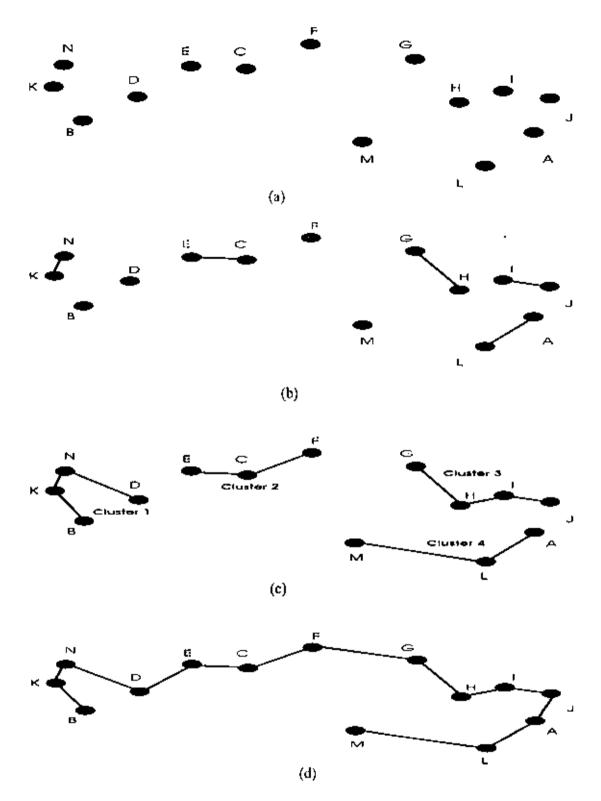


Figure (5.2) Algorithm Procedures to Design MST Network with Number of Nodes 14:

(a) Unconnected Nodes; (b) Connecting all Pairs of Unconnected to the Nearest Nodes
(c) Connecting isolated nodes to closest cluster; (d) MST Configuration

Figure (5.2d) illustrates the connection between nodes which form bus topology with maximum node degree 2, since this network does not satisfy 2-connectivity, where the connectivity of a network describes if a fully connected network is still fully connected if one or more links fail. A network in Figure (5.2d) is link 1-connected where there is at least one distinct path between each node pair in the network. A failure of one link already disconnects a link 1-connected network. So we will make some mutation in network configuration, by adding links between nodes to improve reliability. Link added between nodes M and B, where the configuration appears as a ring topology. Thus we will get new configuration as in Figure (5.3)

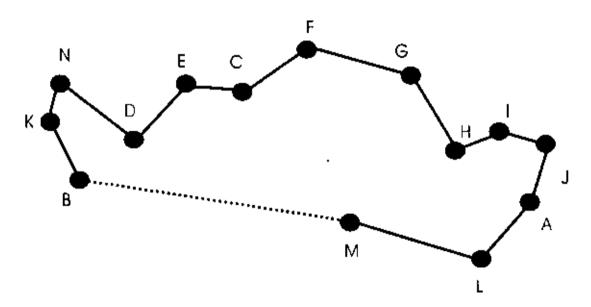


Figure (5.3) Network configuration after mutation

5.5 Network Performance Criteria

The selection of a route is generally based on some performance criterion. The simplest criterion is to choose the minimum-hop route (one that passes through the least number of nodes) through the network. A generalization of the minimum-hop criterion is least-cost routing. In this case, a cost is associated with

each link, and, for any pair of attached stations, the route through the network that accumulates the least cost is sought.

Table (5.8) shows the relative cost of all links, that is the product between link length in km and link load traffic in Mbps.

So we will design an algorithm to handle routing of data between nodes in a network of N nodes. The algorithm is based on the Forward Search Algorithm (also known as Dijkstra's algorithm). Each node in the network is assumed to serve M stations [11].

The algorithm computes the least-cost route between any pair of nodes (nodes to which source and destination stations are attached), and based on the following assumptions:-

a- For min cost:

- The cost of the least-cost path is the sum of costs of the links forming the path
- The cost of each link is the product of link distance and data rate of the link.

b- For min delay:

- The same algorithm can be used to set the delay of the link based on propagation delay, so the minimum propagation delay is related the minimum distance of the path.
- c- The algorithm will not consider links between stations and the nodes to which they're attached, because these links will always be part of the desired route as they are the only links that connect the stations to the network.

Table (5.8) Link Cost Matrix (km . Mbps)

To From	A	В	С	D	E	F	G	н	I	J	K	L	М	N
٧	0	1.787	1.494	1.652	1.517	1.427	0,483	0.101	101'0	0.089	2.998	0.187	1.030	2,998
B	1.931	0	180'0	0.038	0.118	801.0	0.359	0.685	0.416	0.421	6100	0.416	0.282	0.019
c	2,69,3	0.097	0	190'0	510.0	0.027	0.315	0.382	0.385	0.391	0.088	0.391	0.241	0.088
<u> </u>	1.786	0.045	0.072	0	0.048	0.090	0.363	0.420	0.423	0.429	0.042	0.423	0.276	0.036
ы	2.733	0.140	0.018	0.057	0	0.036	0.275	0.551	0.332	0.338	0.067	0.335	0.208	0.112
<u>.</u>	1.543	0.216	0.036	0.107	0.045	0	0.341	0.420	0.427	0.434	0.131	0.434	0.263	0.131
v	0.510	0.427	0.373	0.432	0.341	0.393	c	0.094	0.094	0,100	0.377	0.125	0.204	0.377
н	0.182	0.075	0.453	0.499	0.680	0.483	0.112	0	0.005	0.018	0.410	0.035	0.132	0.410
_	0.182	0.495	0.457	0.503	0.412	0.492	0.112	0.011	0	0,014	729'0	0.102	0.366	0.677
	0.097	0.831	0.464	0.510	969:0	0.500	0.119	0.013	0.014	0	0.395	0.039	0.135	0.405
×	3.240	0.022	0.105	0,050	0.083	0.151	0.448	0.521	1.838	0.805	0	0.703	0.798	0.001
	0.202	0.495	0.464	0.503	0.415	0.500	0.149	0.044	0.100	0.077	1.75!	0	0.139	0.429
N	1.113	0.337	0.286	0.328	0.257	0.303	0.146	0.168	165.0	0.161	1.193	0.184	0	0.546
z	3.240	0.037	0.105	0.042	0.083	0.151	0.448	0.521	1.095	0.483	0.003	0.579	0.755	0

The algorithm is designed to handle any number of nodes; we will use a network of 14 nodes to demonstrate the algorithm. The flow chart of the algorithm is as given in Figure (5.4), where:

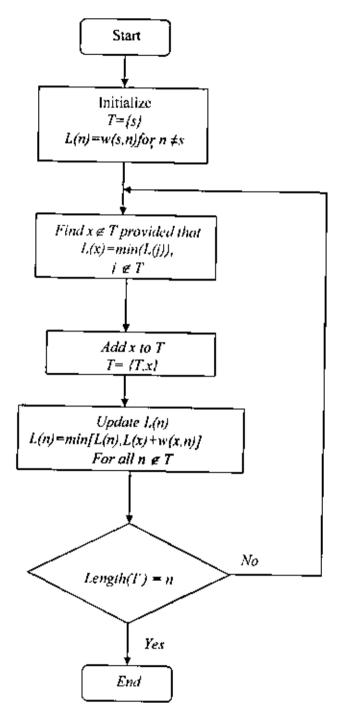


Fig. (5.4) Algorithm Flow Chart

- N= set of nodes in the network
- S= source node.
- T= the set of nodes for which the least cost path form the source is defined by the algorithm
- w(i,j)=link cost from node i to node j; w(i,i)*0; w(i,j)=infinity if the two nodes are not directly connected.
- L(n) =cost of the least-cost path from node s to node n that is currently known to the algorithm

We will apply the algorithm on the network in Figure (5.3); where the input to the algorithm is the source node s and the link costs matrix we get the least cost, minimum distance (shortest path) to connect nodes.

The final configuration is defined in Table (5.9) which has overall cost = 166.6 (km.Mbps) and overall minimum delay = 108.7 µsec.

Table (5.9) Optimum Network Configuration

		10010 (31	y) Optimum	11614016	t Cominguia	1	
N	od e s	Links	Distance Km	Load M	lbps	Cost	Delay
From	To	j l	Km	Up	Down	Km.Mbps	hrzec
Λ	J	LII	0.8	1.8_	2.2	3.2	2.66
J	1	1.10	0.2	2.2	2.7	0.98	0.66
1	H_	1.9	0.2	2.4	3.0	1.08	0.66
Н	G	L8	0.4	2.6	3.1	2.28	1.32
G	F	L,7	9.6	1.8	3.3	48.96	32
F	С	Ló	1.1	1.7	3.8	6.05	3.67
С	Е	1.5	0.5	2,6	3.9	3.25	1.67
Ē	. D	1.4	1.6	2.3	3.8	9.76	5.33
])	N.	1,3	1.2	2.2	3.8	7.2	4.0
N	К	L.2	0.03	2.1	4.2	0.19	0.10
K	В	L1	0.7	2.2_	2.9	3.57	2.33
В	M	LI4	10.4	2.2	3.1	55.1	34.67
M	L	L.13_	4.9	1.8	2.6	21.6	16.3
I.	A	1.12	1.0	1.2	2.2	3.4	3.33

5.6 Network Dimensioning.

As we know the demand between all pairs of nodes, then we will dimension the links between all nodes as in Fig. (5.5). Since it consists of 14 nodes and 14 links,

demand corresponding to pair of nodes. So before dimensioning the links we must calculate the accumulated demand related to network in Figure (5.3). Thus the Demand Matrix for network of Fig.(5.3) is as in Table (5.10) units are Mbps.

Node	A	В	C	D	E	F	G	H	I	J	K	Ţ	M	N
	0	0	0	0	0	0	0	0	0	1.8	0	1.2	0	0
B	0	0	0	0	0	0	0	0	0	0	2.2	0	2.2	0
С	0	0	0	0	2.6	1.7	0	()	0	0	0	0_	0	0
1)	0	0	0_	0	2.3	0	Ü	0	0	0	0	0_	()	2.2
E	0	0	3.9	3.8	0	0	0	0	0	_0	0	0	0	0
F	0	0	3.8	0	0	0	1.8	0	0	0	0	Ö	0	0
G	0	0	0	0	0	3.3	0	2.6	0	0	0	0	0	0
<u> </u>	0	0	0	0	0	0	3.1	0	2.4	0	0	0	0	0
	0	0	0	0	0	0	0	3.0	0	2.2	0	0	0	0
	2.2	0	0	0	0	0	0	0	2.7	0	0	0	Ö	0
K	0	2.9	0	0	0	0	0	0	0	0	0	0	0	2.1
L	2.2	0	0	0	0	0	0	()	0	0	0	0	1.8	0
M	0	3,1	0	0	0	0	0	Ü	0	0	0	2.6	0	0
N.	0	0	n	3.8	0	n	ő	0	0	0	42	0	O.	0

Table (5.10) Demand Matrix of the Final Configuration

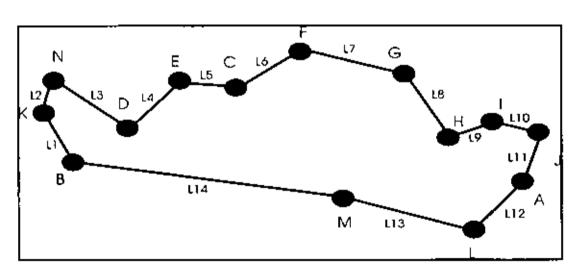


Figure (5.5) Link Dimensioning

5.7 Transmission Media Selection

Transmission media characteristics

The main issue and most critical part in the network design is the backbone links, which carry the main traffic between the nodes.

Problems on this backbone will affect severely the performance of the network. The selection of appropriate transmission media between different nodes is not an easy process. The network designers are always confronted with different attractive alternatives. The selection process depends on a set of parameters some of them according to technology and media characteristics, and the others depend on the sites and the physical route and terrain between them.

Table (5.11) Evaluation Scores of Different transmission Media versus Evaluation Parameters that depend on technology of transmission media [8]

Evaluation parameters\score	Fiber optic	MW link	Pair gain
Availability of equipment	7	7	5
Capacity & up grading flexibility	9	7	L
Interfacebility requirements	5	9	9
Reconfiguration flexibility	. 5	9	3
Design & link Engineering requirements	7	5	9
Technology life time	5	7	5
State of the art technology	9	7	5
Security of information	9	7	3
Total scores	56	58	40

In some situations, some parameters are directly omitted from the evaluation process such as the following situations:

- a- Coaxial cable is no longer recommended in long distance inter-sites links, due to enormous advantage of fiber optics over coaxial cables.
- b- Satellite links may be used to provide service to distant and isolated sites coastal or desert.

We will evaluate each transmission media with respect to each evaluation parameters. A numerical result is obtained for each transmission media. The highest score corresponds to the first choice of appropriate transmission media.

Table (5.12) Evaluation Scores of Different Transmission Media versus Evaluation Parameters that depend on the actual physical links [8]

Evaluation	Fiber optic	MW link	Pair gain
parameters\score			
Cost	9	5	l l
Operation &maintenance requirement	7	9	l
Spectrum availability	9	7	
Implementation requirement	9	7	Į
Terrain characteristic	7	9	3
Interference & environment effect	9	7	1
Execution time	5	7	1
Total scores	55	51	9
	1	1	1.

Table (5.13) Total Evaluation Scores

Transmission Media	Fiber optic	MW link	Pair gain		
Total scores	111	109	49		

Although when it comes to optical fiber cables most of its cost comes from excavation work. However with the GMRWUA project i.e where a pipe line work is underway, a fiber optic cable is laid in parallel with the pipe line which will reduce the installation cost of optical fiber. This explain why as in table (5.13) we notice that the highest score is given to fiber optic as a transmission media.

CHAPTER VI

Results, Conclusions and Recommendations

6. Results, Conclusions and Recommendations.

6.1 Results & discussion

When connect the links between nodes will get the final configuration as in Fig. (6.1), which is representing a ring topology with MST degree constraint.

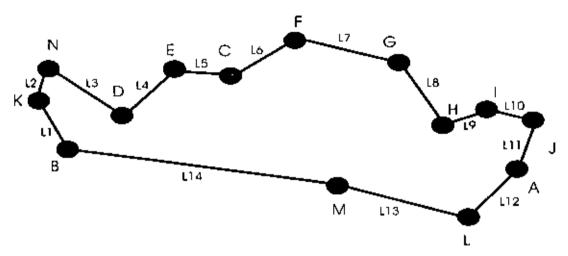


Figure (6.1) Final Network Configuration

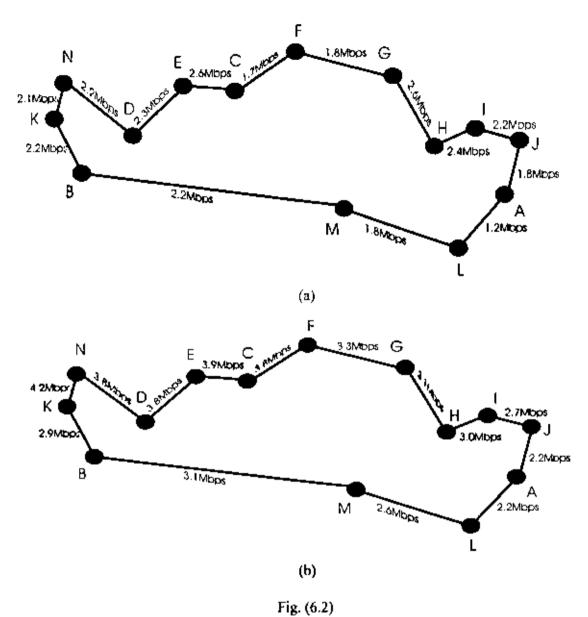
Thus by applying the algorithm on the network in Figure (6.1); where the input to the algorithm is the source node s, and the link costs matrix we get the least cost, minimum distance (shortest path) to connect nodes.

The final configuration has overall cost = 166.6 (km.Mhz), and the overall minimum delay = 108.7 µsec.

The demand between any pair of nodes resulted from node activities, as in the Table (6.1). Figures (6.2a, 6.2b) indicates the capacities of links of the up load and down load respectively.

Links		LI	1.2	L3	L4	L.5	L6	1.7	L8	L9	L10	ווו	L,12	L13	L14
Load Mbps		2.2	2.1	2.2	2.3	2.6	1.7	1.8	2.6	2.4	2.2	1.8	1.2	1.8	2.2
	Down	2.9	4.2	3.8	3.8	3.9	3.8	3.3	3.1	3.0	2,7	2.2	2.2	2.6	3.1
Distan	се Кт	0.8	0.2	0.2	0.4	9.6	1.1	0.5	1.6	1.2	0.03	0.7	10.4	4.9	1.0

Table (6.1) Demand between Nodes

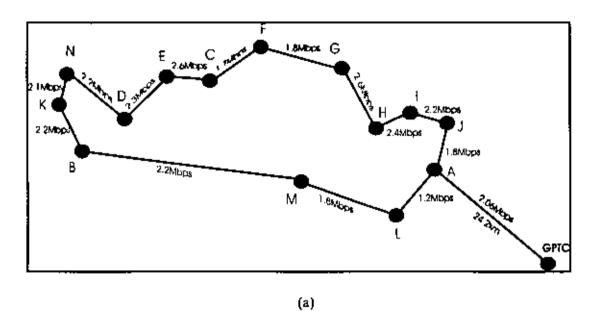


(a) Upload Network Dimensioning, (b) Download Network Dimensioning

This private network needs a gateway to connect to PSTN. At node A (Regional Control Center), we will connect this network with the PSTN through node A that represent the gateway of GMRWUA network, hence the traffic between all the sites and node A in the two directions will dimension the link between node A and the PSTN as in Figure (6.3a, 6.3b). The link between Node A and the PSTN is with a length of 24.2 km, and assumed to route 25% of the total traffic,

then the capacity of up load is 2063.8 kbps and capacity of down load is 2321.3 kbps.

As there are many obstacles through this transmission route as buildings, roads and farms, then we suggest the expected appropriate transmission media for this link is to be Microwave radio link.



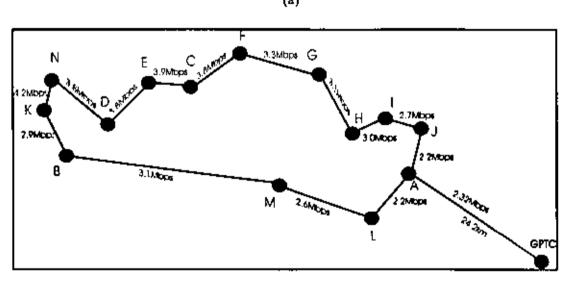


Figure (6.3)
(a) Up link Final Configuration, (b) Down link Final Configuration

(b)

6.2 Conclusions

From previous results we conclude the following points:-

- The architecture of communication networks can be complicated, this is transpired by not only the large number of nodes that can form a particular network, but also due to the traffic and transport network.
- A traffic network needs a transport network to connect the needed links for the traffic network.
- Where surveying all nodes (sites), knowing their functions and type of services, the generated traffic by each node could be estimated, and can compute the total traffic in bps at each site.
- By applying MST method we get a ring topology for backbone network which form the final connection between sites.
- Dimensioning which result in number of links, it uses the traffic flow between sites, where the traffic flow between (sites) nodes is determined by knowing the relationship between them.
- The optimum network topology has the least cost and minimum distance, then by applying dijkstra's algorithm to find the shortest path when know the source(s) and destination (d), then the shortest path has the minimum length among all possible paths connecting s to d.
- The final backbone configuration interconnecting these sites is a ring topology that can provide a sufficient reliability which has an overall cost equals 166.6 km. Mbps and a time delay of 108.7 µsec. The links of this configuration are dimensioned with enough capacity to carry the traffic between them. For example, capacity between node M and L is 1.8 Mb/s for up load and 2.6 Mb/s as a down load, where this capacity comes by detailed calculations of the requirements and a margin of 25% is added.

6.3 Recommendations

- The designed network is an enterprise network designed to connect the GMRWUA sites, but it's possible to use it as a media to connect the surrounding places (Villages) with Sirte city, where it is needed to add some extra capacity to the backbone network depends on the requirements of that places.
- The main issue and most critical part in the network design is the backbone links, which carry the main traffic between the nodes. Therefore it is recommended to develop a model to evaluate and select appropriate transmission media between different sites.

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APPENDIX-A Network Design Analysis

A.I Data Stream Analysis

There are times when it is required to study the manner in which the packets of a message become distributed in time over a shared input/output transmission line when several local ports act as sources of message streams in a packet assembler and dissembler (PAD), Figure A.1.

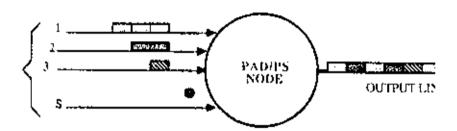


Figure A.1 Merge operation involving several data streams

Assuming a first-in-first-out (FIFO) mechanism, identical speeds at both the input and output channels, and effective output channel utilization less than unity, one can show that each message on the output link will experience some clongation in time. The average message expansion factor (AMEF) is related to the average number (N) of slots (or packets) per message and the number (S) of active sources (or local ports). An analytical solution was obtained through using computer simulation. The resulting expression for AMEF is as follows:

AMEF = 1+
$$[1 - 1/N - 1/S + 1/(NS)] \times \rho \dots (A.1)$$

Where.

N = average number of packets (or slots) per message

S = number of active sources of messages

 ρ = utilization of the shared channel

Figure (A.2) plots several useful curves relating AMEF to N and S and for ρ equal to 1.

It is interesting to observe that the maximum value of AMEF is 2 for an infinite number of active sources and large values of N. That is not intuitively obvious.

Of course the value of AMEF is reduced to 1 for N=1 and any S. And this value is intuitively obvious. The result of Equation A.1 can be used to estimate the delays in receiving the entire length of a multipacket message at the receiver.

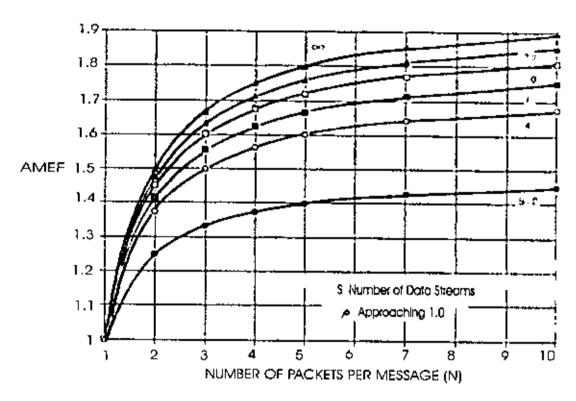


Figure A.2 Message expansion factor versus the number of packets per message and the number of data streams.

A.2 System Reliability Analysis

There are many occasions when it is necessary to compute the reliability of a nodal subsystem or the entire network system. In order to achieve

that goal, we must define several quantities, since reliability can be expressed in several ways.

I- System Availability

System availability is defined as the percentage of time the system is available for its assigned mission. It can be expressed as follows:

$$A = (MTBF) / (MTBF + MTTR))*100....(A.2)$$

Where

MTBF = mean time between system failures

MTTR = mean time to repair a system failure.

The system can possess any arbitrary scope or size. It could be a nodal subsystem or the entire network system. The value of MTBF for nodal products is generally supplied by the vendor. The vendor for a proposed system generally estimates MTBF of a network system, if required by the user. In every case, the product is modeled as a collection of unique indivisible parts, each part model associated with a unique failure rate. Military standards exist to aid in the selection of such failure rates. Using such models, the MTBF of a product is determined. Some of the models are discussed in the following paragraphs. The values of MTTR are estimated using experimental data and some extrapolations based on product maturity.

The probability of a successful mission (or mission reliability) during an observed mission time T can be stated as follows:

$$R(F) = EXP[-T/MTBF]...(A.3)$$

Where

EXP [x]= exponential function of $x = e^x$

Probability of K failures during a mission time T can be expressed as follows:

$$P[K,T] = EXP[-N_f]*[(N_f)k]/[K!].....(A.4)$$

Where

N_f = average number of failures during a mission time T = T / MTBF

Each large system can be represented as a set of connected subsystems. The reliability of the entire system is a function of the way the subsystems are connected together and the manner in which the system functions together. There are two ways the subsystems can be connected together to allow the system to operate as a whole:

- i. Series connection. The system requires all subsystems to function concurrently.
- ii. Parallel connection. At least one subsystem needs to function properly.

2- Reliability of a Series Type Redundant System

A large system can be modeled as a set of subsystems connected together in a series, as shown in Figure A.3

The reliability of the entire system can be expressed as follows:

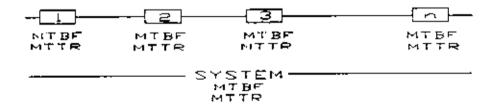


Figure A.3 System with Series type redundancy.

$$A_{i} = \prod_{i=1}^{n} A_{i} = A_{1} * A_{2} * A_{3} * A_{n}$$

$$(MTBF_{i})_{i} = \left[\sum_{i=1}^{n} 1 I MTBF_{i}\right]^{-1}$$

$$(MTTR_{i})_{i} = \left\{\left[1 - A_{i}\right] I A_{i}\right\} * (MTBF_{i})_{i}$$

3- Reliability of a Parallel Type Redundant System

A system characterized by a parallel type redundancy is shown in Figure A.4. The reliability of a system employing parallel type redundancy can be expressed as follows:

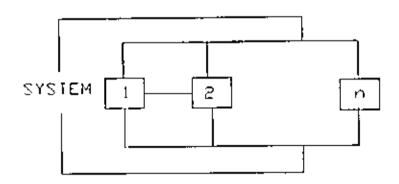


Figure A.4 System with parallel type redundancy.

$$A_{s} = 1 - \prod_{i=1}^{n} (1 - A_{i})$$

$$(MTTR)_{s} = \left[\sum_{i=1}^{n} \frac{1}{MTTR_{i}} \right]^{-1}$$

$$(MTBF)_{s} = \left[A_{s} / (1 - A_{s}) \right] * (MTTR)_{s}$$

A.3 Computing Distance of a Transmission Line

The monthly cost of any transmission link is generally proportional to its length. Furthermore, the task of optimizing a network topology requires a large number of computations related to finding the closest and the farthest nodes from a given node. The distance between any two locations can be expressed as follows:

$$D12 = SQR [(VI - V2)2 + (HI - H2)2]$$
 kilometer.....(A.7a)

Where:

VI, V2 are the V-coordinates of the two locations

HI, H2 are the H-coordinates of the two locations

D12 = straight-line distance between the two locations in miles

The distance D12 is never equal to the exact distance of the physical link employed to connect the two CPEs of the customer. Equation (A.7a) is merely an aid to quickly compute the distance for pricing a direct distance dialed (DDD) telephone call or a leased line.

For countries without such a coordinate system, the value of D12 can be expressed in terms of the readily available longitudes and latitudes using equation (A.7b) as follows:

Where

LAT1 and LAT2 are latitudes of the two locations LNG1 and LNG2 are the longitudes of the two locations.

APPENDIX-B

Network Design Tools for Data and Voice

B.1 Voice Networks

1. Traffic Analysis Tools

Traffic analysis is required to compute the performance of a CS voice network in terms of internodal blocking and the number of internodal circuits as a function of the allowed blocking probability B.

Erlang-B Formula

The Erlang-B formula assumes (1) infinite sources are responsible for a steady rate of random call arrivals, and (2) the lost calls are cleared as soon as they are blocked and these calls never return. If a represents the offered call intensity measured in Erlangs and c is the number of servers, the blocking probability B(c) is given by the Erlang -B formula:

$$B = (c, a) = \frac{\frac{a^{-c}}{c!}}{\sum_{k=0}^{c} \frac{a^{-k}}{k!}} \dots B.1$$

One can also compute the average utilization of the outlet AL or Trunk bundle that carries only a (1-B) Erlang. Such a quantity represents the efficiency of the network facilities. The average utilization of the AL or TK (or server) bundle is therefore as follows:

$$\rho = a(1-B)/c \dots B.2$$

Figure B.1 for several curves relating average AL or TK (or server) utilization to the number of servers. It should be emphasized that above equation assumes an infinite number of traffic sources. The curves of Figure B.1 clearly

illustrate the desirability of larger bundles. Larger bundles always result in higher efficiency.

The curves of Figure B.1 are very useful for interpreting the behavior of voice networks. A network with heavy traffic on its facilities will generally exhibit high efficiency. That is just fine for large users. A network with little traffic on its facilities will generally exhibit low efficiency. This penalty should not be acceptable to small users.

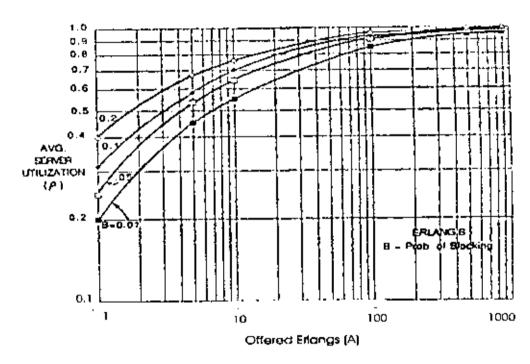


Figure (B.1) Average Server Utilization Versus Offered Erlangs (A) for some Useful Values of Blocking (B)

2. Network Performance Analysis Tools

There are occasions when several CS network systems must be compared with one another in terms of their performance. This will require the computation of network throughput and the GOS parameters described as follows:

- Effective throughput of the entire CS network system
- Total end-to-end connection time measured as the elapsed time between the moment the last digit is dialed and the moment the destination terminal is made busy
- End-to-end blocking probability experienced by a call request

a- System Throughput

One way to compare a CS network system with another is in terms of the total number of calls handled during a busy period. If each CO type network node handled only local calls, the throughput of the entire system will be the sum of all CO nodal throughputs ($C_S=C_1+C_2+C_3+...$). This will also imply no need of tandem switches or trunks. In the other extreme, if every CO type node handled only tandem calls, the total network throughput Cs must be divided by a factor k that represents the number of identical CS nodes in the path of the call. The actual throughput of a practical CS network system will be somewhere in between the two limits.

b- End-to-End Connection Time

Another way to compare two CS network systems is to study their end-to-end connection time distribution. The total connect time can be expressed as the sum of (1) processing time delays experienced by each network node in the path of the call, and (2) sum of the delays experienced by the signaling data on each inter-nodal link. Since the delay encountered in each node and on each inter nodal link is a random variable characterized by an average and a variance, the end-to-end connection time will also exhibit randomness. Its average and variance can be expressed as follows:

$$Avg_{-}(Tc_{-}) = \sum_{l=1}^{n} Avg_{-}(Tin_{-}) + \sum_{j=1}^{L} Avg_{-}(Tjl_{-})$$

$$Var_{-}(Tc_{-}) = \sum_{l=1}^{n} Var_{-}(Tin_{-}) + \sum_{j=1}^{L} Var_{-}(Tjl_{-})$$

$$Where:$$

Te = total connection time

Avg(Tc) and Var(Tc) are the average and variance of Tc

 T_{in} = delay in the ith node

 $T_J = delay$ on the jth internodal link

N = total number of nodes in the path of the voice call

L = total number of links in the path of the voice call

c- End to End Blocking Probability

Two CS network systems can also be compared in terms of their end-to-end blocking probability. The blocking probabilities Bs experienced in the N network nodes in the path of a call can be computed as follows:

$$Bs = 1 - \left[\prod_{i=1}^{N} Bi\right] = 1 - \left[B_1 * B_2 * \dots * B_N\right] \dots \dots \dots \dots (B.4)$$

Or one can get a simpler relation for N*Bi<1:

$$Bs \approx B_1 + B_2 + \dots + B_N = \sum_{i=1}^{N} B_i \dots (B.5)$$

B.2- Data Networks [2]

1- Traffic Analysis Tools

Whereas traffic analysis for voice traffic is used to size AL and trunk bundles in a voice network, traffic analysis for data must also be used to size the AL and trunk bundles in a data network. In order to develop meaningful analysis tools for data, one must first understand the behavior of data traffic.

Data traffic differs from voice traffic in many significant ways. Whereas each voice call is characterized by its well-behaved service time, T_{st} data traffic is generally very bursty in nature. Data traffic generally involves the transmission of messages, both small and large, as required by the associated protocol defined as the set of rules for interchanging data between two communication devices.

Almost all data applications employ store and forward techniques involving delays. Consequently, data traffic analysis tools can only be expressed in terms of queuing theory.

Figure B.2 for a representation of two queues within a classical PS/MS node. One queue represents the input process and the other represents the output process.

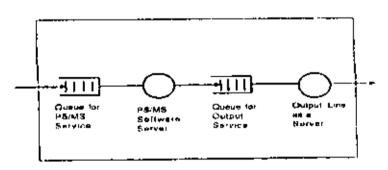


Fig (B.2) Queuing Model of a Typical PS/MS with Two-Stage Service.

Basically two types of queuing models are of interest here. Each model assumes a unique traffic model. The first type is characterized by random arrivals, N servers, and negative exponential distributions of the service times, Ts. It is defined as the M/M/N type traffic with infinite sources. The second type of data traffic is characterized by random arrivals, N servers, and constant service times. It is defined as

the M/D/N type traffic with infinite sources. These two types of traffic determine delays in the queue within a PS/MS nodes and data networks.

1.1- The M/M/N Queue Analysis

Most queues in a large network system employ more than one server (i.e., N > 1) to either handle a large number of requests for data transmission or minimize delays experienced within the network nodes. For the M/M/N type queue characterized by random arrivals, negative exponential service times and N servers, one can define the performance of such a system by specifying the probability of delay exceeding a given value or by requiring the average wait time in the queue. Denoting the traffic intensity by A (equal to N*p where p is average utilization of each server) and average service time by T_s, one can express several useful relations as follows:

Prob.(dela y > T) = (Po) * Exp[- (N - A) T / Ts]
Avg(Tw) = Ts / (N - A)delayed transactions only
Avg (Tw) = Ts * Po / (N - A)all transactions

$$Var(Tq) = [Ts^2 / (N - A)^2] * [Po (2 - Po) + (N - A)^2]$$

Where:

 $T_s = A \text{ verage service time, and}$

P₀ is the probability that delay is greater than zero. Its value can be derived by using,

 $P_0 = \text{Prob} (\text{Delay} > 0) = (B*P) / [P-A(I-B)]$ for given values of N, A, and T_s .

1.2- The M/D/N Queue Analysis

The analysis of an M/D/N type queuing system characterized by random arrivals, fixed service time, and N servers is quite complex. The traffic theory does not provide simple expressions for the first two moments of the time spent in the M/D/N type queue. There are simulated the M/D/N type queue for a large number server loads (p) and N, the following expressions agree very well with the simulation results.

2- Network Performance Analysis Toots.

There are times when several network systems must be compared with one another. This can be done by comparing their performance in terms of system throughputs.

* Network System Throughput Analysis

The nodes of a WAN are generally interconnected by non-shared links according to a well-defined topology. If every node of a WAN handled only the local traffic, the throughput of the system will be equal to the product of nodal throughput and the number of PS central offices. Such an extreme case will require no internodal trunks for user data. If each PS node handled only the tandem traffic, then the system throughput C of a WAN can be approximately expressed as follows:

$$C = N * Cs / L_p$$
 (B.8)

where

C_s = system capacity in packets or messages per second

N = number of identical PS/MS nodes in the network system

 L_P = average number of nodes in the path of a packet or message

The data networks usually employ two types of nodes: (1) concentrator nodes (i.e., PADs) that serve subscriber lines only, and (2) large packet/message

Switching nodes. The above equation also assumes that a sufficient number of concentrator nodes are available to handle the traffic intensities required to achieve the network capacity, Cs. The voice networks, on the other hand, employ two types of switching nodes: (1) CO type nodes for handling the originating and destination traffic, and (2) tandem nodes for handling only the tandem traffic.

The nodes of a local area network (LAN) are generally connected by means of a shared media. In case LAN nodes are connected by separate links, the LAN throughput can be computed using the same methodology as used for WANs. The throughput of a typical LAN depends upon the shared media capacity (Ro), number (N) of stations, interface delay T_{int} and type of access employed. Stuck describes a simplified methodology for computing the throughput of a LAN based on the three well-known access techniques and for two cases of interest: Case A, when only one out N stations are active, and Case B, when all stations are equally active.

The peak throughput rates for Token Ring, Token Bus, and CSMA/CD LANs can be expressed for two special cases of interest as follows:

1- Token Ring:

$$R_{p} = L_{m} / [T_{msg} + T_{p} + N + T_{int}] bps \dots CaseA$$

$$R_{p} = L_{m} / [T_{msg} + T_{int} + T_{p} / N] bps \dots CaseB$$
......(B.9a)

2- Token Bus:

$$R_{p} = L_{m} / [T_{mag} + N * (T_{int} + T_{p})] bps \dots CaseA$$

$$R_{p} = L_{m} / [T_{mag} + T_{int} + T_{p}] bps \dots CaseB$$

$$\cdots \cdots \cdots (B.9b)$$

3-CSMA / CD :

$$R_{p} = L_{m} / [T_{msg} + T_{ifg}] bps.....CaseA$$

$$R_{p} = L_{m} / [T_{msg} + T_{ifg} + (2e^{-1}) * (T_{s} + T_{f})] bps....CaseB$$

where

Rp = peak average throughput rate in bps

 $T_s = \text{slot/ frame time} = (2Tp + T_{int})$

T_J = jam time for CSMA/CD = $48/R_0$

 T_p = Propagation time on the shared media

 T_{msg} = message transmit time over the shared media = $(Lm+96)/R_0$

Tifg = interframe gap time for CSMA/CD =9.6 microseconds

 T_{int} = interface delay time = 4 microseconds (token bus)

=1/R₀ (for a LAN based on token ring)

 $L_m = bits per message$

e = 2.71828

R0 = transmission capacity of the shared media in bps

APPENDIX-C

Voice Traffic Measurement

Table C.1
Number of calls in one month

No 	No of calls	Observation time (hour)	Calls per Hour	Notes
1	110	7	15.7	No of office = 13
2	130	7	18,6	140 of office - 15
3	120	7	17.1	
4	134	7	19.1	
5	125	7	17.8	
6	120	7	17.1	
7	110	7	15.7	
8	105	7	15.0	
9	146	7	20.9	
10	130	7	18.6	;
<u>l</u> 1	90	7	12.9	
12	142	7	20.3	
13	150	7	21.4	
14	107	7	15.3	
15	160	7	22.9	
16	112	7	16	
17	110	7	15.7	
18	137	7	19.6	
19	70	7	10	
20	100	7	14.3	
22	80	7	11.4	
23	90	7	12.9	
24	120	7	17.1	
25	119	7	17.	
26	126	7	18	<u> </u>
Total	3076		16.9	
Avo	erage call duration	in minutes	3,6	No of calls per day per office = 9

Table C.2 Representation of Communication Requirement of GMRWUA sites

Node	Rc	0	WS	Cr	S	Sg	М	Со	Ac	G	UPS	TR
A	_	60]	1	<u> </u>	-	1	6	30	2	-	103
В		2		i	<u> </u>	Γ		1		\vdash	_	4
C		1		1		1				1	_	4
_ D		2	1		ī					i		5
_ É _	Ι	2		1						1		4
_ F _	1	4	1					1	10	1		19
G		_2	İ			_			4	1		9
<u>H</u>	1	_ 2		1						i		4
1	1	4		_[_]	1	1	1	1	4	1	1	17
1 1		1	i	1	ī	_				1	- i	3
<u>K</u>	1	_3]	1	1	1	2	1	1	4	1	- 1 - 1	17
_ L _	l	1				1			<u> </u>	1		4
M	1	10	1		2		$\neg \neg$	1	10	2		28
_ N _	1	3	1	1	7	1		1		1	1	14

1- Rc -Reception 4- Cr - Control room 2- O – Office

5- S - Storage

3- WS - Workshop

7- M - Meeting room

6- S - Switchgear room

8- Co - Coffee

9- G - Gate

10- UPS - Uninterruptible Power Supplier 12- TR - Total Requirements

11- Ac - Accommodation

Table C.3
Offered traffic flow in Erlang [12]

2 0.1 3 0.3 4 0.7 5 1.2 6 1.7 7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	007 0.003 00705 0.003 12600 0.133 39664 0.41 77729 0.810 2332 1.261	8 0.009 806 0.00908 532 0.14416	0.15259	0.02 0.02041 0.22347	0.03	0.05
2 0.1 3 0.3 4 0.7 5 1.2 6 1.7 7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	2600 0.133 39664 0.41 77729 0.810	532 0.14416	0.15259			0.05263
3 0.3 4 0.7 5 1.2 6 1.7 7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	39664 0.41 77729 0.810		0.15259			
4 0.7 5 1.2 6 1.7 7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	77729 0.810	757 0.43711		1 17.44347	0.28155	0.38132
5 1.2 6 1.7 7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7			0.45549	0.60221	0.71513	0.89940
6 1.7 7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	332 1 261	0.84085	0.86942	1.0923	1.2589	1.5246
7 2.3 8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	11.20	10 1.0423	1.3632	1.7623	2.1732	1 2,2127
8 2.9 9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	7531 1.809	93 1.8610	1.9090	2.2759	2.5431	2.9603
9 3.5 10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	149 2.382	20 2.4437	2.5009	2.9354	3.2497	3.7378
10 4.1 11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	2,990	3.0615	3.1276	3.6271	3.9865	45430
11 4.8 12 5.5 13 6.2 14 6.9 15 7.7	395 3.627	74 3.7080	3.7825	4,3447	4.7479	5.3702
12 5.5 13 6.2 14 6.9 15 7.7	911 4.288		4.4612	5.0840	5.5294	6.1257
13 6.2 14 6.9 15 7.7	3637 4.970		5.1599	5.8415	6.3280	7.0764
14 6.9 15 7.7	5.670		5.8760	6.6147	7.1410	7.9501
15 7.7	6.386		6.6072	7,4015	7.9667	8.8349
			7.3517	8.2003	8.8035	9.7295
16 8.4	139 7.856	58 7.9874	8.1080	9.0096	9.6500	10.633
	579 8.609		8.8750	9.8284	10.505	11.544
	119 9.371		9.6516	10.656	11.368	12461
	751 10.14		10.437	11.491	12.238	13.385
	747 10.92		11.230	12.333	13.115	14.315
	526 11.70		12.031	13.182	13.997	15.249
-	312 12.50		12.838	14.036	14.885	16.189
	105 13.30	13.484	13.651	14.896	15.778	17.132
	904 14.11	.0 14,297	14.470	15,761	16.675	18080
	709 14.92	2 15.116	15.295	16.631	17.577	19.031
	519 15.73	9 15.939	16.125	17.505	18.483	19.985
	334 16.56		16.959	19.383	19.392	20.943
	153 17.38		17.797	19.265	20.305	21.904
	977 18.21		19.640	20.150	21.221	22.867
	805 19.05		19.487	21.039	22.140	23.833
30 19.6	637 19.89	1 20.123	20.337	21.932	23.062	24.802
40 28.1			1		1	
	134 28.45	1 28.741	29.007	30.997	32.412	34.596
n• number of	134 28.45 870 37.24	1 28.741 5 37.586				

n- number of lines

C.4 - Program listing

A MATLAB program was developed to implement this algorithm; this program is designed to handle a network of n nodes.

where:

w: an input matrix indicating the cost of link between all nodes in pair.

s: an input indicating the source node.

d: an input indicating the destination node.

cost: an output indicating the cost of the least-cost path

path: an output indicating the least-cost path between s and d.

The function code is indicated below:

```
function [xx,yy,M]=lepa(s,d)
load a.dat
b=triu(a,1);
a=b'+a;
crd=[
184735.9222 3447304.3699
168902.8999 3448543.8774
171655.4679 3449762.9030
170043.0469.3448548.1384
171400.1964 3449329.2010
172425.3698 3450351.3465
181974.7256 3450541.4472
184017.7969 3447922.0668
184182.5018 3448023.1878
184377.1967.3448028.4605
168849.8313 3449250.8644
184040,7614 3446600,3838
179196.4199 3447300.0011
168850.8211 3449253.8944
1;
x=crd(:,1);
y*crd(:,2);
N=size(crd,1);
k=1;
w≠[];
for n=1:N
x0=crd(k,j);
y0=crd(k,2);
dis=sqrt((x-x0).^2+(y-y0).^2);
w=[w dis];
k=n+1;
end
```

```
w=w/1000;
 C=a,*w;
 W
 Ċ
 n=size(C.1); %# of nodes
 x=s;
 N=1:n:
 N(x)=[];
 T=x;
 it=();
 while size(N,1) \sim = 0
    it=it+1;
    if it=1
    L=size(C,1);
  for ii=1:L
    M(it,ii)=C(x,ii);
    %calculate the path
   if C(x,ii) = 0
     path {it,ii}=0;
   elseif C(x,ii)==\inf
     path{it,ii}=[];
   clse
     path{it,ii}=[x ii];
     end
    end
  else
for i=N
  a=C(x,i)+M(it-1,x);
   b=M(it-1,i);
 if a<b
   M(it,i)=a;
    path{it,i}=[path{it-1,x} i];
  else
   M(it,i)=b;
   path{it,i}=path{it-1,i};
  end
 for h=T
   path{it,h}=path{it-1,h};
  end
 end
end
idx = find(M(it,:)>0);
[x \ y] = \min(M(it,idx));
x=idx(y);
 if it~≂l
  M(it,T)=M(it-1,T);
```

end

```
T=[T x];
k=find(N~=x);
N=N(k);
end
xx=M(n-1,d);
yy=path{n-1,d};
T
```

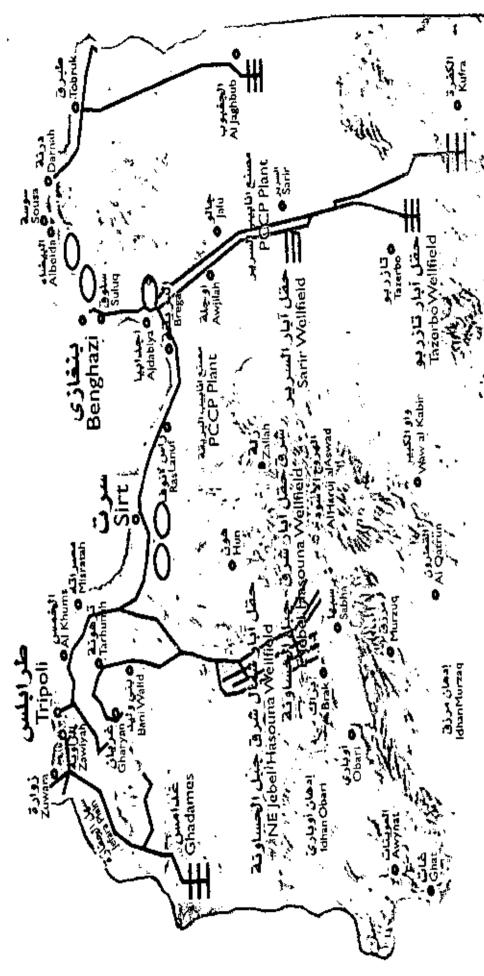


Figure (C.1) GMRA Locations on Libya Map

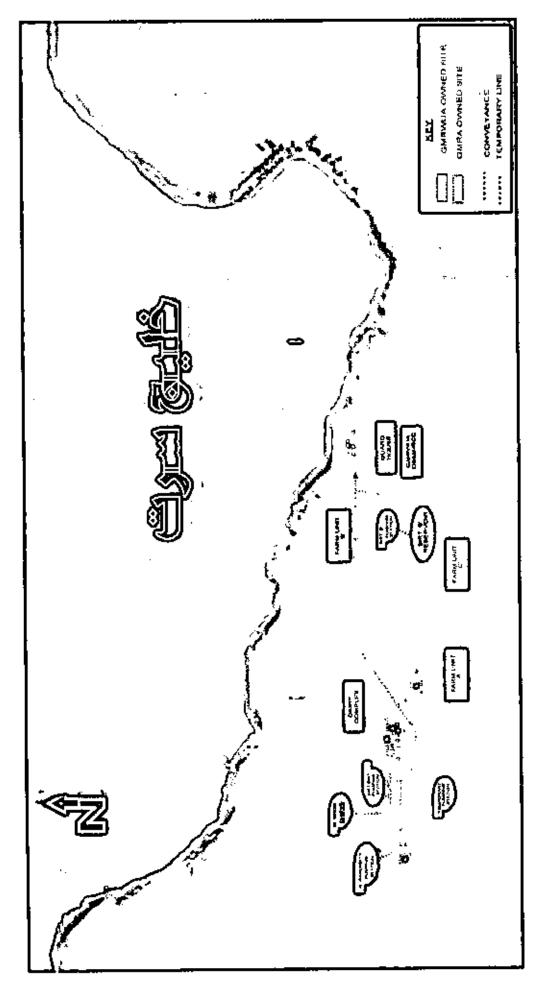


Figure (C.2) GMRWUA Locations on Sirte Map

APPENDIX-D SCADA Parameters Collection

SB-SP-001	CR-CE-001 002 003 003 006	CB CF 007
Strainer Panel P.VL-001	Small Farm Punns Panel PNL-003	Small figure Paner Paner 1003
(Strainer Chamber)	(Pump House Control Room)	(Pump House Control Room)
1) Reservoir/tunk levels	1) Pumps instrumentation	1) Header pressures
2) Inlet/outlet headers	2) Motors instrumentation & control	(2) Forebay tanks
3) Strainers	3) Isolating valves	3) Operating logic
4) Sump	4) Breaker status	4) Plow meter
SB-SP-002	SB-LF-001,002,003,004,005,006	SB-LF-007
Outlet Surge Panel PNL-002	Large Farm Pumps Panel PNL-004	Large Farm Pumps Panel PNL-004
(Air Compressor House)	(Pump House Control Room)	(Pump House Control Room)
1) Surge vessels	1) Pumps	1) Header pressures
2) Flow meters	2) Motors	2) Operating logic
3) Air compressors	3) Isolating valves	3) Flow meter
	4) Breaker status	
SB-CS-001	SB-SP-003	
Common Services Panel PNL-005	Inlet Surge Panel PNI, 006	
(Pump House Control Room)	(Pump House)	
1) Pressurisation units	i) Inlet surge vessels	
2) UPS	2) Alr compressors	
3) HVAC		
4) Telecomstelephones		
5) Generators/switchboards		
6) Fire alarm system		
7) Communications system		
8) PABX		
9) Site security		
10) Reservoir/tank levels		
11) Inlet/outlet headers		
12) Diesel storage		
13) Sump pumps		

GAGPS PUMP STATION - PLC DUTY ALLOCATON

101	101	01	500	COV		701			900	03	103	303	503	003	03		-			003	704)04	104	35	904	-004)04				200	
	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		PNL-001			PNI,-002			900-7NJ	PNL-003	PNL-003	PNL-003	PNL-003	PNL-003	PNL-003					PNL-003	PNL-004	PNL-004	PNL-004	PN1004	PNI,-004)-JNd			PNL-004				PN1,-005	
-	3	83	2	æ	æ	9	~)	**	9	4	3	3	<u>~</u>	m	4	-	2	-	0	3	۴٠,	دی	~	~	3	~	=	7	7	7	=	æ	<u>e</u>	
<u>ر</u>	2	12	0	0	0	0	0	0	0	_	_	_		_	_	0	0	5	0	0		-	_	-	-	-	=	Q	0	=	0	9	0	
Į.	3	51	0	ν.	~	9	3	3	9	2	2	2	2	2	2	0	0	æ	÷	U	-	3	~	<u></u>	~	60	-	=		c	_	×	5 .	
2	=	569	09	7	17	31	7	7	14	29	28	2.8	28	28	29	٧÷		5	3	18	27	27	27	27	27	27	-	æ	12	œ	7	06	102	
I BUINE	SERVICE	TOTAL I/O COUNT	Screen strainers panel	Outlet surge vessels panel	Outlet surge vessels panel	Outlet surge vessels panel TOTALS	In let surge vessels panel	Inlet surge vessels panel	Inlet surge vessels panel TOTALS	Small farm pump no.1 panel	Small farm pump no. 2 panel	Small farm pump no.3 panel	Small farm pump no.4 panel	Small farm pump no. 5 panel	Small farm pump no. 6 panel	Small farms pumps common panel TOTALS	Large farm pump no. I panel	Large furn pump no. 2 panel	Large farm pump no. 3 panel	Large farm pump no. 4 panel	Large farm pump no. 5 panel	Large farm pump no. 6 panel	Large farm pumps common panel	Large farm pumps common panel	Large farms common panel TOTALS	Small & large farms common services panel	Small & large farms common services panel	Small & large farms common services panel	Small & large farms common services punel TOTALS					
PLC TAC NO +	FLC IAU NU		SB-SP-001	SB-S1-002a	SB-SP-002b	SB-SP-002	SB-SP-003a	SB-SF-003b	SB-SP-003	SB-SF-001	SB-SF-002	SB-SF-003	SB-SF-004	SB-SF-005	SB-SF-006	SB-SF-007a	SB-SF-007b	SB-SF-007c	SB-SF-007d	SB-SF-007	SB-LF-001	SB-LF-002	SB-LF-003	SB-LF-004	SB-LF-005	SB-LF-006	SB-LF-007a	SB-L/F-007b	SB-LF-007	SB-CS-001a	SB-CS-00lb	SB-CS-00lc	SB-CS-001	

SIRT END(AGPS) PUM	SIRT END(AGPS) PUMP STATION - PLC DUTY ALLOCATON	LOCATÓN
SE-SF-001,002,003,004,005,006 Small Farm Pumps Panel PNL-003 (Pump House Control Room)	SE-SF-007 Small Farm Fumps Par	SE-SF-007 Small Farm Fumps Panel PN1,-003 (Pump House Control Room)
(1) Pumps instrumentation	1) Header pressures	
2) Motors instrumentation & control	2) Forebay tanks	
3) Isolating valves	3) Operating logic	
4) Breaker status	4) Flow meter	
	5) Telemetry Pressure	
SE-SP-002 Outlet Surge Vessels Panel PNL-002 (Air	SE-LF-001,002,003,004,005,006	SE-LF-007 Large Farm Pumps Panel PNL-
Compressor House)	Large Farm Pumps Panel PML-004 (Pump House Control Room)	004 (Pump House Centrol Room)
1) Surge vessels	1) Ришру	1) Header pressures
2) Flow meters	2) Motors	(2) Operating Jugic
3) Air compressors	3) Isolating valves	3) Flow meter
	4) Breaker status	
SE-CS-001 Small & Large Furms Common Services Panel	SE-SP-003 tolet Surge Vessels Panel	
PNL-005 (Pump House Control Room)	PNL-006 (Pump House-west wall)	
1) Pressurisation units	1) Infet surge vessels	
2) UPS	2) Air compressors	
3) HVAC		
4) Telecoms/telephones		
5) Generators/switchboards		
6) Fire alarm system		
7) Communications system		
8) PABX		
9) Site seenrity		
10) Reservoir/tank levels		
11) Inletfoutlet headers		
12) Diesel storage		
(13) Sump gamps		

	PANEL				PNL-002	PNL-003	PNL-003	P.V.L-003	PNL-003	PNI_003	PN1,-003			PNL-003	PNL-004	PNL-004	PNL-004	PNL-004	PNI-004	PN1,004			PN1,-004				PNL-005	PN1,-006
TATION	14.	1.1	 **	7	12	۳		~	۳.	3	٠.	~ 1	2	4	3	~	۳		3	اما	<u></u>	2	7	ř1	0	12	14	7
PUMP S	AO	12	-	-	Q	1	-		_	1	_	0	0	0	_	- 		-			0	0	0	0	•	0	0	0
(AGPS)	00	\$		۳.	9		2		2	2	2	0	0	0	2	2	2	2	2	2	0	0	Ð	٥	7	2	12	0
RTE EN	IC	81+	<u> </u>	16	32	20	18	20	18	20	18	1	-	7	26	23	26	2.3	26	23	~ 1	-7	ė	×	ť	64	105	12
PLC SCHEDULE - SIRTE END (AGPS)PUMP STATION	SERVICE	TOTAL VO COUNT	Surge panel	Surge panel	Surge panel TOTALS	Small farm pump no.1	Small farm pump no.2	Small farm pump no.3	Small farm pump no.4	Small farm pump no.5	Small farm pump no 6	Small farm pamps common	Small farm pumps common	Small larm pumps common TOTALS	Large farm pump no. 1	Large farm pump no. 2	Large farm pump no. 3	Large faint pump no. 4	Large farm pump no. 5	Large farm pump no. 6	Large farm pumps common	Large farm pumps common	Large farm pumps common TOTALS	Common to large & small farms TOTALS	Pump suction surge vessels			
	PLC TAG NO		SE-SP-002a	SE-SP-002b	SESP-002	SE-SF-001	SE-SF-002	SE-SF-003	SE-SF-004	SE-SF-005	SE-SF-006	SE-SF-007a	SE-SF-007b	SE-SF-007	SE-LF-001	SE-LF-002	SE-LF-003	SB-LF-004	SE-LF-005	SE-1.F-006	SE-1,F-007a	SE-1.F-007b	SI:-1.F-007	SE-CS-00la	SE-CS-00lb	SE-CS-00lc	SE-CS-001	SE-SP-003

SCADA PAKAN	SCADA PARAMETER SCHEDULE SIRT GAG RESERVOIR	AG RESERVOIR			
SERVICE	ALARM! FUNCTION	DAT	DATALINK SIGNAL TYPE	NAL TYPE	
		Id	8	90	₹
GAG RESERVOIR		55	43	10	09
BYPASS INLET VALVE	OPENCLOSE		7		
BYPASS INLET VALVE	CLOSED	 -			
BYPASS INLET VALVE	OPEN	-			 ! .
BYPASS INLET VALVE	FAULT	-			-
BYPASS OUTLET VALVE	OPEN/CLOSE		7		
BYPASS OUTLET VALVE	CLOSED				
BYPASS OUTLET VALVE	OPEN	 			
BYPASS OUTLET VALVE	FAULT	 			-
DRAINDOWN VALVE	OPEN/CLOSE		~		
DRAINDOWN VALVE	CLOSED	-			
DRAINDOWN VALVE	NEAO	 -			
DRAINDOWN VALVE	FAULT	_			
RESERVOIR LEVEL	INDICATE				7
RESERVOIR LEVEL	нен нен	 - 			
RESERVOIR LEVEL	нон	 -			
RESERVOIR LEVEL	WO.1	 - 			
RESERVOIR LEVEL	.wo'1.wo'1	_			
RESERVOIR OUTLET VALVE	OPENCLOSE		7		
GUARDHOUSE CONTROL UNIT TEMPERATURE	INDICATE				7
GUARDHOUSE CONTROL UNITIEMPERATURE	HIGH	 -			
GUARDHOUSE CONTROL UNIT TEMPERATURE	нон нон	1			
GUARD HOUSE AIR CONDITIONING START	CONTROL		_		7
			Ĭ	-	

SCADA PARAMITER SCHEDULE: GAG RESERVOIR

SCADA PAF	SCADA PARAMETER SCHEDULE: GAG RESERVOIR	AG RESERVOI	<u>~</u>		
SERVICE	ALARAV FUNCTION		DATALINK	DATALINK SIGNAL TYPE	
		IG	00	OV	14
CI DOWNSTREAM JETTING GUARD VALVE	OPEN	-			
CI DOWNSTREAM JETTING GUARD VALVE	FAULT	_			
BI OPSTREAM JETTING GOARD VALVE	OPEN/CLOSE		77		
BI JETTING FLOW	INDICATE				2
B1 JETTING FLOW	шен	1			
BI JETTING FLOW	иси вісн	1			
BLIETTING FLOW CONTROL VALVE	OPEN/CLOSE			ı	
BI JETTING FLOW CONTROL VALVE	CLOSED	1			
BI JETTING FLOW CONTROL VALVE	OPEN	1			
BI JETTING FLOW CONTROL VALVE	FAULT	1			
BUJETTING FLOW CONTROL VALVE	INDICATE				2
BI DOWNSTREAM JETTING GUARD VALVE	OPENCLOSE		2	1	
BI DOWNSTREAM JETTING GUARD VALVE	CLOSED	1			•
BI DOWNSTREAM JETTING CUARD VALVE	OPEN	1			
BI DOWNSTREAM JETTING GUARD VALVE	FAULT	1			
AT UPSTREAM JETTING GUARD VALVE	OPEN/CLOSE		ы		
AL JETTING FLOW	INDICATE				rı
AL JETTING FLOW	HIGH	1			
ALJETTING FLOW	нописы			1	
ALJETTING FLOW CONTROL VALVE	OPENCLOSE			-	rı
AL JETTING FLOW CONTROL VALVE	CLOSED	_			:

	SCADA PAKAMBI EK SCHEDOLE GAG KESEKVOLK	SERVER			
SERVICE	ALARM/ FUNCTION		DATALINK S	DATALINK SIGNAL TYPE	
		5	oa	0V	N.
AT JETTING FLOW CONTROL VALVE	OPEN PALICT	-			
AT JETTING FLOW CONTROL VALVE	INDICATE				7
AT DOWNSTREAM JETTING GUARD VALVE	OPEN/CLOSE		2		c1
AT DOWNSTREAM JETTING GUARD VALVE	CLOSED	-			
AT DOWNSTREAM JETTING GUARD VALVE	OPEN	1			
AT DOWNSTREAM JETTING GUARD VALVE	FAULT				
A2 UPSTREAM JETTING GUARD VALVE	OPENICLOSE	1	2		
A2 UPSTREAM JETTING GUARD VALVE	CLOSED	-			
A2 UPSTREAM JETTING GÜARD VALVI	OPEN	_			
A2 UPSTREAM JETTING GUARD VALVE	FAULT				!
A2 JETTING FLOW	INDICATE				м
A2 JETTING FLOW	HOH	1			
A2.IETTING FLOW	IIIGH HIGII	i – <u>i</u>			
A2 JETTING FLOW CONTROL VALVE	OPEN/CLOSE		2		ы
A2 JETTING FLOW CONTROL VALVE	CLOSED	_		ļ	
A2 JETTING FLOW CONTROL VALVE	OPEN	!			
A2 JETTING FLOW CONTROL VALVE	Links				
AZ JETTING PLÓW CONTROL VALVE	[NDICATE]				2
AZ DOWNSTREAM JETTING GUARD VALVE	OPENCLOSE	_	2]_ [
B2 UPSTREAM JETTING GUARD VALVE	OPEN/CLOSE	ı	2		

SCADA PARAM	SCADA PARAMETER SCHEDULE GAG RESERVOIR	RVOIR			
SERVICE	ALARM/ FUNCTION		DATALISK S	DATALINK SIGNAL TYPE	
	;	<u>a</u>	001	OV	Αl
B2 JETTING FLOW	INDICATE				C1
B2 JETTING FLOW	HIGH	_			
B2 JETTING FLOW	HIGH BIGB	-			
B2 JETTING FLOW CONTROL VALVE	OPEN/CLOSE		۲3	-	~
B2 JETTING FLOW CONTROL VALVE	CLOSED	_			
B2 JETTING FLOW CONTROL VALVE	OPEN	_			
B2 JETTING FLOW CONTROL VALVE	FAULT	- -			
B2 JETTING FLOW CONTROL VALVE	INDICATE	!			~
B2 DOWNSTREAM JETTING GUARD VALVE	OPEN/CLOSE		7	i	<u> </u>
B2 DOWNSTREAM JETFING GUARD VALVE	CLOSED	_	!		
B2 DOWNSTREAM JETTING GUARD VALVE	OPEN		i :		
B2 DOWNSTREAM JETTING GUARD VALVE	FAULT		i		
C2 UPSTREAM JETTING GUARD VALVE	OPEWCI.0SE		۲,	-	٤,
C2 UPSTREAM JETTING GUARD VAJ.VE	CLOSED	_			
C2 UPSTREAM JETTING GUARD VALVE	OPEN	_			
C2 UPSTREAM JETTING GÜARD VALVE	FAULT				•
C2 JETTING FLOW	INDICATE		_	ļ	۲,
C2 JETTING FLOW	HCH	-			
C2 JETTING FLOW	HIGH HIGH	-			ļ
C2 JETTING FLOW CONTROL VALVE	OPEN/CLOSE		7	-	F1
C2 JETTING FLOW CONTROL VALVE	INDICATE			Ì	rı