KNOWLEDGE BASED SYSTEM FOR THE EFFICIENT TRANSMISSION OF DATA IN A COMPUTER NETWORK ENVIRONMENT

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CERTIFICATION

We hereby certify that this work was carried out by Mr. **ADESESAN BARNABAS, ADEYEMO** in the Department of Industrial Mathematics and Computer Sciences(Computer Science Option), Federal University of Technology, Akure. To the best of our knowledge,this work has not been submitted elsewhere for the award of a degree.

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DEDICATION

This work is dedicated to all those souls whose lives have been stressed because vital resourses they need have had to be diverted to enable me complete this postgraduate programme.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In this research work, a study of computer network architecture, protocols, data transmission, switching techniques, and data routing algorithms is carried out. The Travelling Salesperson Problem is also reviewed because of its apparent similarity to the transmission of data in a computer network environment.

A model for the transmission of data in a computer network environment is conceptualised. A modified form of the two phase travelling salesperson algorithm is adopted for the minimization of the cost of transmitting data in the network. The cost element is generated from the case data obtained from Nitel Plc. A software package is coded using Basic language. The package is menu driven, user friendly and interactive. The software will generate all the feasible alternate paths for the routing of data in a computer network and attempts to select the minimum paths. A case study using a hypothetical Nigerian national computer network comprising all the states' capital in Nigeria and the Federal Capital Territory (Abuja) as nodes is carried out and the results obtained were presented.

CHAPTER ONE

OVERVIEW OF RESEARCH

In this chapter, an overview of the Research is presented. The Motivation, Objective and Methodology of research is discussed. The organization of the dissertation is also provided.

1.1 Motivation

World wide, the number of people who are using the facilities provided by cable and wireless communication systems is growing tremendously. This growth is being driven mainly by the value consumers and the business world place on mobility, convenience, and more effective use of time. It is sometimes said that there is a race going on between transportation and communications. If one wins, the other one becomes unnecessary. Using a computer network as a sophisticated communication system may reduce the amount of travelling done, thus saving energy (and time).

Most developing countries have been unable to fully utilise the enormous potential that exists as a result of the merging of the two powerful technologies of computing and communications. This is due to the lack of an efficient commmunications system. In many developing countries the communications facilities are either obsolette or grossly inadequate. This has resulted in the high cost usually incurred. Cost in this case is defined in terms of time wasted, energy consumed, and monetary loss. There is therefore, the need for an efficient communications model that will support the transmission of data and information with minimal cost incurred.

Virtually every aspect of any communication system can be modelled. Models that have been applied to communications systems include those of linear graph, linear programming, convex programming, queuing theory, and network models. Some models which are well known in other fields have not really found a wide application in communications systems for example the transshipment problem . In communications systems networking the following network models have been applied: the shortest path model, the maximal flow models and activity networks.

The cost of a transmission system is to a large extent a function of the loads carried by the network and the distance (in kilometers) over which it is transmitted. Where computers are connected together to form a network spread out over a number of geographically distant locations, the problem of designing a minimum cost communications network becomes economically significant. The design issues involves finding a way of connecting all the computers inorder to minimise the transmission costs. In communications system modelling, the mathematical theory of shortest connecting tree has been applied to the problem. A mathematical tree is a type of graph in which each pair of computer site is connected by only one line. The use of mathematical theory of trees permits a minimum cost network to be devised without an exhaustive search.

1.2 Objective

The objectives of the research are:

a. To propose a framework for the efficient transmission of data in computer network environments.

b. To carry out an experimental study of the framework proposed.

1.3 Methodology

The Travelling Salesperson Problem, the Minimum Spanning Tree optimization technique and the Hamiltonian cycle problem will be studied. In order to be able to identify those factors like the transmission time, line capacity, load, transmission distance and duration which determine the cost of data transmission per unit time. Computer networking and the mechanisms of data transmission in a computer communications network will also be extensively studied.

The Nitel network and billing procedures will also be reviewed. The cost of putting a call through to any part of the country where computers may be located will be determined. A framework will then be designed for efficient data transmission in computer networks. The experimental study of the framework will then be carried out by software simulation on the computer.

This experimental study will be based on a network comprising of the state capital cities and the federal capital (Abuja). A computer software package coded using Basic Programming Language will be used in the research for the experimental study. This software will be designed to be user-friendly, menu-driven, and interactive.

1.4 Organization of dissertation

The thesis is organised as follows: Chapter one contains the Overview of the research. The motivation, objective, methodology and the organization of dissertation is presented.

Chapter two presents the basic concepts of Knowledge Based Systems. Artificial Intelligence ,Knowledge Based Systems and Expert Systems is reviewed. Chapter three presents a Review of Travelling Salesperson Problem and the Minimum Spanning Tree optimization technique. Chapter four focuses on Local Area Networks and Wide Area Networks. Routing in data network, network protocols, data transmission mechanisms and switching methods for computer networks are also considered. A review of Nitel Plc telephone network services and their billing procedures is also carried out.

Chapter five presents the framework proposed for data transmission in a computer network environment. The design of the Knowledge Based Software package is also considered. Chapter six presents the implementation of the computer software developed for the research work. The case study carried out is also reported. Chapter seven presents the conclusion and recommendations.

CHAPTER TWO

REVIEW OF KNOWLEDGE - BASED SYSTEMS

In this chapter, the Basic Concepts of Knowledge Based Systems is presented. Topics covered include a Review of Artificial Intelligence, Knowledge Based Systems and Expert Systems.

2.1 Introduction

Knowledge Based systems are computer based systems which incorporate factual and inferential data as well as uncertain, heuristic and subjective data [Savory,1988]. In other words, a knowledge based system can be described as being a system that possesses a store of knowledge in a particular expert domain and is able to make deductions or inference from the knowledge base to solve problems in that domain of knowledge.

The conventional file system and database system have proved effective for solving problems with mathematical or statistical basis or a routine data processing nature. However, in areas such as management, industry and medicine, important problems exist which do not fit into this category. Solving such problems is still critically dependent on evaluating alternatives, predicting outcomes and making complex decisions. Scientists have been looking for ways of solving these unstructured problems.

These are the types of problems that people solve by trying various approaches and learning from their mistakes. Until now only a human intelligence could do this, but intelligent computer programs are now being developed for this. Computer systems that exhibit the characteristics associated with human intelligence are classified under the heading of Artificial Intelligence (AI). Using concepts from such disciplines as Psychology, Linguistics, and Computer Science researchers are learning how to prepare programs or construct systems that do tasks that no machine has ever done automatically before. Computers can be programmed to act as "experts" in fields of diverse nature as medical diagnosis and oil exploration [Akinyokun,1994].

These types of systems are also known as Intelligent Knowledge - Based Systems (IKBS), since the knowledge of an expert in a particular field has to be stored in the computer systems and tapped by a user having an intelligent conversation with the computer.

2.2 Artificial Intelligence

Artificial Intelligence can be defined as being a collection of computer supported technique emulating some of the natural capabilities of human beings. This collection includes primarily:

a. Problem Solving

b. Understanding natural language

c. Vision and robotics

d. Expert systems and knowledge acquisition/representation methods .

There are three basic methods of problem solving in use in Artificial Intelligence research. These are:

a. The search based methods

b. The algorithmic based methods

c. The knowledge based methods.

The algorithmic method is said to be associated with a curious phenomenon. That is, as soon as an algorithmic method for solving a problem is known, people cease to regard the problem as being one in the area of artificial intelligence. The corollary is that the algorithmic solution no longer separates its domain knowledge from its inference mechanisms, so that the self-explanation capability disappears [Savory,1988].

All the basic methods of artificial intelligence appear to involve searching through a space of possible solutions whilst optimizing some (predefined) evaluation function. Knowledge (often in the form of heuristics) is used to guide and constrain the search space. The major approach to problem solving now in use is that of knowledge controlled search.

2.3 Knowledge Based Systems

Knowledge based systems are programs that consist of at least two active components: a knowledge base and a so called "inference" engine. The concept of a "program" initially was that of a series of instructions. This classical Von Neumann computational schema concept lacked the ability to distinguish context dependent situations, and with its inherent linearity proved to be unsatisfactory practically. Therefore some subsequent developments of programming paradigms developed dual programming concepts.

One concept arose out of the mathematical differentiation between operators and operand. i.e., distinguishing between the algorithm and the data structures of a problem. PASCAL is a typical member of a group of languages that represent data structured oriented programming (i.e. algorithm plus data structures). The conceptual split of the algorithm and the objects on which the programming instructions act led to a certain degree of data independence, with the data structures being removed (or hidden) from the program itself. This is what has led to the development of database systems.

Another concept imported its principal ideas from the first order predicate logic and it draws a distinction between the descriptive (factual) logic of a program and the algorithmic control functions. PROLOG (i.e. Programming in Logic) is a language based on this programming concept. It is frequently used in Europe for the implementation of intelligent systems, and is the base implementation concept of the

Japanese 5th Generation project "KLn" (Kernel Language version "n").

Yet another viewpoint is represented by the research domain of artificial intelligence in the language SMALLTALK. This is based on the abstract data type (an abstract datatype is composed of an abstract data structure and an associated access function,). A program based on SMALLTALK consists of a number of objects that are composed of (local) procedures as well as (local) data. The execution of a program conceived in this style consists of a form of action by program objects so that objects send or receive communications from other objects, called "message passing".

This object oriented programming concept consists of a set of objects in the form of (data, procedure) couples. In this object oriented programming paradigm, the conceptual duality is hidden by the concept of the object, but the program behaves as if it were explicitly incorporated.

The most recent duality concept arose in the field of artificial intelligence that is, that of the knowledge based program. This consists of the knowledge base and the inference component. The knowledge base can contain descriptive and/or procedural knowledge for the solution of problems. It is the function of the inference machine to instantiate the knowledge base to the problem at hand. That is, to interpret the problem in the context of its knowledge about the problem domain. The method of representing knowledge for example predicate logic set rules, specific rules and facts, graphs, trees, nets, frames or procedures, is without significance, as far as the conceptual level of the knowledge base is concerned.

In the 1950s there was a preconception dominant in artificial intelligence research that it was sufficient that problem solving systems should contain general, domain independent, knowledge coupled with very powerful problem solving strategies which would give quantitatively satisfactory results. Practical experience, however, conflicted with this preconception.

Since the mid 1960s, and reinforced in the 1970s the above directions were replaced by the recognition of the fact that the construction of problem solving knowledge based systems that give satisfactory performance requires emphasis on precisely the previously neglected aspect that is to highlight domain specific problem solving knowledge. Therefore, the new concept of knowledge based systems emerged. It is a domain specific knowledge oriented system paradigm, and this concept has now percolated all artificial intelligence activity in this area [Savory,1988].

The Knowledge-Based system for the Efficient Transmission of Data in a Computer Network Environment is based on a heuristic method developed for solving the traveling salesperson problem. This rule of thumb method which would give a sub optimal solution near the optimal but which is also computationally feasible and efficient is applied by an interactive process which takes place between the user and the menu driven system. Hence, while a knowledge base consisting of the problem domain and mathematical procedures have been created, the human intuition and experience is still needed to complete the processing of the algorithm.

2.4 Expert Systems

A person is considered an expert if he has a large knowledge domain in the form of facts and rules, and in addition has individual experience generally not found in the literature of the domain. Experience consists of heuristics, analogies, judgments on the basis of individual decision criteria. Such experience and knowledge enables the human expert to choose promising problem solving strategies or, if these turn out to be unsuccessful, to go back to the point from where the strategy failed and to try another alternative.

Expert systems are computer based programs which store experts factual and inferential knowledge. They use heuristics and fuzzy knowledge and are able to draw conclusions themselves, based on their database from given case data. In addition they can inform the user at any point of the solution, what hypothesis they are currently pursing, why they have chosen a particular strategy, what conclusions have been drawn so far, and why these conclusions were drawn. Expert systems are thus intrinsically knowledge based systems.[Savory,1988].

The first applications of Expert systems occurred in the USA as a result of close cooperation between the industry and academia. The majority of these systems were developed within the frame work of the famous "Heuristics Programming project" (HPP) at Stanford University. However, it is the more speculative yet relatively rare applications in industry that brought artificial intelligence into the world headlines. For example, Expert systems being used for mineral prospecting (system "Prospector").

Early knowledge based systems, such as Stanford's MYCIN for the diagnosis of infectious diseases or Nixdorf's CHICO for generating commercial application program suites, did not separate their knowledge clearly from their inference mechanism. They also did not have an explanation component or only a rudimentary one as in MYCIN. R1 an expert system for computer systems configuration developed by DEC (Digital Equipment Corporation) however remains a classic example of a successful, yet relatively simple, expert system in industrial everyday use.

To develop the Knowledge Base for an Expert system, AI researchers spend many months picking the brains of specialists to extract and structure the knowledge that is the basis for the specialists expertise. Once a knowledge base is created, programmed techniques for efficiently representing and processing the stored facts and ideas are then used to probe the base. Different approaches are used by different Expert system packages to deduce factual relationships and arrive at conclusions.

Knowledge may be expressed in a natural language for example English, and a series of exchanges between the user and the Expert system is usually needed. As the user supplies the inputs, the Expert system responds as an intelligent assistant by giving advice and suggesting possible decisions.

Decision support systems (DSS) software are the programs which come closest to Expert systems in purpose. However, a DSS cannot help to decide what questions to ask, or what data to key in, neither can it suggest further actions based on the result of an analysis. Only an expert system that can assume the role of teacher/partner can do this.

The human input to Expert Systems remain a crucial element in their development. Expert systems are used as consultants, not decision makers. The human user must decide how to make use of a systems knowledge.

CHAPTER THREE

REVIEW OF TRAVELLING SALESPERSON PROBLEM

This chapter reviews Travelling Salesperson Problem" with emphasis on some existing published work in the area. The review is relevant because of the apparent similarities of travelling salesperson programmes and data transmission programme in a computer network environment.

3.1 Basic Concept of Travelling Salesperson Problem

The Travelling salesperson problem (TSP) can be represented by undirected graph G(V,E,C) where V,E and C are the vectors which define the finite set of the vertices, edges and cost of edges respectively of the graph. A tour of G is a directed cycle that includes every vertex in V. The cost of a tour is the sum of the cost of all the edges in the tour. The cost of a tour may be defined in terms of kilometer, the time in terms of hours it takes to make the tour or the fuel consumption during the tour.

The travelling salesperson finds application in a variety of real life situations such as in:

a. The tour of company goods delivery vans.

b. The tour of post office mail delivery vans.

c. The communication of data in a network of computers.

d. The movement of robot arm to tighten the nuts of some pieces of machinery on assembly line of a manufacturing company.

A number of attempts have been made at solving the travelling salesperson problem. The travelling salesperson problem has been modelled using dynamic programming technique in [Horowitz et al,1978]. The drawback of this technique is the large computer storage space and computational time needed even for a tour consisiting of modest value of n vertices. On a general note, dynamic programming model is characterised by a multi-dimensional state vector which presents a serious obstacle in solving medium-size to large size dynamic programming problems.

A least cost Branch and Bound algorithm is proposed in [Horowitz et al,1978] for solving the travelling salesperson problem. The algorithm involves the construction of a state space tree and the formulation of a constrained cost function for each vertex of the weighted conceptual graph of the problem. The state tree is given by:

$$T = (i,n , 1)$$

Where n is the permutation of the n vertices of the conceptual graph. The cost of the mathematical permutation in terms of computational time is 0(n-1)! which may be expensive when n is large.

A heuristic procedure for solving travelling salesperson problem is proposed in [Golden,1980]. The procedure selects any vertex of the weighted conceptual graph of a tour as the central depot, computes the savings for navigating the edges from the initial vertex. The savings are sorted in ascending order of magnitude and the tour of the graph is constructed by linking the appropriate vertices in the sorted order. One of the drawback of the procedure is that the computation of the saving is exhaustive and may be very expensive when the degree of a vertex is very large. Another drawback of the procedure is that, the approximate optimal tour obtained is not guaranteed to be a Hamiltonian cycle. A tour is Hamiltonian cycle if each vertex in the conceptual graph is visited only once and returns to its starting position. This is the requirement for the travelling salesperson problem

In [Christofides,1976], a Three-step heuristic procedure for travelling salesperson problem is reported. The first step constructs the minimum spanning tree of the weighted conceptual graph of the travelling salesperson problem. The second step transforms the minimum spanning tree into Euler cycle. The Euler cycle is transformed into Hamiltonian cycle which is least costly in the third and final step. The experimental study of that procedure carried out in [Golden et al,1980] addressed a tour of limited vertices and the implementation of the third step was not reported. That experimental study is, however, improved upon in [Lithe,1984] by considering clustered vertices of a tour which facilitates the transformation of Euler cycle into Hamiltonian cycle with considerable reduce cost.

In [Akinyokun, 1990] a two phase-heuristic procedure for solving travelling salesperson problem is proposed. The heuristic is an extension of Christofides procedure with emphasis on the designers interaction with the mathematical algorithmic procedure for generating the Hamiltonian cycle of the tour of a salesperson.

The objectives of [Akinyokun, 1990] are:

a. Given a set of cities and a start city, it is desired to generate the tour of a salesperson so that each city is visited only once.

b. To minimise the cost of the tour.

The first phase of the algorithm employs the greedy philosophy in the construction of sub optimal initial tour of a travelling salesperson. The empirical rules which guide the construction of the initial tour are as follows.

a. Select the start city for the travelling salesperson

b. Identify all the cities connected to the start city and visit the city whose cost from the start city is least.

c. From the current city, select the next city to be visited by applying the following criteria:

c.1 Identify all the cities connected to the current city which have not been visited and visit the city with the least cost.

c.2 If all the cities connected to the current city have been visited, select the one with the least cost as the next city to be visited. (This selection criteria violates the requirements for Hamiltonian cycle of the travelling salesperson problem. This requirement would however be restored in the second phase).

c.3 If all cities in the route have been visited and the start city is among the city connected to the current city, then visit the start city and end the journey.

d. Repeat step c until all cities have been visited.

The time complexity of the generalised algorithm has been proved in [Akinyokun,1990] to be O(Q(n)) where n represents the vertices of the tour and Q(n) represents a polynomial in n. This time complexity has a polynomial growth which is computationally tractable.

Applying these rules to the weighted conceptual graph of Fig. 3.1 where the vertex represented as A is considered as the start city, that is the take off point of the salesperson. The initial tour depicted in Fig. 3.2 is obtained.

The initial suboptimal tour obtained from the first phase acts as the primary input to the second phase. The main goal of this phase is to obtain an approximate optimal tour which is a Hamiltonian cycle. The processes of the second phase are as follows:

a. Display on the computer screen the initial tour.

b. Identify the subtours of the initial tour which are not Hamiltonian cycles.

c. Select a subtour which is not a hamiltonian cycle.

c.1 Generate all the tours of the subtours such that in each tour, every node in the subtour is visited only once.

c.2 Select the tour of the subtour which has the cheapest cost.

d. Repeat step c until the subtours are exhausted.

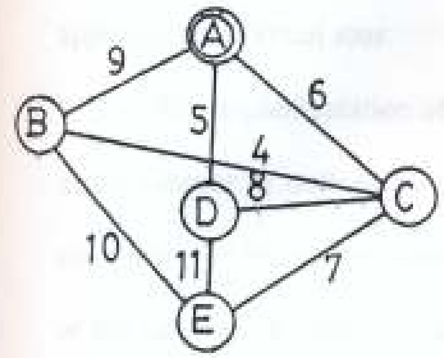

Fig 3·1 : Conceptual graph

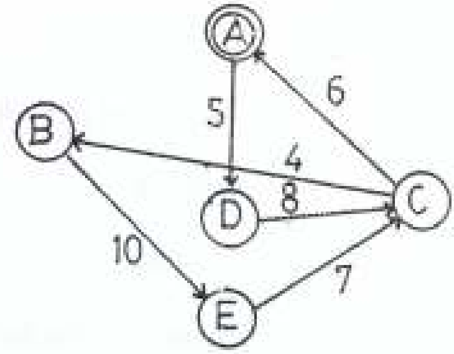

Fig 3·2 - 40 Km initial tour

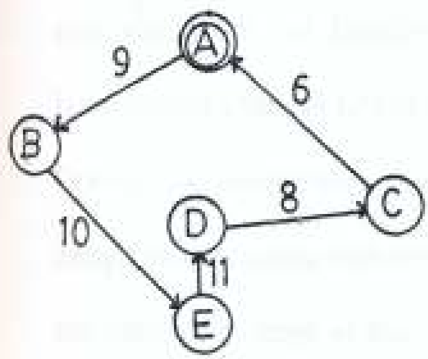

Fig 3·3 : 44 Km tour

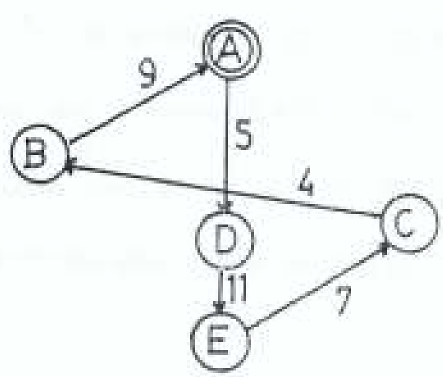

Fig 3·4 : 36 Km tour

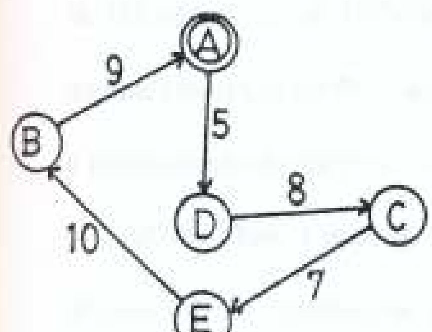

Fig 3·5 : 39 Km tour

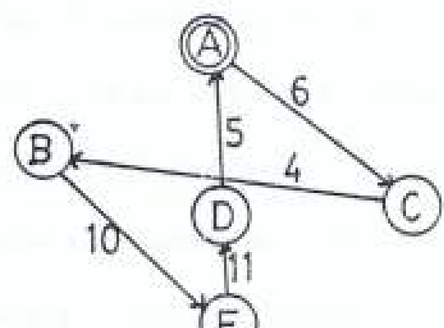

Fig 3·6 : 36 Km tour

Applying these rules to the initial tour of Fig 3.2, four Hamiltonian cycles are generated. These are depicted in Figures 3.3, 3.4, 3.5 and 3.6. Two of them have the same cost which is the cheapest. Hence any of these two can be selected as the approximate optimal tour.

The implementation of these rules is interactive and menu driven. A tour T of a given subtour is defined by the permutation of the vertices of the subtour. The time complexity of the mathematical permutation is O(n-1)! where n is the number of vertices of the subtour. A subtour is constraint to be of limited and manageable size; hence n is small and the time complexity is not explosive. Let k represent the subtours of the initial tour which are not Hamiltonian cycle. Then the time complexity of generating all Hamiltonian cycle is O(k(n-1)!. Since k is a constant, this time complexity reduces to O(n-1)!. A permutation may give rise to an infeasible tour of the subtour. By the designers interaction with the scheduling system, such permutation can be ignored during the subsequent steps of tour evaluation.

The algorithm for generating Hamiltonian cycle of a salesperson tour proposed in [Horowitz et al,1978]is the recursive formulation of backtracking whose time complexity is O(p(N)N!), where N represents the vertices of the tour and P(N) represents a polynomial of order N. Let t represent the time complexity of the proposed heuristic procedure. Then, t is defined by t = O(Q(n)(n-1)!) where Q(n) represents a polynomial of order n. In practice, N is very large compared with n. Therefore O(P(N)N!) > > O(Q(n)(n-1)!). Hence the two-phase heuristic procedure is more efficient than the mathematical algorithmic procedure proposed in [Horowitz et al,1978].

The following conclusions can be derived from [Akinyokun 1990].

a. The minimization of cost in terms of computational time and storage space have been achieved.

b. The time complexity of the proposed heuristic procedure is not explosive, hence it is computationally feasible.

c. Extensive experimental study of the proposed algorithm of the first phase and the variant of Prims minimum spanning tree generalised algorithm have been carried out and the results obtained show that the proposed algorithm reflects the true nature of a travelling salesperson while the Prims algorithm does not.

d. From the results of the case study carried out, it has been shown that given a salesperson tour and a start city, two or more approximate optimal tours can be obtained. When any of the other vertices is chosen as the start city, the results obtained (that is the cost of the approximate optimal tour) in each case vary from one to another.

3.2 Concluding Remarks

The travelling salesperson problem is one of the problems, whose solution is being sought by using the theory of networks in the field of operations research. The simplicity of the statement of the problem has been described as being misleading, because until very recently, there existed no computationally feasible algorithm for its solution.

With the advent of the computer, the ultimate goal has always been to minimise the cost in terms of the computational time and storage space required. Hence only approximate algorithms like that proposed in this paper which are based on heuristic solutions have proven to be better than the other methods that have been applied to problems with large number of vertices.

The heuristic method proposed in this paper has proved to be efficient in producing a sub-optimal solution close to the optimal. It also reduces the computational time from an exponential to a polynomial function (of the input).

CHAPTER FOUR

REVIEW OF COMPUTER NETWORKING

In this chapter, a review of the software, hardware and techniques for implementing computer networks is carried out. Other topics covered are Network Protocols, Routing systems and Switching Techniques for computer networks. A review of Nitel plc services and tariff structure is also carried out.

4.1 Local Area Networks(LANs)

Computer network is the interconnected collection of autonomous computers. Two computers are said to be interconnected if they are able to exchange information via a communication medium such as cables, microwaves or satellite between them. Two computers are autonomous when there is no master/slave relationship between them. Each of them has a processor (Central Processing Unit) hence capable of processing its local data without reference to any other computer.

The goals of cabled computer network are:

a. To share resources:typical resources are data files, programs, computer memory, output devices, input devices and software packages.

b. To provide high reliability:the components of computer network are often replicated. A faulty component cannot cause a breakdown of the computer network.

c. To save money:interconnection of low cost and high cost components with a view to optimizing users and system performance gradually as the workload grows just by adding more processors.

d. To provide communication medium among widely separated people:electronic mail, multi-media system, electronic bulleting board system.

A Local Area Network (LAN) is essentially a network designed for intelligent workstations. The workstations attached to the network can use the processing capability of other intelligent devices for certain shared processing functions, such as network management and batch processing. However, in most applications, the workstations use their own computing power.

The response time experienced by a user of a LAN must be very high, and it should be able to transfer large amounts of data quickly since the network may be used for sharing file storage devices or for real time cooperation between processors situated on the network. The distances that a LAN spans are relatively small, compared to a Wide Area Network (WAN) hence high grade communications media can be used without the cost of the complete system being too heavy. This also means that the information transfer rate can be high without the need for expensive signal strengthening, to be carried out, at frequent intervals along the communications path.

A local area network (LAN) consists of the following:

a. Computers

b. Data transmission medium

c. Network hardware interface

d. Network software that runs on each of the computers and allows the computers to work in conjunction with each other.

Computers in a LAN environment can be connected in any of the following ways.

a. A host-to-terminal connection

b. A peer-to-peer connection

c. A client-server connection

4.1.1 Host-to-Terminal connection

The host computer has all the processing power in the LAN environment and drives the terminals each of which serves as a workstation. In this environment the terminals rely on the host computer for all its processing.

Host-to-terminal systems were created at a time when computer processors were extremely expensive. To be economical, one processor had to support many people using dumb terminals. Today the cost of processors has declined to the point that intelligent workstations are as inexpensive as dumb terminals. The cost efficiency of host-to-terminal protocols, therefore, have diminished.

4.1.2 Peer-to-Peer connection

When two computers connected to each other are capable of passing data back and forth, they are peer-to-peer connected. The typical peer-to-peer system is designed for transferring large files from one host computer to another. Where peer-to-peer types of protocols have been used on LANS, performance has suffered because the protocols were not optimized for handling multiple requests. Reliability also declines when no special-purpose machine is placed in control of shared resources,that is there is no client nor server, but every computer is both a client and a server to all the other computers.

4.1.3 Client-Server connection

In the client-server LAN environment, there is a computer which serves as the file server and a host of other computers each of which serve as an intelligent workstation. Each of the workstations has a processing power and capable of storing local data files and programs. However, the server has a large processing power such as large storage space, high processing speed, expensive peripherals such as Printers and expensive software packages which each of the workstations has to share.

Client-server protocols are designed for optimal use of the computing resources that are available in the LAN environment. The workstations uses its own resources for most processing. It is only when the workstations local resources are not sufficient that it sends a request to the network.

The primary role of a server is to share resources with users at the workstations. Servers get their name from their role of serving the needs of users at clients. A computer that operates as a server must have a large hard disk. Files and applications that are shared across the LAN are stored on the server hard disk. In addition, the server will have special network software that enables it to share printers with other computers on the network. A network must have at least one server but a large network may have more than one server. Every workstation has access to a shared directory on the server that provides essential network utilities to a workstation. The utilities include programs that enable workstations to access other resources on the network.

Most of the computers on a LAN operate as workstations. Workstations use resources shared by servers. Shared resources may include directories and printers. For example, a workstation can connect to a servers shared directory and then use that directory as though it were one of the workstations own disk drives. In order for a computer to become a workstation on a LAN it must have the client program installed on it.

4.2 LAN Software

It is often necessary to interconnect many different types of computers, each with a different operating system. A LAN software or network operating system software may be used for this purpose. The LAN software functions in the network in the way a local operating system functions in a standalone computer. The network operating system can provide a standard connection language and message passing protocol among the individual operating systems of the networked machines as well as providing access to files in other machines. The LAN software provides the software environment in which the LAN hardware operates. Functions provided by LAN software may include, File and record locking, Security, Print Spooling and Electronic mail.

In order to enable several computers share a harddisk, early network systems were based on a multiplexer device. It used a polling scheme to regulate computers access to a central hard disk, but does not however, have a mechanism for security or data integrity. Such concepts as data organization, disk management, and information sharing were nearly impossible. This leads to the introduction of the Disk server in the early 1980's on which early network operating systems were based.

The Disk server is a software program that runs on top of PC-DOS, and provides a level of network management. Many LANs used this management approach before 1985. In a Disk server environment workstations access the shared harddisk as if the disk was their own dedicated device. Input/output (I/O) requests to the disk storage are redirected by Disk server software to go out onto the network to the shared hard disk. The workstation operating system is tricked into thinking that it is talking to a local disk, when in reality the disk is somewhere else on the network. Disk servers include many information sharing features, however, because of the inherent design of the Disk server, sharing information without losing data integrity was still not possible.

In 1983, Novell introduced a new management approach for LANs called File service. The File server software is a centralized software for managing disk. While in a Disk server environment, each computer manages its own disk, in a File server environment, the File server does this function. The File server systems enforces all disk

I/O request to go through the File server and the system can synchronize disk. Data integrity and security is better maintained, since only one device controls the disk at a time, and all requests must pass through the File - server. The File server architecture also enables dissimilar workstations operating systems to access the same disk and to share information. In 1984 IBM and Microsoft adopted the File server approach to network management.

Among the network software available are: Microsoft LAN manager, NCR (Star Group) LAN manager, Novel Netware, Unix and WindowsNT Advanced Server. Operating systems that provide support for networking include Dos 3.1 and all higher versions, WindowsNT, and Windows '95 operating systems.

4.2.1 MS-DOS/Netbios

MS-DOS is the most common operating system for single - user computers. With the earlier versions of MS-DOS each LAN vendor developed proprietary file and record locking techniques, and applications software had to be modified to suit each type of LAN. MS-DOS 3.1 included multiuser primitives for controlling application access to the network. This provided a standard interface for applications software and permitted one version to run on all MS-DOS 3.1 compatible networks. Consequently, a large range of compatible applications software were developed for multiuser computer network applications. The versions of MS-DOS greater than 3.1 have improved on and enhanced this network support.

The IBM NetBios (Network basic input/output system) is a peer - to - peer, session layer interface for the IBM computer network. For compatibility with the IBM computer, a network operating system must emulate NetBios and, if the IBM PC network program is to be run, a LAN must emulate NetBios because NetBios is implemented in firmware on the computer network adapter hardware.

4.2.2 Novell Netware

Novel created its first networking product in the early 1980's. In 1983, it produced a product that converted the IBM PC XT hard disk system into a file sharing system, and later, it introduced Netware/86, which provided file server capabilities. In 1986, a new version of Netware called Advanced Netware, was able to provide more support for LAN hardware by bridging different network types within the file server or an external workstation, hence it became possible to install both an Ethernet and Token Ring card in the same server.

The Advanced Netware 286 is designed to take advantage of Intel 80286 based systems and it provides multitasking capabilities long before products such as 0S/2 and Microsoft Windows existed. In 1989, the Netware 386 V3.0 was introduced. This operating system was completely rewritten to take advantages of features built into the Intel 80386. It has a full 32 bit operating system that was designed for large networks with massive data handling needs. It also had enhanced security performance and flexibility. Version 3.1 came out in June 1990 and in 1991 the Netware V3.11 which supports DOS, Macintosh, Windows, 0S/2 and UNIX file and print services is produced. The Novell Netware version 3.11 has been widely used all over the world in the 90's.

The Netware 4.2, is however an enterprise - wide network operating system, that is, it encompasses all the computing resources of an organization. This has made Novell Netware very popular in business environments. Novell Netware can operate cooperatively with an MS-DOS system, because it has been upgraded to take advantage of the enhanced MS-DOS features. In place of the directory used in DOS, there is a Netware shell which sits between DOS and applications in a Netware environment. The shell receives all operating systems commands, and decides if they are intended for the network or the local systems. Local commands are associated to MS-DOS and remote commands to the Internetwork Packet Exchange (IPX), which passes them across the LAN to the server. Netware allows the shell to interpret commands rather than MS-DOS. This makes it more efficient for networking. Novell also provides a Netbios emulator for the clients workstations [Sheldon,1994]. The ability of Novell Netware to cooperate and coexist with MS-DOS has made it popular and most widely used in LAN environment worldwide in the past decade.

4.2.3 Unix in the network environment

Most Unix implementations nowadays include TCP/IP and support for Ethernet, and this has greatly simplified networking in the UNIX environment. Also the Network File System (NFS) is the distributed File - sharing system included with UNIX. NFS lets users access files on remote systems as if the remote systems were a part of their own systems. The remote file system is 'mapped' so that it appears as a local drive. The TCP/IP has several applications to facilitate file transfers and remote access between systems, such as Telnet and File Transfer Protocol (FTP). Hence UNIX provides in one package the ability to install a powerful operating system on a computer that lets users share files and run programs on other users computers. Unix is very popular in research environments.

4.2.4 Microsoft Windows NT/Windows NT Advanced Server

Microsoft Windows NT is designed to take advantage of powerful new desktop systems, and is not restricted to Intel systems as are DOS and WINDOWS. It runs on the Motorola Power PC; Intel 80386, 80486 and Pentium processor systems; MIPS R4000

64 - bit Risc systems; DEC Alpha based 64 bit Risc systems and ' super server' systems. Windows NT expands on the features of Windows 3.1 and offers many features that makes it unique.

Windows NT is a 32-bit operating system with pre-emptive multitasking and memory protection, as well as support for symetrical multiprocessing and networking, all with a graphical user front - end. The ability of Windows NT to fully access 32-bit processors allows it to work with larger numbers of memory addresses and instructions.

The Networking features enables files to be shared with other network users and connections with shared directories on other systems. Windows NT has software and drivers to support connections to other types of operating systems, such as UNIX and IBM mainframes.

The Windows NT Advanced Server is an enhanced version of Windows NT that provides sophisticated file server features for large network environments. It provides all the features of Windows NT, such as 32-bit operations, preemptive multitasking, symmetrical multitasking, gigabyte memory addressing capabilities, networking, and security, in a system designed to operate as a network server. The system provides network administration features and the data protection features of advanced fault tolerance. Features available only in Windows NT Advanced serves include more control over administrative domains and advanced fault tolerance features. The Remote Access server features also provide a way for administrators to access and control systems remotely using asynchronous telephone lines, Integrated services Digital Network (ISDN), and X.25 networks [Sheldon, 1994]

4.2.5 Windows 95 and Networking

WINDOWS 95 was launched as a full - fledged operating system by Microsoft Corp. to replace the Windows operating environment for MS-DOS which the previous versions of Windows that is, Windows 3.x provided. Windows 95 has many new features that are not available in the older Windows 3.x and Windows for Workgroups 3.11 releases.

Windows 95 uses a 32 - bit architecture to provide for faster communications between applications and the network. The network drivers in Windows 95 are implemented as Virtual Device Drivers that are 32 - bit, protected - mode applications. Being 32 - bit protected mode, they do not require any of the machines conventional memory, leaving this vital resource for memory - hungry applications. The 32 - bit architecture is extended to all facets of networking support. Windows 95 includes 32 - bit network client software, 32 - bit network protocols, 32 - bit network interface card drivers, 32 - bit file and printer sharing software, and much more. This is combined with support for existing 16 - bit software applications currently in use with Windows for Workgroups.

Windows 95 supports more than one protocol at a time, which makes it possible to be connected and working on two or three different networks at the same time. Hence while Novell Netware IPX/SPX might be used for workgroup client/server systems, it could be switched to TCP/IP when a UNIX server is to be connected. Files can also be transferred between the TCP/IP network and the Novell Netware network without having to reconfigure and reboot each time. Windows 95 is designed to integrate as cleanly with Netware as possible. The default network protocol is now Netwares IPX/SPX instead of Windows for Workgroups NetBIOS, although NetBEUI can still be used in a Windows for Workgroups network. The new network drivers included with Windows 95 are written in 32 - bit protected mode and have been designed for faster performance for Netware 3.x and 4.x systems.

Windows 95 supports several different peer-to-peer protocols directly. For dial -

up use, the Remote Access server, allows access to desktop machines or workgroup servers from laptops anywhere, and file transfer or application usage can take place over a modem line. Network printing and network backup software are also included in the Windows 95 package. Windows NT and Windows NT server versions have also been upgraded to the Windows 95 standard, with the same Graphical User Interface being provided for them also [Tilley,1995].

4.3 Local Area Network Architectures

The topology of a LAN is usually a description of the wiring which connects the network workstation, however, it does not always describe the route which packets take when they traverse the network. The topologies employed by LANs are simple unlike WANs which are normally more irregular. The most common topologies in the 80's in use for LANs are the bus and the ring, because they are both very simple to implement. They require only one sort of node on the network, which serves to connect hosts to the network and perform packet routing. In the business education and research environment today, the Star topology has assumed a state of prominence.

4.3.1 Bus Topology

The Bus topology is the simplest of all LAN topologies. It has a common communicating medium to which all network nodes are connected, and a device has only to tap onto the medium. It contains no active circuitry to amplify signals that is it is passive. When a packet is placed on the bus, it is seen by all devices which are attached to the bus. The computers share a common communications medium,only one computer can transmit data at a time. Transmission employs a packet containing the source and destination address fields and data. Each computer monitors the communication medium and copies the packets addressed to itself. Bus systems have been implemented using a very wide range of communications media, for example both cable (coaxial and twisted pair) and atmosphere types (radio) are suitable for use. Fig.4.1 shows a conceptual diagram of a bus LAN. The workstations are labelled A - H in the diagram. Any one of them could be the server, they are all connected by the common communications medium provided.

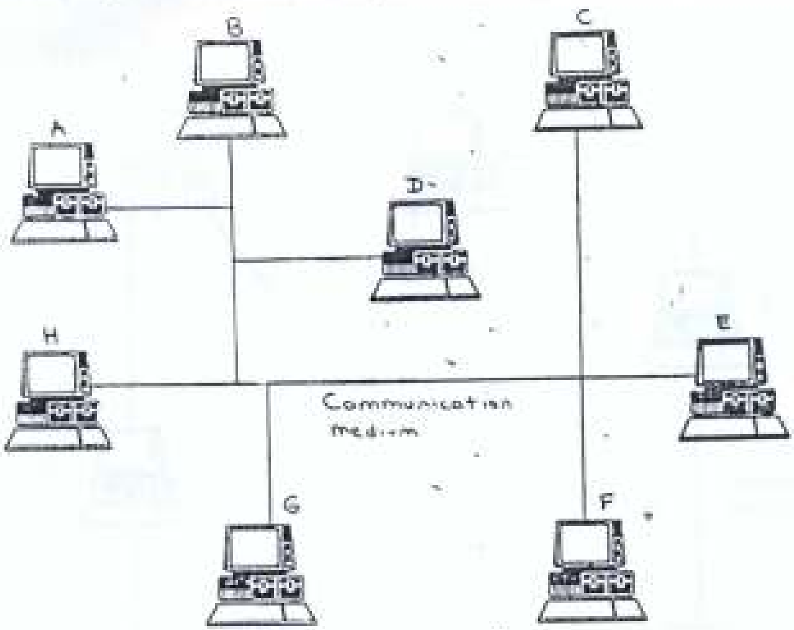

FIG 4.1 Conceptual diagram of a Bus LAN

4.3.2 Ring Topology

A ring network contains a loop of communication medium. Data flows around the ring in only one direction with the devices connected to the ring receiving data from it, and interrupting the data on the ring to inject their own when they wish to transmit. Rings are normally "active", that is they include regenerating circuits which must operate continuously. Hence rings can be extended to any size provided sufficient regenerating circuits or repeaters are included. Packets transmitted on a ring can be removed by the source or the destination, otherwise it will circulate indefinitely until removed. Rings have a broadcast nature. Any packet transmitted may be seen by all nodes on the network, this makes it possible to transmit to many nodes with only a single packet. All that needs to be done is to reserve a particular network address that is recognized by all nodes. Ring systems have advantages over bus systems as far as network access techniques are concerned, although it may appear to have poor reliability, since the failure of any element in the ring will disable the entire network. A number of schemes have been proposed to counter this situation and actually ring failures are very rare in practice.

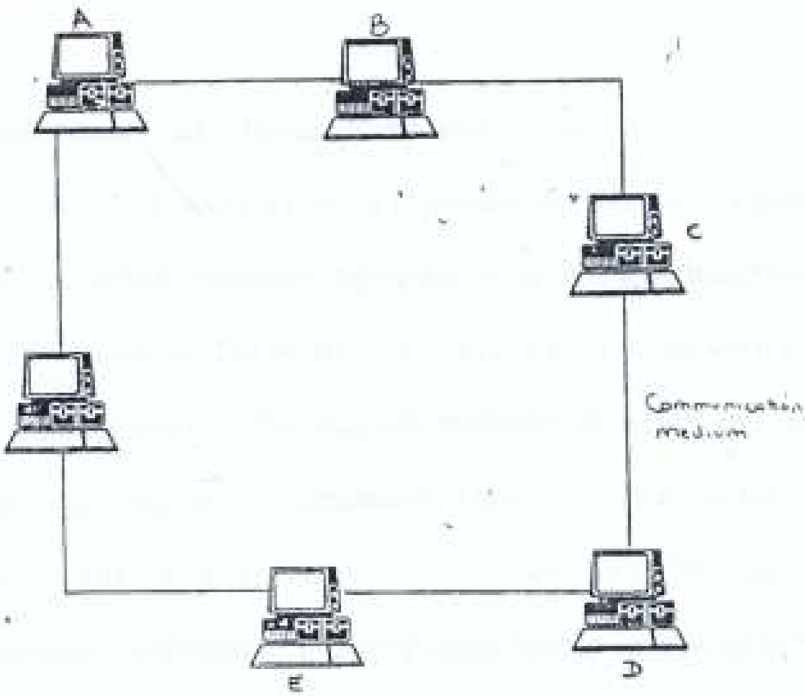

FIG 4.2 Conceptual diagram of a Ring LAN

The maximum size of a single ring communication system is limited for a number of reasons. The greatest degradation in service occurs when a ring is populated with many devices which generate packets at a high rate. Another is the round trip delay that would be experienced on a physically large ring. An alternative to large scale rings is a collection of smaller rings interconnected by bridges. When a dialogue with a device connected to a different ring is required, packets are directed to the local bridge, which then forwards them to the adjoining ring. Complex structures of multi-ring systems can be built, and in such a network a dialogue may take place across several bridges. Also as the number of stations on each individual ring is reduced, reliability is increased. Fig 4.2 shows a conceptual diagram of a ring LAN. The workstations are labelled A - F . Any one of them could be the server. They are all connected together by the commmon communications medium provided.

4.3.3 Star Networks

A star network employs a central switching node to which all network nodes are connected by bi-directional links. In order to transmit a packet, a network node sends the packet to the central switch where a number of forwarding schemes are possible. In the simplest method, the switch broadcasts the packet on all its links, thereby enabling the packet to reach its destination. The switch will also have to arbitrate when several nodes are trying to transmit at once so that only one transmission occurs at a time. A more complex switch will look at the destination address of each packet, choose the appropriate link on which to relay the packet, and if another arrives, can also relay it provided the destination is different. If many packets have to be handled in this way, the switch will of course become more complex.

Expanding a star network can be a problem if only one switch is employed, since the number of links it can support is likely to be fixed. Using switch nodes of limited size and allowing them to be connected to both network nodes and other switch nodes to form a multi-switch star (or tree) has some additional advantages over the single switch star. It will use rather less of the communication medium and provides adequately for growth.

The multi-switch star configuration has been employed in Wide Area Networks for some time with the switches being used in a store and forward manner. The most common star network in use is the private automatic branch exchange (PABX) used for office telephone switching. Fig 4.3 shows a conceptual diagram of a star LAN. The server in this instance is a dedicated one. The supervisor, which is a workstation serves as a backup to the dedicated server. The other workstations are clients on the network

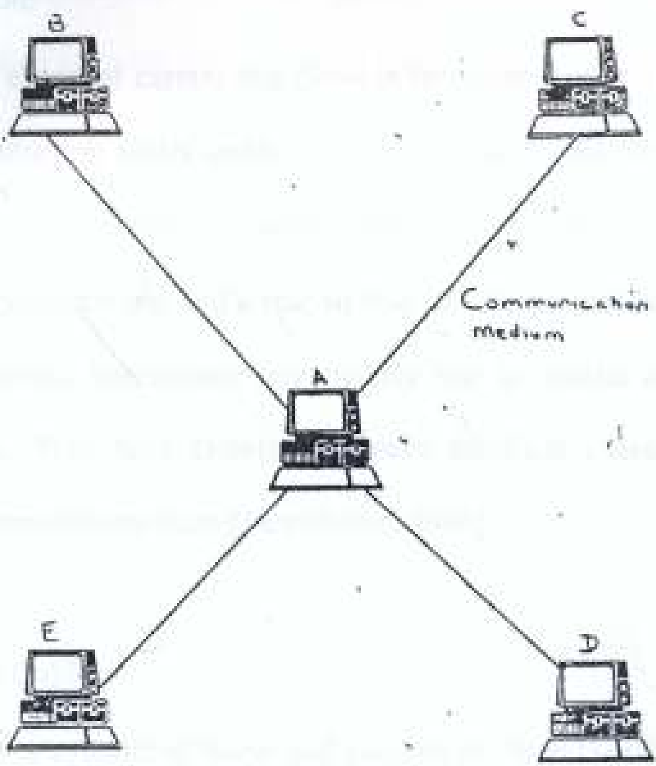

FIG 4.3 Conceptual diagram of a Star network

4.4 Transmission Media

4.4.1 Twisted Pair Cable

A twisted pair Wire consists of individual insulated pairs of conductors enclosed in a common protective sheath. Twisting the wires together increases the immunity to electromagnetic interference by increasing the coupling between the two wires so that interference will affect both more equally. Twisting the wires together also reduces radiation and cross-talk between pairs in a cable because the radiation flowing in one wire is almost cancelled out by radiation from current flowing in the return wire of the pair. A well defined characteristic impedance is necessary to ensure uniform propagation of high speed signals down the cable and to permit the equipment connected to have a characteristic impedance which matches the line [Akinyokun et al,1996].

4.4.2 Coaxial Cable

The high-frequency electrical current that flows in the outer skin of a conductor makes twisted pair (and multicore) cables inefficient, and this skin effect increases attenuation with the square root of frequency. A coaxial cable surrounds the inner conductor with a dielectric such as polyethylene, and a coaxial fuse of solid or braided metal surrounds the dielectric. Electrical interference is extremely low in coaxial cables if the outer screen has no gaps. They have closely toleranced electrical characteristics and are efficient electrical transmission lines [Tanenbaum, 1996]

4.4.3 Fibre Optic Cable

An optical fibre has a cylindrical shape and consists of three concentric sections, the core, the cladding and the jacket. The core is the innermost section and consists of one or more very thin strands, or fibres, made of glass or plastic. Each fiber is surrounded by its own cladding, which is glass or plastic. The jacket is the outermost layer surrounding one or a bundle of cladded fibers. The jacket is composed of plastic and other materials layered to protect against moisture, abrasion, crushing, and other environmental dangers.

The advantages of fibre optic cables over electrical cables for data transmission are:

a. Higher transmission speed

b. Increased transmission capacity

c. It does not generate electromagnetic interference nor is it susceptible to Nuclear Elecromagnetic pulse (NEMP) that accopanies a nuclear explosion.

d. Ground loop or cross-talk problems are rectified.

e. Less bit error rates

f. no risk of short circuits or electrical sparks

g. It is lighter than screened copper cable (this is important in ships and aircrafts) and more flexible. It also takes less time to install.

h. It is suitable over a wide temperature range.

i. Eavesdropping or tapping is more difficult because there is no Electromagnetic radiation.

j. It has higher insistence to corrosive atmosphere and liquids.

4.4.4 Terrestrial Microwave

The most common type of microwave antenna is the parabolic dish. A typical size is about ten feet in diameter. The antenna is fixed rigidly and focuses a narrow beam to achieve line of sight transmission to the receiving antenna. They are normally located at substantial heights above ground level to extend the range between antennas and to be able to transmit over intervening obstacles. To achieve long distance transmission, a series of microwave relay towers is used, and point-to-point microwave links are strung together over the desired distance. Their primary use is in long haul telecommunication service, as an alternate to coaxial cable for transmitting television and voice. They can support high data rates over long distances. It requires fewer amplifiers and repeaters than coaxial cable for the same distance, but requires line-of-sight transmission.

4.4.5 Satellite Microwave

Communications satellite is, in effect, a microwave relay station. It is used to link two or more ground based microwave transmitter/receivers, known as earth stations or ground stations. The satellite receives transmission on one frequency band (uplink), amplifies it, if it is an analog transmission or repeats the signal if its a digital transmission, and transmits it on another frequency (down link). A single orbiting satellite will operate on a number of frequency bands. Satellites can be used to provide point-to-point links between earth stations, or broadcast links (i.e. transmitting and receiving from a number of earth stations simultaneously).

For a satellite to function effectively, it must be in geostationary orbit at a height of 35,784 km. This and the fact that a spacing of 4° in the 4/GHz band or 3° in the 12/14 GHz band is required to prevent interference, limits the number of satellites that can be placed in orbit. Because of the long distances involved, there is a propagation delay of about 240 to 300 ms from transmission from one earth station to reception by another [Tanenbaum,1996]. Given below in table 4.1 is an estimate of the one-way maximum delay for various orbit heights.

4.4.6 Radio

The main difference between radio and microwave is that radio is omnidirectional and microwave is focused. Hence radio does not require dish shaped antennas, and the antennae need not be rigidly mounted to a precise alignment. Radio in general is used to cover a wide frequency band, but particularly it is used for VHF and part of the UHF band of 30 MHz to 16 Hz. This range covers FM radio and VHF television.

Table 4.1Maximum Propagation Delay for Satellite Channel

DISTANCE (MILES)	APPROPRIATE DELAY (MS)
7,000	100
10,000	140
20,000	250
22,300	270*
25,000	300

* - Synchronous satellite

A well known use of radio for digital data communications is packet radio. A packet radio system uses ground-based antennas to link multiple sites in a data transmission network. For example, the ALOHA system in Hawaii used two frequencies one at 407.35 MHz for transmitting from users to a central controller and one at 413.475 MHz for transmission in the opposite directions the bandwidth on both channels was 100 KHz with a data rate of 9600 bps. Transmission is in the form of short bursts of data called packets. The point-to-point range is about 30km. Repeaters were used to extend the system to a radius of about 500 km. [Tanenbaum,1996]. Table 4.2 presents some applications of the various transmission media.

Table 4.2 Transmission media applications

	USES
1. Twisted Pair	Telephone system, intrabuilding communications, low-cost microcomputers local network within a building.
2. Coaxial cable	Long distance telephone network, long distance television transmission (cable TV), local area networks, short range connection between devices (I/O devices on computers).
3. Optical fibre	Long distance telecommunications
4. Terrestrial microwave	Long haul telecommunications service, point-to-point links between buildings.

4.4.7 Relationship between Medium and Topology

The choices of transmission medium and topology cannot be made independently. The bus topology can be implemented with either twisted pair wire or coaxial cable. The Tree topology can be implemented with broadband coaxial cable. The unidirectional nature of broadband signaling allows the construction of a Tree architecture. The bidirectional nature of baseband signaling on either twisted pair wire or coaxial cable would not be suited to the Tree topology.

The Ring topology requires point-to-point links between repeaters. Twisted pair wire, baseband coaxial cable, and fibre optics all can be used to provide these links. Broadband coaxial cable would not work well in this topology, as each repeater would have to be capable, asynchronously, of receiving and retransmitting data on multiple channels.

The star topology requires a single point-to-point link between each device and the central switch. Twisted pair wire can be used for this task. The higher data rates of coaxial cable or fibre optic cable would overwhelm most of the switches being used currently [Stallings,1994]

4.5 Transmission Techniques

Two transmission techniques are in use for bus/tree LANs. These are Baseband and Broadband. Baseband uses digital signaling and can be employed on twisted pair wire or coaxial cable. Broadband uses analog signaling in the radio frequency (RF) range and is employed only on coaxial cable. There is also a variant known as single channel broadband, which has the signaling characteristics of broadband but some of the restrictions of baseband. Table 4.3 highlights some of the differences between baseband and broadband.

4.5.1 Baseband Systems

A baseband LAN is by definition one that uses digital signaling. The entire frequency spectrum of the medium is used to form the digital signal, which is inserted on the line as constant-voltage pulses. Baseband systems can extend only about a kilometer at most because the attenuation of the signal, especially at higher frequencies, causes a blurring of the pulses and a weakening of the signal to the extent that communication over larger distances is impractical.

Table 4.3 Baseband Vs Broadband transmission

BASEBAND	BROADBAND
1. Digital Signaling	1. Analog signaling (requires RF modem)
2. Entire bandwidth consumed by signal-no FDM	2. FDM possible-multiple data
3. Bidirectional	3. Unidirectional
4. Bus topology	4. Bus or Tree topology
5. Distance, up to a few km.	5. Distance up to tens of km.

Baseband transmission is bi-directional i.e. a signal inserted at any point on the medium propagates in both directions to the ends, where it is absorbed. Baseband systems require a bus topology, because unlike analog signals, digital signals cannot easily be propagated through the splitters and joiners of a tree topology.[Stallings,1994]

4.5.2. Broadband Systems

A Broadband system is by definition one that uses analog signaling. Here digital signals are passed through a modem and transmitted on a carrier wave over one of the frequency bands of the cable. Unlike digital signaling, in which the entire frequency spectrum of the medium is used to provide the signal, analog signaling allows frequency-division multiplexing (FDM). With FDM, the frequency spectrum on the cable is divided into channels or sections of bandwidth. Separate channels can support data traffic, TV and radio signals. The broadband system is categorized as being FDM broadband and single channel broadband (this is a special case of a low-cost broadband system using a single channel)[Stallings,1994]

4.5.3 FDM Broadband

The Broadband LAN can be used to carry multiple channels, some used for analog signals such as video and voice and some for data. One of the advantages of the use of multiple channels is that different channels can be used to satisfy different requirements. The three kinds of data transfer techniques that can be used are dedicated, switched and multiple access.

For dedicated service, a small portion of the cables bandwidth is reserved for exclusive use by two devices. No special protocol is needed. Each of the two devices attached to the cable through a modem. Both modems are tuned to the same frequency. Transfer rates of up to 20Mbps are achievable. The dedicated service could be used to connect two devices when a heavy traffic pattern is expected.

The switched transfer technique requires the use of a number of frequency bands. Devices are attached through "frequency agile" modems, capable of charging their frequency by electronic command. All attached devices, together with a controller, are initially tuned to the same frequency. A station wishing to establish a connection sends a request to the controller, which assigns an available frequency to the two devices and signals their modems to tune to that frequency.

The multiple-access service, which is by far the most common, allows a number of attached devices to be supported at the same frequency. As with baseband, some form of medium access control protocol is needed to control transmission. It provides for distributed, peer communications among many devices, which is the primary motivation for a local network.[Stalling,1994].

4.5.4 Single Channel Broadband

An abridged form of broadband is possible, in which the entire spectrum of the cable is devoted to a single transmission path for analog signals. A single-channel broadband LAN uses bi directional transmission and a bus topology. Therefore, there can be no amplifiers, and there is no need for a headend. Transmission is generally at a low frequency (a few Megahertz). This is an advantage since attenuation is less at lower frequencies. Because the cable is dedicated to a single task, it is not necessary to ensure that the modem output is confined to a narrow bandwidth. As a result the electronics are simple and inexpensive. This scheme would appear to give comparable performance, at a comparable price, to baseband [Stallings, 1994].

4.5.5 Broadband Integrated Services Digital Network

Broadband Integrated Services Digital Network(Broadband ISDN or B-ISDN)is a technology vision which attempts to address the requirement for data transmission above the 64Kbps capacity provided by ordinary ISDN. These higher rates are required to support video conferencing using normal-sized screens, and other applications such as high speed and color FAX.

To meet these requirements, combining several ordinary ISDN channels together is not feasible since the delay on different channels is not guaranteed variations may occur as a result of routing in part via satellite links. It is possible to overcome such delays by using buffers in the receiving terminal to equalize the delay across channels. Otherwise a network solution could be provided which enforces a uniform delay across all channels. B-ISDN can be implemented by media such as optical fiber once the economical problems of laying fiber cable to individual subscribers is resolved. BISDN promotes the idea of a universal socket for various applications ranging from low speed data transmission to high speed definition television systems.

4.5.6 Asynchronous Transfer Mode

Asynchronous Transfer Mode(ATM) is a new switching technology being introduced for implementing LANs and WANs. Some sources classify it as Broadband ISDN. It may also be described as fast packet switching with short fixed length packet. ATM is not a shared medium and data rates of between 51Mbps and 155Mbps can be achieved. Unlike Synchronous Transfer Mode(STM) which reserves a fixed bandwidth for a connection whether data is transmitted or not, with ATM bandwidth is not wasted when data is not being transmitted although while setting up a connection it is guaranteed that the network would be able to accomodate the bandwidth which the connection will require when transmitting. When a connection is set up a specific virtual path is defined which the transmition would follow unlike ordinary packet switching.

Implementation of B-ISDN with ATM networks will encourage the development of new applications. A complete overhaul of the copper-based low-bandwidth telecommunications technology currently in place is however required. The introduction of Asymetric Digital Subscriber Line (ADSL) technology may solve this problem.

4.6 Medium Access Control Protocols

All local networks consist of a collection of devices that must share the network's transmission capacity. Some means of controlling access to the transmission medium is needed so that any two particular devices can exchange data when required. How access is controlled is constrained by the topology and is a trade-off among competing factors:

cost, performance and complexity.

Since in all cases, multiple data transfers share a single transmission medium, this always implies some sort of multiplexing, either in the time or frequency domain. In the frequency domain, any technique on a multiple-channel broadband system is by definition based on frequency-division multiplexing (FDM). Within a single channel, however, some form of time-division multiplexing is required. Time-division access control techniques are either synchronous or asynchronous. With synchronous techniques a specific capacity is dedicated to a connection. This is not optimal in bus/tree and ring network. The needs of the stations are unpredictable, and the transmission capacity should be allocated in an asynchronous (dynamic) fashion in response to these need.

Access to the medium using asynchronous time-division multiplexing (TDM) may be random (stations attempt to access the medium at will and at random times) or regulated (an algorithm is used to regulate the sequence and time of station access). The random access category includes two common bus techniques, Carrier Sense Multiple Access (CSMA) and Carrier Sense Multiple Access with Collision Detection (CSMA/CD), and two common ring techniques, register insertion and slotted ring. The regulated access category includes both token bus and token ring for LANS [Stallings,1994]

4.6.1 Bus/Tree LANs

For the Bus/Tree topology the access protocols for which standards have been developed by the IEEE 802 committee are:

a. CSMA/CD: In the simpler version or CSMA or listen before talk (LBT) A station wishing to transmit listens to the medium to determine whether another transmission is in progress. If the medium is idle the station may transmit. Otherwise, the station backs off for some period of time and tries again. There are three algorithms developed for this trying again and these are called

i. Non-persistent

ii. 1-persistent

iii. p-persistent algorithms

After transmitting, a station waits for a reasonable amount of time for an acknowledgement. Collisions only occur when more than one user begins transmitting within the period of progagation delay. CSMA/CD also referred to as listen while talk (LWT), attempts to overcome one glaring inefficiency of CSMA, that is, when two packets collide, the medium remains unusable for the duration of transmission of both damaged packets. For packets that are long in comparison to their propagation time, the amount of wasted bandwidth can be considerable. This waste is reduced with the CSMA/CD protocol.

b. Token Bus: In this technique, the stations on the bus or tree form a logical ring that is the stations are assigned positions in an ordered sequence, with the last member of the sequence followed by the first. Each station knows the identity of the station preceding and following it. A control packet known as the token regulates the right of access: when a station receives the token, it is guaranteed the control of the medium for a specified time, during which it may transmit one or more packets and may poll stations and receive a response. When the station is through it passes the toke on to the next station in logical sequence [Stallings,1994].

4.6.2 Ring LAN

The various type of Ring LAN are as follows:

a. Token Ring: This technique is based on the use of a small token packet that circulates around the ring. When all stations are idle, the token is labelled as a "free" token.

A station wishing to transmit waits until it detects the token passing by, alters the bit pattern of the token from "free" to "busy token", and transmits a packet immediately following the busy token. Other stations wishing to transmit must wait until the packet on the ring has made a round trip and will be purged by the transmitting station. The transmitting station will then place a new free token on the ring.

b. Register Insertion: This technique derived its name from the shift register associated with each station on the ring, which is equal in size to the maximum packet length and used for temporarily holding packets that circulate past the station.

When a packet arrives along the ring, it is inserted bit by bit in the shift register. The packet begin with an address field. As soon as the entire address field is in the buffer, the station can determine if it is the addressee. If not, then the packet is forwarded by being shifted bit by bit out until the packet is gone. If another packet is due, as the first is being shifted out, the new one will be accumulating in the register. If the arriving packet is addressed to the station, it can either erase the address bit and divert the remainder of the packet to itself, thus purging the packet from the ring or retransmit the data, while copying it to the local station. In this technique maximum utilization of the ring is achieved since a station may transmit whenever the ring is idle at its location and multiple packets may be on the ring at any one time.

c. Slotted Ring: In the slotted ring, a number of fixed length slots circulate continuously on the ring. Each slot contains a leading bit to designate the slot as empty or full. All slots are initially marked empty. A station wishing to transmit waits until an empty slot arrives, marks the slot full, and inserts a packet of data as the slot goes by. The station cannot transmit another packet until this slot returns. The slot may also contain response bits, which could indicate accepted, busy or rejected by the addressed station.

The full slot makes a complete round trip to be marked empty again by the source. The total number of slots on the ring is known by each station and it can thus clear the full/empty bit it had set as it goes by. Once the now empty slot goes by, the station is then free to transmit again [Stallings, 1994].

4.7 Extended LANs and Internetworking

Large organizations that have adopted LAN technology have come to the conclusion that a single LAN is unlikely to satisfy the needs of all the user departments. The desire to have a unified approach to corporate networking, however, has resulted in the development of various ways of linking LANs, either within a local environment, which may be termed on extended LAN, or between widely separated systems, which is termed internetworking. The reasons for adopting a system of multiple LANs are usually due to the physical limitations of a given technology and the complexity of managing a large network. The methods available for extending LANS are through the use of Repeaters, Bridges, Routers and Gateways.

4.7.1 Repeaters

A repeater is a simple signal regenerator which can be used to extend the length of a bus topology LAN. The extended LAN operates as one network. Repeaters operate at the physical layer of the ISO model, and are used to join, exactly identical LANs, being specific to each LAN. However, even with the use of repeaters, there is still a relatively low limit imposed on the number of segments and stations permitted.

4.7.2 Bridges

A Bridge is a simple store - and - forward device, used to connect two or more LANs which use the same protocols at or above the media access level of the data-link layer. The interconnected individual LANs (known as segments) form what is called a bridged local network. A bridge usually consists of two processors, one handling each LAN, plus a large amount of common memory to buffer the message packets. In practice, since the bridge has very little processing to do, quite impressive performance figures can be achieved, At present most bridges are used with Bus/Tree LANs and Ring LANs.

4.7.3 Routers

A Router transfers packets over a switched wide area network, rather than over a dedicated point-to-point link of the Bridge. A router offers more sophisticated services than a bridge, since it can select one of many different possible paths to forward a packet. This decision can be based on a number of parameters such as transit delay, congestion at other routers, or the number of routers between the source and destination stations.

The route over the WAN can either be established by manual control of the bridge, or where IP is being run on the LAN, the destination IP address can be used to route over the network to a similar router. This is very close to the gateway function except that communication is restricted to router to router traffic i.e. LAN station to LAN station, and not LAN station to WAN station.

4.7.4 Gateways

The term Gateway is used to describe several essentially different entities, which basically perform the same function, that of linking different networks together. A Gateway operates at the network layer, and it is used to link different addressing domains or significantly different technologies, e.g. LAN to WAN. A second type of Gateway connects networks which run very different protocols on either side. This may be between two LANs, LAN to WAN, or between two WANs [Tanenbaum,1996].

4.8 Wide Area Networks

The principle of Wide Area Networks (WANs) also known as long haul networks, began as a means of connecting remote terminals to computer systems. In these loosely coupled systems the communicating devices can function as independent units and are connected by a network which can span a large area. The communications media used for the networks are either the national telecommunications systems telephone lines or cables laid specifically for the network. The scale of WANs is now so large that intercontinental links have been provided using satellite technology. The data rate required by these systems can be rather low. Network speeds in the range of 10 -50 kbps, with response times in the order of a few seconds are typical. These networks are packet switching networks using switching nodes and the store and forward method of operation.

The recent years have seen the development of both WANs and LANs to carry integrated digital services including data, voice and video traffic. Although WANs and LANs can be categorized separately, many LANs have gateways to LANs, hence global communications often make use of combinations of both types of networks.

In a typical WAN topology more than one path usually exists between a source and a destination node. Each node accepts data from computers or terminals connected to it, in a series of bursts, and assembles the data into packets with the appropriate address information. The nodes then determine the routing, provide buffering and error control, and return acknowledgement information to the sender when the packet reaches the final destination. If an acknowledgement is not received within a specified interval such as 125ms the packet is retransmitted. The end to end delay for short messages, varies between 50 and 250ms, depending on the packet length used.

In most WAN topologies the individual links are quite separate and routing algorithms are required. An alternative topology is one where each individual node is connected to a common broadcast channel and has to compete for access, with all other nodes. Wide area networks based on a single communications channel use either radio to connect many geographically separate nodes, or satellite communications. This approach to a WAN is cost-effective because it replaces the very expensive long distance dedicated links with a single wideband channel. The Satellite is actually regarded as being a node in the network. In a typical satellite system each ground station transmits on a frequency f-up and receives on a frequency f-down. The equipment used for receiving signals, amplifying it and retransmitting it on another frequency is called a transponder. In such a system each ground station can monitor its own output for error-free transmission [Tanenbaum,1996].

4.8.1 Circuit Switched (Dial - Up) Networks

The circuit switched (Dial-up) networks is used in the public Telephone networks. It can be referred to as a point-to-point connection and was originally designed for voice and telex, but now used for data transmission also.

The Bandwidth services in Dial-up networks include:

a. Narrow Band Dial-up (up to 300 bps)

b. Voice Band Dial-up (600 - 4800 bps)

c. Wide Band Dial-up (above 9600 bps)

The advantages of using the telephone networks for data transmission includes:

a. It is relatively inexpensive

b. It is available as an already established network.

c. The bandwidth is conserved.

The disadvantages include:

a. There is a limited transmission speed

b. Variable line quality

c. There are usually connection delays

d. There are limited connection points.

The connection protocols used in dial-up networks are the Point-to-Point protocol (PPP) and the Serial Line Internet Protocol (SLIP). The Point-to-Point protocol (PPP) is a popular standard for remote access which is used in Microsoft Networks. It supports IPX, TCP/IP and NETBEUI. The Serial Line Interned Protocol (SLIP) is used in the older remote access standard, and is typically used by UNIX remote services.

4.8.2 Leased Networks

The leased (private) Networks provides a private, full-time connection between users. It can be used for Point-to-Point or multi-point configurations. There is no dialing required to establish a connection between users.

The Bandwidth services in leased lines include:

a. Narrow Band private (up to 300 bps)

b. Voice Band private (above 4800 bps)

c. Wide Band private

Its advantages include:

a. It is cost effective in locations that have medium to heavy data volume.

b. It offers good line quality always

c. It guarantees line availability always

d. There are connection points available.

The main disadvantage is the cost of maintaining or leasing the line.

4.8.3 Wireless Computer Networks

The physical connection of the devices that make up a local Area Network (LAN) is usually done by cable wires made of the coaxial type, twisted pair wire or fibre optic cables. These connections could become very cumbersome and even expensive when the cables have to be laid across barriers such as streets and high rise buildings. It is also susceptible to interference when the cables are laid beside power lines, while the movement of heavy vehicles around the cables could lead to vibration of the computer system. Attempts at reorganizations of offices where a LAN exists will lead to a relaying of cables with its attendant inconveniences. The number of add-on devices allowed in a cabled network is limited, while cabled networks does not permit mobile communication from remote locations, from vehicles or even airplanes. These and other difficulties form the need for wireless computer networks.

Wireless Computer Networks (WCN) have become possible due to advancements in communications technology. These include the introduction of cellular phones, the increased usage of VLSI technology to produce miniaturized devices and Laptops or Notebooks and Palmtop computers with processing power and storage capacities rivalling those of larger systems.

The desire to be able to access data in the office server from remote locations or the implementation of cableless LANs in places prone to frequent reorganization have become a reality. The components needed for implementing a wireless computer network are: The transmission medium, an Access point, integrated radio transceiver, Antenna, wireless modem, Bridges and the network software.

The transmission medium used by wireless networks are radio waves and light waves. The radio waves used fall into either of two categories, i.e. the licensed radio and the unlicensed radio frequencies. Both operate within a geographical distance of between 1km and 14km. Light waves which make use of low power infra red waves as the carrier on which the data to be transmitted is modulated can be used. Infra-red rays does not require licensing to be used and provides good security. It is however, only good for room connections since it cannot penetrate walls, ceilings, etc, and has limited coverage.

The Access point is a radio equipment that allows groups of workers to stay tuned to the office LAN for file and print services. They can also still move about from one access point to another without losing their connection to the network.

The Integrated Radio receiver enables users to have a high degree of mobility. Desktop computers can be fitted with a Network Interface Card (NIC) adapter with a radio transceiver, while a Personal Computer Modem Card Interface Adapter (PCMCIA) with a radio transceiver is required for Notebooks. The wireless PCMCIA LAN adapter is fitted into the PC card slot of the Notebook with an antenna attached.

The Antenna is a passive device that radiates the same amount of power as it receives from a transmitter to a receiver. Its dimensions is usually related to its frequency of operation. It has maximum sensitivity in its band of operation and becomes increasingly less sensitive at frequencies further away from this band.

A Bridge collects data packets from one network and retransmits them as soon as possible to intended recipients on another network. Its connection to the LAN allows multiple networks to appear like a single one.

The WCN Network Interface Card contains its network operating system drivers. This allows it to be used with existing network operating systems. However, an interface is need between the application software and the wireless network, before application software developed for wire-based networks can be used on a wireless network. The objective of this middleware is to minimize the liability of the restricted bandwidth available. In a wireless LAN, adequate security and control measures exist for the protection of network resources against unauthorized disclosure, modification, utilization and destruction.

4.9 Routing in Data Networks

The main function of the network layer is routing packets from the source machine to the destination machine. The routing algorithm is that part of the network layer software responsible for deciding which output line an incoming packet should be transmitted on.

It can also be described as the network layer protocol that guides packets through the communication network to their correct destination. Routing in a network involves a rather complex collection of algorithms that work more or less independently and yet support each other by exchanging services or information. The complexity is due to a number of reasons, some of which are:

a. Routing requires coordination between all the nodes of the network

b. The routing system must cope with link and node failures which requires the redirection of traffic and an updating of the databases (and routing tables) maintained by the system

c. To achieve high performance, the routing algorithm may need to modify its routes when some areas within the network become congested.

When a routing decision is made depend on whether the network uses datagrams or virtual circuits. In a datagram network, two successive packets of the same user pair may travel along different routes, and a routing decision is necessary for each individual packet. In a virtual circuit network, a routing decision is made when each virtual circuit is set up. The routing algorithm is used to choose the communication path for the virtual circuit. All packets of the virtual circuit subsequently use this path up to the time that the virtual circuit is either terminated or rerouted.

There are a number of ways to classify routing algorithms. They can be divided into centralized and distributed routing. In centralized routing algorithms, all route choices are made at a central node. In a distributed routing algorithm, the computation of routes is shared among the network nodes with information exchanged between them as necessary.

Another classification of routing algorithms relates to whether they change routes in response to the traffic input patterns. In static routing algorithms, the path used by the sessions of each source-destination pair is fixed regardless of traffic conditions. It can only change in response to a link or node failure. This type of algorithm cannot achieve a high throughput under a broad variety of traffic input patterns. It is recommended for either very simple networks or networks where efficiency is not essential. Most major packet networks use some form of Adaptive routing. In this case the paths used to route new traffic between origin and destinations change occasionally in response to congestion, then the routing algorithm would try to change its routes and guide traffic around the point of congestion.

Generally, routing algorithms are based on the notion of a shortest path between two nodes that is a source node and a destination node. Here, each communication link is assigned a positive number called its length. A link can have a different length in each direction. Each path (which is a sequence of links) between two nodes has a length equal to the sum of the lengths of its links. The routing algorithm therefore, tries to route packets along a minimum length (or shortest path) between the source node and destination node. The ARPANET has a distributed adaptive algorithm that makes use of a distributed computation of routes in the nodes in a datagram network. The TYMNET on the other hand has a centralized adaptive algorithm operated at a special node called the supervisor. TYMNET uses virtual circuits, so a routing decision is needed only at the time a virtual circuit is set up.

Some static routing algorithms in use are based on : Shortest path routing, Flooding, and Flow based routing. The first two takes only topology into account, while the third also considers the load. Some dynamic (adaptive) routing algorithm in use are

: Distance vector routing, Link state routing, and Hierarchical routing [Huitema,1995].

4.10 Network Protocols

A protocol may be conceived as a set of agreements between two communicating entities, to facilitate the orderly exchange of information, and to efficiently manage network resources. The communicating entities maybe user application programs, file transfer packages, database management systems, electronic mail facilities, and terminals. For two entities to communicate successfully, they must "speak the same language". What is communicated, how it is communicated, and when it is communicated must conform to some mutually acceptable conventions between the entities involved.

The concept of layering has generally been used in the designing of protocols. The main principle used in layering is that a given layer in a node logically exchanges messages with its corresponding layer in another node and that the processing at other layers is transparent to it. The advantages of layering includes:

a. It allows interactions between functionally paired layers in different nodes.

b. It allows simpler descriptive, development and testing processes of the protocol software.

c. Changes or modifications may be made to layers independently of each other.

Virtually all aspects of communications networking is governed by various protocols which follow either a hierarchical, or layered structured approach, with lower level protocols serving higher level protocols and vice-versa. There are protocols for data transmission, medium access control, various aspects of network management, for process synchronization, the management of priorities, routing and flow control, error control and recovery and internetworking. [Stallings,1994]

4.10.1 The TCP/IP

The TCP/IP (Transmission control protocol/Internet Protocol) is the most widely used networking protocol in the world. After originally being developed for tying Unix machines together to form the Internet, it became the dominant Unix network protocol because of its simplicity, standardization, and speed. TCP/IP is not a single protocol but a whole family of several protocols with different purposes. The TCP/IP protocol family is listed below:

a. Transport: These protocols control the movement of data between two machine.

 T C P (Transmission control protocol): A connection-based service, which means that the sending and receiving machines are communicating with each other at all times and is designed to use an underlying IP service. It provides reliability, multiplexing and flow control.

 U D P(user Datagram Protocol): A connectionless service (the two machines are not communicating with each other). It is used in conjunction with IP to provide a datagram mode environment for application processes to send messages to other programs.

b. Routing: These protocols handle the addressing of the data and determine the best routing to the destination. They also handle the way large messages are broken up and reassembled at the destination.

 I P (Interned protocol): IP handles the actual transfer of data. It is protocol designed to transfer variable sized blocks of data (datagrams) between hosts. IP does not guarantee correct delivery of datagrams, nor correct sequencing. Bad delivery or other problems with datagrams are signalled via a sub-protocol called ICMP (Internet Control Message Protocol).

ICMP(Internet Control Message Protocol): This handles status messages for IP, such as errors and network changes that can affect routing.

R I P (Routing Information Protocol): One of several protocols that determine the best routing method.

OSPF (Open shortest path first): This is an alternate protocol for determining routing.

c. Network Addresses: These services handle the way machines are addressed, both by a unique number and a more common symbolic name.

ARP(Address Resolution Protocol): This determines the unique numeric addresses of machines on the network. It is used in Ethernet systems to convert the 32 bit IP address into 48 bit Ethernet addresses.

DNS(Domain Name System): Determines numeric addresses from machine names.

RARP (Reverse Address Resolution Protocol): Determines addresses of machines on the network, but in a manner backward from ARP.

d. User Services: These are applications to which users have access.

BOOTP (Boot Protocol):Starts up a network machine by reading the boot information from a server. BootP is commonly used for diskless workstations.

FTP (File Transfer Protocol):A simple file transfer method that uses UDP as the transport.

Telnet: A high level terminal-oriented protocol for user interaction with a remote system. Allows remote logins so that a user on one machine can connect to another machine and use the remote machines resources.

e. Gateway Protocols: These services help the network communicate routing and status information, as well as handle data for local networks.

EGP (Exterior Gateway Protocol): Transfers routing information for external networks.

GGP (Gateway-to-Gateway protocol):Transfers routing information between Interned gateways.

IGP (Interior Gateway Protocol): Transfers routing information for internal networks.

f. Other Categories: These are services that do not fall into the categories mentioned earlier, but they provide important services over a network.

NFS (Network File System): Enables directories on one machine to be mounted on another machine and then accessed by users as though the directory was on a local machine.

NIS (Network Information Service): Maintains user accounts across networks, simplifying logins and password maintenance.

RPC (Remote Procedure Call): Enables remote applications to communicate with each other using function calls.

SMTP (Simple Mail Transfer Protocol): A protocol for transferring electronic mail between machines.

SNMP(Simple Network Management Protocol): An administrator's service that sends status messages about the network and devices attached to it [Tilley,1995].

4.10.2 The ISO Reference Model for Open Systems Interconnection

Widely publicized step towards the standardization of computer networks was the definition by the International standards organization (ISO) of its Reference model for open systems Interconnection (OSI). This standard attempts to define the structure of a network as a seven layer hierarchy, each of which has a well defined function. Each level provides a service for the level above it and in turn uses the services provided by the level below it. The users feels that communication with another user takes place across a direct link, whereas this virtual connection only happens through all the network layers below. The only level at which there is an actual physical transmission medium connecting the host to the network is at the very bottom. The layers are described below:

a. Application Layer

b. Presentation Layer

c. Session Layer

d. Transport Layer

e. Network Layer

f. Data Link layer

g. Physical Layer

The Application layer: This is the highest layer, and it provides communication between two application processes, such as for application programs. It provides application - specific aspects of communication between the network users.

The Presentation layer: This layer provides services for the application layer to interpret the meaning of the data exchanged. It includes management of the entry, exchange, display, and control of structured data.

The Session layer: This layer provides session initiation and termination, session recovery, data delimiting, and dialog control.

The Transport layer: This layer provides the transparent transfer of data. It also includes such functions as class of service, sequencing of messages, delivery and flow control.

The Network layer: This layer provides message routing. It determines whether the message should be sent to the transport layer in the local node or through the data-link layer to another node. The layer also segments and blocks messages to facilitate transmission. A message between two network users traverses the lowest three layers in each of the transit nodes in the network.

The Data-link layer: This layer establishes and maintains one or more data links between network entities, and provides sequencing and link flow control.

The Physical layer: This layer supports the mechanical, electrical and functional procedures for creation, maintenance, and release of data circuits between link entities.

One of the major issues at the network level is the use of connection-oriented or connectionless protocols, connection-oriented protocols are commonly known as virtual circuit service, while connectionless protocols are known as datagram systems.

Connection-oriented protocols supports broadcasting, the use of multiple stations and provides for correct sequencing of data, guaranteed delivery, error recovery, and data flow control. Connectionless protocols does not guarantee delivery of message packets, confirmations are not sent and the responsibility for proper message receipt rests on the sender and receiver.

4.11 Switching Techniques for Computer Networks

In a network, data which is sent between two hosts travel along a number of links and through some switching nodes. However, the concept of a single communication link between two host devices can still be supported. This can be done by ensuring that all the communications links between the two hosts devices are reserved for their sole use, while the transmission is on. This technique is called Circuit Switching. Problems can occur in a circuit switched data network when a communication line which connects two heavily populated switching nodes is in great demand, since once a connection across the network has been made, this prevents other devices from setting up a link by using any of the lines already in use.

The dedicated line' problem of circuit-switched networks is therefore solved by not letting host devices reserve the lines. For example the message to be transmitted could contain an address field, which the nodes could distinguish from the data and thereby send the message on in the right direction, hence lines are reserved by the switching nodes only for the duration of the message. This technique is known as Message switching. Problems that may occur with this technique is inter message interference and queuing problems at the switching nodes. In an adaptive system, it is possible to overcome this problem by adjusting the routes used by the messages so that the traffic load is spread more evenly across the network.

The complexity of the switching nodes can be reduced by the use of Packet switching: In a packet-switched network the data to be sent is divided into small chunks called Packets which are typically a few hundred bits in length. Each packet contains enough addressing information to enable the switching nodes to route it to its destination. It also contains a portion of the message being sent and sufficient information to allow the message to be reconstructed from all the packets. There can still be contention for a link in this scheme and switching nodes must be able to store whole packets while a link is busy and forward them when it becomes free. Networks based on this principle are known as Store and Forward networks. Two packet transmission techniques can be identified:

A Virtual circuit transmission system is one in which a path is set up between source and destination and all packets follow the same path and arrive in the sequence in which they were transmitted.

A Datagram transmission is one in which individual packets are transmitted by whatever route is available when they are presented for transmission. No fixed route is set up and each intermediate node decides on the appropriate path, according to some routing algorithm. In the case of datagram the packets do not necessarily arrive in the order in which they are transmitted, and each packet must identify its position in the transmitted sequence.

The main feature of the datagram type of packet switched network is that the data links between nodes are used at near their full capacity. Further packets are scheduled for transmission so that their is no contention. Essentially each node queues packets for transmission and since there is more than one outlet, each node can select an alternative route if the queue for the direct route becomes too long. There are many possible algorithms for this.

Circuit switching is essentially a transparent service. Once a connection has been established, a constant data rate is provided to the connected station. This is not the case with message switching and packet switching. These services introduce variable delay so that data arrives in a choppy manner. The data may also arrive in a different order from the way they were transmitted.(Hopper et al,1986)

Three types of delays can be identified, these are:

a. Propagation delay: This is the time it takes a signal to propagate from one node to the next. This time is generally negligible. The speed of electromagnetic signals through a guided medium, for example, is typically $2x10^8$ m/s and for an unguided medium is $3x10^8$ m/s.

b. Transmission time: This is the time it takes for a transmitter to send out a block of data. For example, it takes one second to transmit a 10,000 bit block of data onto a 10kbps line.

c. Node delay: This is the time it takes for a node to perform the necessary processing as it switches data.

For Circuit switching, there is a certain amount of elapsed time before the message can be sent. This is the time needed to set up the call in the first place. After the connection has been set up, the message is sent as a single block, with no noticeable delay at the switching nodes.

Message switching does not require a call set up, however, the entire message must be received at each node before that node begins to transmit. Hence the total delay using message switching is almost always significantly longer than for circuit switching. Datagram packet switching also does not require a call setup and each node along the route can begin transmission of each packet as soon as the packet arrives, and need not wait for the entire message. Hence, datagram service is significantly faster than message switching.

Virtual circuit packet switching actually appears quite similar to circuit switching. However, for virtual circuit packet switching apart from the delay incurred in setting up the connection, there is also a node delay due to the queuing of each packet at each node, even though the virtual circuit has now been set up, and each packet must wait for its turn before retransmission. The rate of transmission is also no faster than circuit switched transmission. This is because circuit switching is essentially a transparent process which provides a constant data rate across the network.

In circuit switching, once a connection has been established, the analog or digital data is passed from source to destination, as it is. For message and packet switching, the data is first organized into digital blocks. This means that analog data must first be converted to digital data before being transmitted.

Further observations made about these transmission techniques are as follows:

a. For interactive traffic, message switching is not appropriate, whereas circuit switching, Datagram packet switching and virtual circuit packet switching are fast enough for interactive transmission.

b. For light and/or intermittent loads, circuit switching is the most efficient, since the public telephone system can be used, via dial-up lines.

c. For heavy and sustained loads between two stations, a leased circuit switched line is the most cost effective.

d. Packet switching is preferred when there is a collection of devices that must exchange a moderate to heavy amount of data. With this technique, line utilization is most efficient.

e. Datagram packet switching is good for short messages and for flexibility.

f. Virtual circuit packet switching is good for long exchanges and for relieving stations of processing burden.

Broadcast communications networks, unlike switching network do not have intermediate switching nodes, rather at each station, there is a transmitter/receiver that communicates over a medium shared by other stations. A transmission from any one station is broadcast to and received by all other stations.

Two similar types of broadcast networks are packet radio networks and satellite networks. In both cases, stations transmit and receive via antenna, and all stations share the same channel or radio frequency. In a packet radio network, stations are within transmission range of each other, and broadcast directly to each other. In a satellite network, data is transferred from the transmitter to the receiver via a satellite. Each station transmits to the satellite and receives from the satellite.

Broadcast transmissions are also found in local networks. In the bus local network, all stations are attached to a common wire or cable. A transmission by any one station propagates the length of the medium in both directions and can be received by all other stations. The ring local network consists of a closed loop, with each station attached to a repeating element. A transmission from any one station circulates around the ring past all other stations, and can be received by each station as it goes by.[Stallings,1994]

4.12 Modems and Multiplexers

Long distance Data communication over analog telephone lines requires a device called a Modulator - Demodulator or a Modem. The Modem convert the digital signals into analog signals with frequencies within the bandwidth of the telephone line.

Signals running between subscribers telephones and the exchange office are direct current, limited by fitters to the frequency range 300Hz to 3KHz. If a digital signal were to be applied to one end of the line, the received signal at the other end would not show a square waveform owing to the capacitance and inductance effects. Rather it would rise slowly and decay slowly. This effect makes baseband signalling unsuitable except at slow speeds and over short distances. The variation of current signal propagation speed with frequency also contributes to the distortion. Alternating Current signalling is therefore used inorder to get around the problems associated with d.c. signalling. A continuous tone, called a sine wave carrier in the 1000Hz range is introduced. Its amplitude, frequency or phase can be modulated, as Amplitude Modulation, Frequency Modulation or Phase Modulation. The MODEM therefore is a device that can accept a serial stream of bits as input and produce a modulated carrier as output (or vice versa). The modulator is inserted between the (digital) computer and the (analog) telephone system.

Early data communications depended on dedicated or public switched telephone lines because there were few alternatives. However, with the introduction of all digital networks in some countries that is, ISDN technology, data can now be entered in a digital form through a standard interface, making Modems unnecessary. Modems are however still necessary where the all digital network is unavailable, or computers, or other data communication devices are to be interconnected [Tanenbaum,1996].

4.12.1 Types of Modems

There are two general types of modems for connecting computers into communications channels. The Acoustic coupler, which is a small stand alone device, can be plugged into a computer terminal or a micro-computer, and has a pair of rubber cups that serve as receptacles for a telephone handset. With the coupler, one needs first to call the number assigned to the computer. When the computer answers with a high-pitched tone, the handset is placed into the cups. The mouthpiece on the handset is placed adjacent to the demodulator. After a few seconds, the computer being called and the microcomputer or terminal will establish communications and await transmission. The microcomputer or terminal can then be used as if it were connected directly to the computer being called.

The direct-connect modem, has cables that are connected to the microcomputer or terminal and then directly into a telephone. The telephone is used to call the computer, and then a switch on the modem is set to direct signals from the microcomputer, or terminal to the computer. This modem works like an Acoustic coupler except that it is not necessary to place the phone handset physically into the modem.

A type of direct-connect modem in popular use with microcomputers is a printed circuit board that resides internally in the microcomputer. A receptacle in the board accepts a wire that is plugged into the phone outlet in the wall. Thus, the modem connects the microcomputer directly into the phone system. Most direct-connect modems are also called "smart" modems because they are driven by software that automatically dials the telephone numbers, keeps a directory of often used numbers, automatically transmits sign-on sequences such as account numbers and passwords, and performs other services for the user.

Modems have been given fax capabilities, so that a digital document can be converted to analog, ending up as a picture file (if the receiver is another fax/modem) or a printed document (if received by a facsimile machine). Also voice in the form of voicemail have been added to modems. These multipurpose modems or voice/data/fax modems automatically direct incoming data or fax calls to the appropriate software module and pass voice calls through to the answering machines / voicemail software. Some Modems can also enable the simultaneous transfer of voice and data. The data transfer rate of these modems are usually between 14.4 kilobytes per second and a maximum of 28.8 kilobytes per second. When dial-up services are used, it may be necessary to set the modem manually at the appropriate transmission rate. With software-driven modems, the transmission speed acceptable by the host computer can often be detected by the terminal modem, which adjusts its rate to match that of the computer.

Modems can be connected to several types of devices that receive data transmissions. These could be terminals, computers, mutiplexers or concentrators.

Multiplexing is a technique for sharing a common channel between several users. Thus, a mutiplexer joins a number of separate signals from different devices for transmission over a single carrier channel. Multiplexers are associated with host computers that service a large number of users. A data concentrator is a computer which accepts digital information from several sources and outputs it on lower speed lines or a smaller number of high speed lines. The name of this device is associated with the fact that it usually has a memory or storage capability. Messages can be held in the concentrator for selective transmission.

4.13 Common Carriers

The primary data communication system in most modern nations is the public telephone network which is government owned in almost all countries (except the United State). In the U.S. telephone system are owned by private, licensed monopolies. In America the best known of these is American Telephone and Telegraph (AT&T).

Common carriers are firms like AT&T, and Nitel plc, that have been authorized by the state (or country) to provide communications service to the public. In Nigeria the sole carrier was Nitel plc, however, in late 1997 the government has licensed other private carriers. The only one of them that is operating to date is Multi-links. In America there are several thousand common carries and most like AT&T are investor owned and privately operated. Three important common carries are Western Union, General Telephone and Electronics (G T E), and the Communication Satellite Corporation

(COMSAT). These firms and others like MCI telecommunication (MCI mail) offer voice and data communication service over land lines and satellite links.

Value Added Networks, or VAN, such as GTEs Telenet, Tymshares Tymnet and Lockheed's Dialnet use common carrier lines to provide additional services such as access to data banks and electronic mail. Because these network provide additional service through the telephone, they are called value added network. These network use special data holding techniques to provide low error rate and fast response time access to subscribers at low cost. VANs provide economical service because they can make the most effective use of their equipment.

4.14 Nitel Plc Services and Tariffs

The Nigerian Telecommunications (Nitel) plc is one of the public carrier for telecommunications services in Nigeria. The company as it is today came into existence with the fusion of the former telecommunications service of the Post and Telecommunications (P&T) with the Nigerian External Telecommunications (NET) in 1986. The postal services of P&T thereafter became the Nigerian postal services (NIPOST).

4.14.1 Nitel Services

Nitel offers a wide range of services to the public. These includes:

a. Telephone with IDD (International Direct Dialing).

b. Telex and Telex Delivery Service

c. Telegraph and registered telegraphic addresses Public coin telephone

d. Transmission and reception of real-time television for network services.

e. Private leased telephone and telex services

f. Pal- Secam tape conversion

g. Private wire

h. Maritime mobile service (MMS)

i. Leased telephone and telex services

j. Alternate Voice Data (AVD) Circuits

k. Voice cost and press reception

l. International Public Counter Service

m. Nifax Services (Fascimile Service)

n. Satellite Mobile Communication (INMARSAT)

o. Training of PBX and Telex Operators

p. Data Switching Systems

q. Electronic Main (National Service Only)

r. Press reception and Broadcast

s. Word processing

t. X.20 Packet Switching

u. X.40 Electronic Message Service

v. Teleconference

w. Air-Traffic Subsystem

x. Collect Calls

y. Cellular Radio Telephone Service

z. International and Local Card payphone

The telephone service, which is advertised as being the most popular medium of communication in the world today, has been greatly enhanced by the use of satellite technology. The international Direct Dialing (IDD) facility is a Do-it-yourself facility, which has gained precedence over operator assisted calls. It offers quick service and customers can dial direct the international numbers they want without the assistance of Nitel operators. Trunk calls can also be either through the operators or the subscriber B dial do it yourself facility which is available on all Nitel modern telephone exchanges.

The off-peak rate for local telephone service is from 7:00 p.m. and 7:00 a.m. and a discount of 50% is offered for off-peak calls. Since Nitel is committed to helping customers improve their business performance by designing and providing telecommunications solutions that enhance productivity, shorten response time and maximize the flow of information exchange, Nitel has embarked on a digitization program by converting its analog exchange facilities to digital telephone exchanges. The systems being installed are among the most modern in the world with many facilities included. They are very fast in information processing and call completion and the subscriber is guaranteed to be connected as soon as the last digit is dialed. Some of the facilities provided by the digital exchanges are:

Malicious call identification

a. Call diversion

b. Traffic restriction

c. Conversation transfer

d. Alarm-Call Service

e. International Direct Dialing.

All Nitel exchanges that have been digitized have also ceased local operator assisted call services. Nitel also offers both on Internal and an International Telex service. The telex equipment used is the teleprinter machine which is mainly acquired by firms, business organizations and governmental agencies who have constant exchange of correspondence with local and overseas partners.

The service is comparable with the telephone service because the telex subscriber is fully in control and establishes both internal and international telex connection within a minute, without the assistance of Nitel operators. The connection is immediate and charges are based on minute-by-minute usage. Privacy and secrecy is guaranteed and records of discussions are automatically printed for record purposes. The machines also have built in facility to receive and record messages unattended . The service combines both speed and accuracy which is regarded as the cornerstone of any efficient modern business organization [Nitel,1990].

Nitel plc has commenced the conversion of its present analog exchange facilities to digital exchange systems. This conversion is expected to boost the performance of the national carrier. Furthermore, optical fibre links, which is a higher grade transmission medium is being used to replace the present cable systems.

These changes notwithstanding, the maximum data transmission rate presently supported by the Nitel network is only 9.6kbps. Correspondingly, this implies that the bandwidth available via the Nitel telephone network is severely limited. Hence, data transmission services that requires a higher bandwidth/data transmission rate cannot be supported by the present Nitel telephone system. This explains why Nigeria as yet cannot have full Internet connectivity. The present system however supports Electronic Mail (E-mail) facilities and probably others which can operate within the present bandwidth limitations. The bandwidth limitation is only one of the problems of data transmission.

4.14.2 Nitel Tariffs

Nitel charges service tariffs on installation , monthly rental charges, and telephone removal/transfer. For telephone call charges both local calls and trunk calls are charged, based on the duration of the calls and the distance away from the exchange in a radial direction. Various categories of rates are available for International calls, Special services, Domestic/Internal leased circuits, and Private wire (full or part-time) services.

Others include, Inland/International telegram service, Nifax service, (facsimile service) for domestic/international service, Television (video) channel (telecast service) charges, Music channel charges, Terminal Earth Station / Message delivery service for INMARSAT services, Ship-shore (radio telegram & telephone) services, Pal-Secam tape conversion, and Licensing fee for privately owned telecommunications systems that is FAX, PBX, PABX, PMBX and INMARSAT [Nitel,1990].

Dial calls for either local or trunk calls are charged uniformly at the same rate all over the country at a rate of #1.80 (one naira eighty kobo) per unit. Each subscriber has an account, where the meter reading are entered, and the number of units used per month is entered. The total bill for that month is just the product of the number of units used and the price per unit i.e. #1.80 . The other inputs to the bill are the Access charge (#100 for businesses and #50 for private subscribers) and a 5% VAT (value added tax) charge.

Commercial call office charges are based on the distance away from the exchange and the demand in that area. e.g. If the demand is high, the price is low and vice-versa. Furthermore, each state is allowed to determine its own tariff structure, by adjusting its value by a factor derived for it, considering its commercial viability. VAT charges are also an integral part of the call-office charges.

CHAPTER FIVE

FRAMEWORK FOR THE IMPLEMENTATION

This chapter presents the framework for the implementation of the Knowledge Based System for the efficient transmission of data in a computer network environment. The issues examined are the Framework Proposed, the Network Design, the Program Logic, the Representation of the Input Data, and the Coding of the Routing algorithm.

5.1 Framework Proposed

When computers are interconnected to one another, the choice of topology usually depends on the type of applications for which the network will be used. The commonly used topologies in Local Area Network are the Bus topology, the Star topology and the Ring topology. The Star topology is widely used in Business environments or in networks where there is a need to enforce a central control. The Ring topology is usually used in Military or Research environments.

In the Star topology the server is used to connect all the workstations in the network. A workstation wishing to transmit data sends a request to the server for a connection to the destination workstation. The server uses circuit switching to establish a dedicated path between the two workstations as if they were connected by a dedicated point-to-point link. In the Star topology, there is no direct link between one workstation and another. A problem however arises if the workstation-to-server route is very busy or out-of-order.

In this research work, a Star/Ring hybrid topology network is proposed for solving the problem. The features of this topology are:

a. Each workstation is linked to the central server independently.

b. There is a direct link between the workstations as conceptualised in figure 5.1

c. The desirable features of the Star topology and the Ring topology are retained in the Star/Ring hybrid topology proposed.

d. The topology being proposed can be used in a cabled long haul network environment.

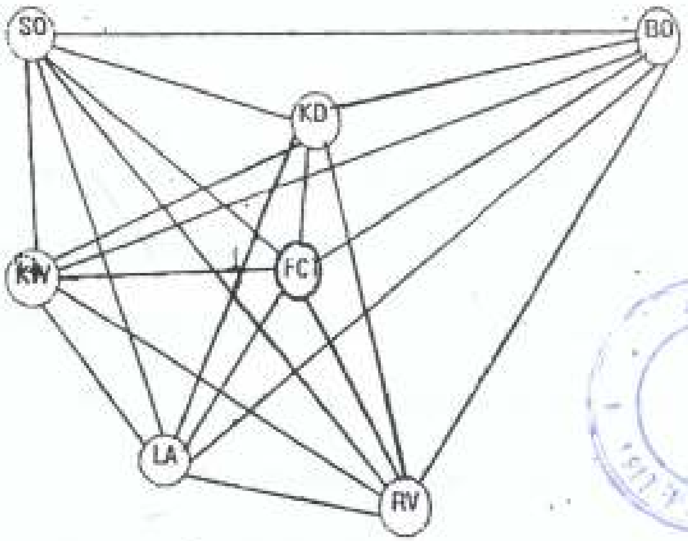

Figure 5.1 Conceptual diagram of a Star/Ring hybrid network.

If the Server to workstation line is busy or out of order, then the data can be routed through the other workstations in the network to the destination workstation since there are now alternative routes available. This confers a greater reliability on the network. It is observed that:

a. If the capital cost of transmission in the Star topology is 'X'.

b. If the Recurrent cost of transmission in the Star topology is 'R'.

c. If the Capital cost of transmission in the Hybrid topology is 'Y'.

d. If the Recurent cost of transmission in the Hybrid topology is 'S'.

Then it can be shown that $X < Y$, while $R >> S$.

In the Star topology and likewise in the Ring topology, there is no need to route data. However, in the Hybrid topology being proposed, there is a need to route the data through the network, and there is also the need to optimize (minimize) the cost of data transmission. The routing algorithm proposed for such hybrid networks will minimise the recurrent cost incurred when the communications channel is busy and a direct point to point link between the server and the destination workstation is not possible.

5.2 Network Design

The conceptual Network graph showing a network linking all the State Capitals in Nigeria and the Federal Capital Territory (FCT) would have 1332 edges and 37 nodes. In the classical travelling salesperson problem, the edge cost used was the road distances between the towns or nodes to be visited. This could however be transformed to speed, time or even monetary cost. In a communications network, the transmission time, the line capacity, the load, the speed of transmission (or the data transmission rate), the duration of transmission and the distance are some of the factors that were examined that could be used for the edge cost in a data transmission network graph.

The cost in monetary terms charged by the common carriers was however selected as the edge cost because all these parameters can be translated to the monetary cost, for example the monetary cost is a function of the transmission time. The longer the duration of the transmission, the higher will be the bill incurred. The cost is also a function of the data transmission rate. This is determined by the speed of the Modem being used, the available bandwidth and the quality of the transmission medium. Hence, when their is more bandwidth available the data transmission rate achievable will be higher and the transmission time and monetary cost will also be reduced.

Nitel PLC multiplexes 40 communications channels at the Akure exchange and their charges are based on the duration of the transmission and the separation distance in a radial direction from the exchange. The cost of processing the call, the number of repeaters used and the switching technology being used at the exchange also contribute to the amount charged. Based on all these considerations an appropriate tariff structure had been worked out by Nitels Customer Engineering Section . Information showing the separation distance, current pulse rate in seconds, units per minute and the current charges per minute were clearly spelt out. Table 5.1 shows the published values for Local and Trunk calls as at 1994. The tariff structure is reviewed periodically and the current structure came into effect in January 1997 and the details have not being made public.

Table 5.1 Summary of Nitel tariff(1994)

Radial dist. in KM	Current Pulse Rate	Unit per minute	Current charge per minute.
0 - 50	60	1	1.40
51 - 90	30	2	1.80
91 - 160	20	3	2.70
161 - 250	15	4	5.00
251 - 400	12	5	7.00
401 - 600	9	6.7	9.38
601 - 700	7	8.5	11.90
> 700	6	10	14.00

The weights used for the edge cost of the conceptual network graphs prepared for the experimental case study of the framework being proposed was the current Nitel call-office telephone rates. These values are a function of the linear separation distance between the nodes. Since this data was not readily available it had to be computed by extrapolation. The call\office rates was chosen rather than the dial call rates because the information available about it was more reliable than that of the dial call. The linear separation distance between pairs of state capitals was first accurately determined from a scaled road map of Nigeria and then converted to kilometers by multiplying the values obtained with the scale or conversion factor used for the map.This computation was carried out for each one of the 1332 different edges possible in a national network comprising of the 36 states and the FCT(Abuja). These values of the distances obtained were then used to determine the appropriate Nitel tariff. The identity of the nodes or vertices of the weighted network graph was represented by codes corresponding to each State Capitals and the Federal Capital Territory (Abuja). The convention adopted for labelling the edges of the weighted graph is to refer to the pair of nodes (or states) they connect together with the source node written first followed by the destination node for example <OD,EK> is interpreted as an edge of the weighted graph connecting ONDO state to EKITI state. The braces used indicate the bi-directional nature of the edge being referred to. Note that a state is described or represented by the state capital. The relational representation of the codes used in the weighted graph is :

WTGRAPH[statename, state capital, state code, code number]

The actual relation is presented in Appendix A.

The call office rates for telephone calls originating from the Akure exchange of Nitel in Ondo State to some state capitals and towns at varying distances from Akure was obtained from the Akure exchange and the relational representation is:

NITELCOST[edge location,separation distance,cost of 3 minute-call]

The actual relation is presented in Appendix B. A graph showing the relationship between the linear separation distance and amount charged for a 3 minute call duration is conceptualised. The graph in figure 5.2 was then used to derive the corresponding values that relate the call-office charges to the separation distance between the source and destination of a call in a radial direction. Table 5.2 shows the summary of the values obtained. The comprehensive data list obtained is presented in Appendix D.

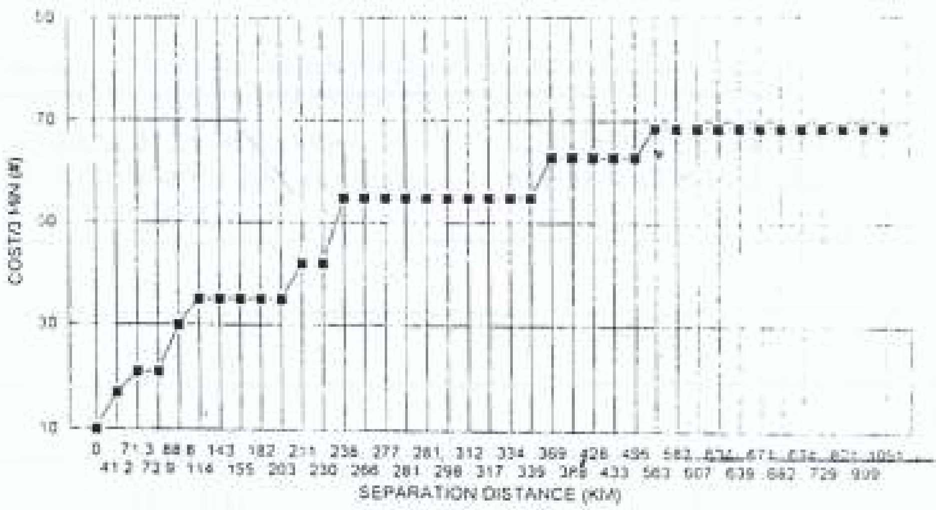

FIG 5.2 GRAPH OF COST VS SEPARATION DISTANCE

It should be noted that it is neccessary to derive the relationship between the call office charges and the linear separation distance, because this set of data is not readily available. This again is due to the decentralisation and commercialisation of the operations of Nitel, hence the rates being charged from Akure to the other states of the federation are not neccessarily being reciprocated from these other states (or exchanges).

5.3. Program Logic

The condition for constructing a Hamiltonian cycle states that each node in the network should be visited only once. In real life experiences, it has been observed that data transmission over the public telephone network is only possible at some locations (exchanges) at specific periods. For example, this might be for only a few minutes at a particular time period each day during which time the line is less busy. The implications of this is that, any attempt to transmit data to a particular node outside this time slot may result in the transmission being delayed for hours (or even days). This situation tends to increase the cost of the transmission. The only alternative left is to route the data to its destination by using other alternate routes that are free.

Table 5.2 Summary of nitel call office tariff for Akure exchange, vat charges inclusive

DISTANCE IN A RADIAL DIRECTION FROM EXCHANGE (KM)	COST/THREE MINUTES, WITH VAT CHARGES (#)
0 - 20	10
21 - 55	17
56 - 80	21
81 - 100	30
101 - 205	35
206 - 235	•42
236 - 355	55
356 - 530	63
531 AND ABOVE	68.5

Therefore it has been proposed that the transmission of data in a computer networking environment can be modelled by a Hamiltonian cycle. This is why the algorithm developed for the solution of the travelling salesperson problem, which is a Hamiltonian cycle problem is being applied to the transmission of data in a computer networking environment.

5.4 Representation of Input Data

There are two common ways to represent network (graph) for processing.These could be refered to as the sequential form and the linked representation. The linked representation is otherwise refered to as the linked list method. The sequential form or matrix method used a square table with n rows and columns where n is the numbers of nodes (or vertices). This table is called the adjacency matrix. For an undirected graph, the adjacency matrix, GRAPH (1:n, 1:n), is defined as

$$GRAPH(i,j) = \begin{cases} 1 & \text{if edge i,j is feasible} \\ 0 & \text{otherwise} \end{cases}$$

When the graph is a network, then the cost of (i,j)is represented as C(i,j). C(i,j) is defined by

$$C(i,j) = \begin{cases} x & \text{if (i,j) is feasible} \\ +\alpha. & \text{otherwise} \end{cases}$$

For undirected graphs GRAPH (i,j) = GRAPH (j,i), and is said to be symmetric. Even though the adjacency matrix normally requires n^2 location, for undirected graph, it would suffice to keep only an upper trianglar matrix, or n (n-1)/2 elements. Also, the main diagonal need not be stored as GRAPH (i,j) = 0, as would normally be the case which indicates that there are no "self-edges". The matrix method is used in this research work to represent the network.

5.5 Coding of the Routing Algorithm

The algorithm used for the optimization of the network was based on the heuristic algorithm proposed and implemented by [Akinyokun,1990] in the paper titled "Interactive and Menu Driven Heuristics for the Travelling Salesperson Problem ". This work has been reviewed in detail in chapter 3.

The algorithm starts by accessing the node which represents the source of data transmission. This is called the start node. From it the other edges are then added to the data transmission route,one at a time. The next edge (i,j) added is such that i is a node already accessed and j is a node not yet accessed. The cost of the edge (i,j) denoted by MAT(i,j) is the minimum among all the edges (k,l) such that node k has already been accessed while node l has not been accessed .

The edge (i,j) is determined by associating with each node j not yet included in the route, an initial value of MIN = 1000, thereafter j is set to the corresponding minimum value in the row being scanned and if no other lower value in the row k, then column l and minimum cost MAT(i,j) is recorded, and the process is repeated till end. When all data rows have been sccanned a test for a path back to the starting node is carried out and if a path is found the algorithm ends, otherwise, the search for a route back to the starting node continues till one is found.

The operation of the program is presented below.

1. PROCESS DATA [NOD,SNOD,MAT,MST,ROW,COL,MIN]

   [NOD is the total number of rows,SNOD is the starting node,MAT is the adjacency matrix (read in as input data), MST is the solution matix containing the output of the route constructed, ROW is the node just last accessed, COL is the node just being accessed and MIN holds the current minimum value of the row being searched.]

2. ROW <----- 0, COL <----- 0,MIN <------ 10000

   [initialise ROW, COL, MIN.]

3. CT <------- 1, WORK(1) <------- SNOD

[Define start node]

4. WHILE CT > NOD , For J <------- 1 To SNOD do

[Search data row correspoding to SNOD and test for value of MAT(i,j) = 0 AND = 10 but less than MIN].

5. Row <---- WORK (CT), COL<----J, MIN <----MAT(WORK(CT),y)

6. endif

7. enddo

8. MST(CT,1) <---- ROW, MST(CT,2) <---- COL, MST(CT,3) <---MIN

[store start node value, currently accessed node value and edge cost in solution matrix array]

9. WEND

10. CT <----- CT + 1, WORK(CT) <-----COL, MIN <----- 10000

[increment counter CT, reset Col, Min to scan the data row containing the next node to be accessed]

11. Flag $ <---- "false"

12. While flag $ <---- "false", if MAT (work(CT), SNOD)

=/= 0, then MST(CT,1) <----work(CT,2) <---- SNOD,MST(CT,3)

<---- MAT(work(CT), SNOD)

flag $ <---- "true"

else Repeat step 4 to step 10

[while the test flag is false, continue the search for nodes/ edges to be included in the data transmission route, but if the test flag is true, test if there is a path back to the starting node, else continue the search for nodes ledges in the route till a path is found leading back to the starting node]

13. end if

14. WEND

15. Cost <---- 0, for I <---- 1 to CT do

16. print MST(CT,1), MST(CT,2), MST(CT,3)

17. Cost <---- Cost + MST (CT,3)

[print the nodes ledges in the route and its edge cost]

[sum the total cost for the route generated]

18. enddo

19. print cost

[print the total cost of the route generated]

20. End.

The algorithm is coded in a manner designed to make it interactive and user-friendly,thereby enabling the user to actually select whichever route he desires among edges of the same weight. The algorithm is tested using sample data that is representative of a computer systems network. The results indicate that a Hamitonian cycle is obtained after applying the first phase of the algorithm. The second phase is not needed, since in a communications network, there are no hanging nodes and there is always a path linking each node to every other node that is, the network is fully connected. The situation is similar to a travelling salesperson in a physical distribution problem, who is travelling by air, rather than by road.

The processing may proceed to the second phase if there are constraints, such as when there is no path between a pair of nodes in the network graph. In this circumstance, the routing problem resembles the classical Travelling salesperson problem.

The program modules are coded in Qbasic which is one of the utilities of MS-DOS. Qbasic is a dialet or version of Basic programming language. Qbasic has features which support data processing, voice processing, and graphics/image processing. Qbasic can be compiled using MicroSoft Quickbasic4.5 or Visual Basics for DOS. These features of Qbasic make it more relevant in the implementation and case study programmes of this research work.

CHAPTER SIX

IMPLEMENTATION AND CASE STUDY

This chapter presents the implementation of the research work. An illustration of the algorithm for the optimal routing of data is first presented. The implementation technique is then considered. The case study carried out is also presented.

6.1 Illustration of the algorithm for Optimal Routing of Data

The graph depicted in figure 6.1 is used to illustrate the algorithm for optimal routing of the data transmission. The processing starts with an examination of all the edges connected to the start city and the cheapest edge is then selected as the path to the first node along the transmission route. In this case the cheapest edge from FCT (the start node) is <FCT,KD> with a cost of 35, the node KD is therefore selected as the first city along the transmission route.

From the node KD, it can be observed that two edges <KD,SO> and <KD,KW> have the some cost value of 63, this being the cheapest amongst all the edges connected to the node KD. Any of them could be selected. Selecting the edge <KD,SO> places the node SO as the next node for the routing of the data. From the node SO, the next node is KW, then node LA, node RV, and then node BO.

Thereafter the circuit is completed by visiting the node FCT again. The linked list representation of the complete route is

FCT --> KD --> SO --> KW --> LA --> RV --> BO --> FCT.

The total cost of the transmission along this route is 416 and the route is depicted in figure 6.2. Three other alternate routes are depicted in figures 6.3, 6.4 and 6.5. The manually generated routes which is not exhaustive is presented in Appendix E.

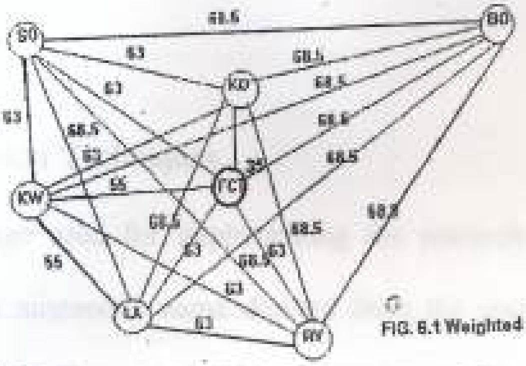

FIG. 6.1 Weighted Network

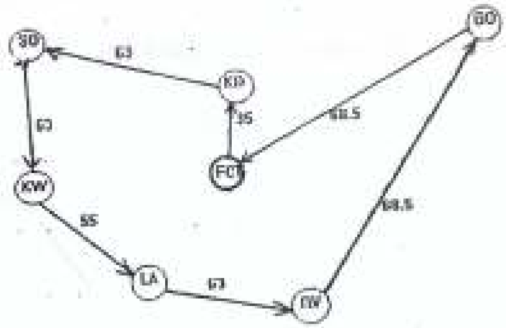

FIG. 6.2 Route of Cost 416

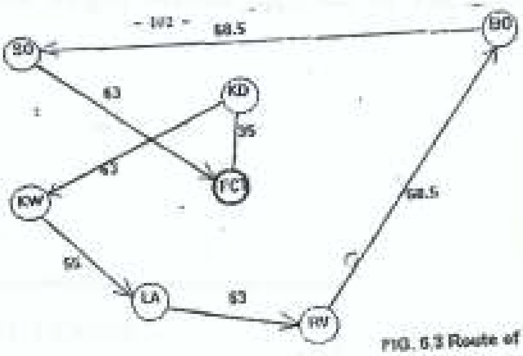

FIG. 6.3 Route of Cost 410

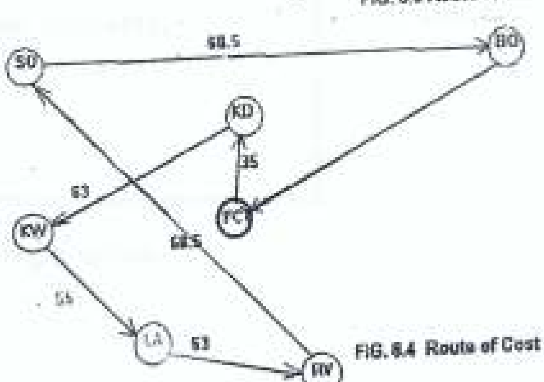

FIG. 6.4 Route of Cost 421.5

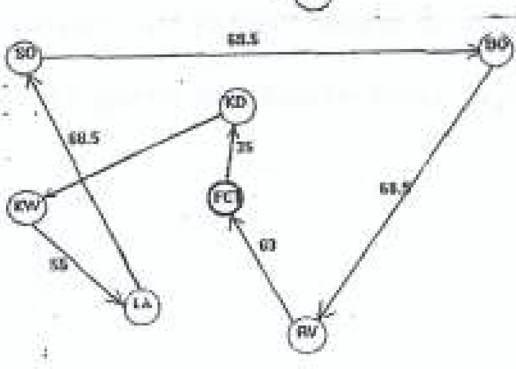

FIG. 6.5 Route of Cost 421.5

6.2 Implementation Techniques

The software package used for implementing the research work is given the name KBSNET. This is a mnenomic name derived from the research topic. The KBSNET supports three sessions. These are a tutorial session, a tour construction session and a graph definition session. The software is activated by typing KBSNET at the DOS prompt. A typical transcript of the dialogues between KBSNET and the user during the three sessions is presented.

As soon as the software is activated at the DOS prompt, the Welcome banner is displayed. Thereafter, the Login Screen depicted in Figure 6.6 is displayed on the screen.

```
              KBSNET LOGIN
        Please enter the following:

  User name:
  User password:
```

Figure 6.6(KBSNET login screen)

The user name and password are entered. Subject to verification and validation, authorisation is granted and the system introductory screen depicted in Figure 6.7 is displayed on the screen.

Are you knowledgeable of the travelling
Sales Person problem?
1. No
2. Yes
3. Exit
Pls. select an option.

Figure 6.7(KBSNET introductory screen)

selecting option 1, the system shifts control to a tutorial session which addresses the followings:

a. What is the travelling sales person problem?

b. What is the Hamiltonian Cycle Problem?

c. Objectives of KBSNET

d. Operation of KBSNET

e. Creation of program data files.

Selecting option 2, calls forth the display on the screen of the Main menu depicted in figure 6.8

KBSNET MAIN MENU

1. Initial Tour Construction
2. Final Tour Construction
3. Define Graph
4. Exit
Please Select an Option.

Fig. 6.8(KBSNET Main Menu)

The second session starts with the tour construction sub menus being selected from the main menu. The two sub menus available for tour construction are:Initial Tour Construction Sub Menu (option 1) and the Final Tour Construction sub menu (option 2).

Selecting option 1 for the construction of the initial tour calls on the screen the sub menu depicted in figure 6.9. When otpion 1 is selected, the screen displayed changes to that depicted in figure 6.10.

INITIAL TOUR CONSTRUCTION SUB MENU
1. Construction of Initial Tour 2. Optimization of Initial Tour 3. Exit Please Select an Option.

Fig. 6.9(Initial tour construction submenu)

Please enter the following:
Name of data file: Enter number of nodes: Enter starting node number:

Figure 6.10(Data input screen)

Upon supplying these information, control is passed back to the initial tour construction sub menu where option 2 can now be selected to start the Optimization process. Once it has been activated, the screen display depicted in figure 6.11 is shown on the screen.

Make a choice please

1. Automated processing
2. Interactive processing

Enter your choice

Fig. 6.11(Processing option screen)

Selecting Option 1 activates the automated processing module. In this module the program gets its input from the data file and processes it without the users input. The route constructed when using this module may not be the cheapest route. It is however observed that for any network, there will probably be more than one route that will give the least cost.

Selecting Option 2 activates the Interactive processing module. In this module, whenever the processing of the data reaches a point where a choice has to be made between two or more alternative routes of the same weight, the program displays a message of the form shown below

From RV

1. B0 is 63
2. S0 is 63

Enter node to include in the route

Fig. 6.12 (Route choice screen)

In this example the user is being prompted to select either the node 'Bo' or 'So' both of them with equal weight of 63, as the next node to visit from the node 'RV'. The selected nodes edge/edge cost is then included in the route being constructed. The processing continues in this manner until the end of the processing.

This module therefore allows the user to actually select the data transmission route he prefers when presented with alternatives and the user 'is able to generate all the alternative route available, when starting from any of the nodes. When option 2 that is, the Final Tour Construction sub menu of the Main Menu is selected, the sub menu depicted in figure 6.13 is displayed on the screen.

FINAL TOUR CONSTRUCTION SUB MENU
1. Display Edges and edge costs 2. Delect/Add edges to network graph 3. Print Results 4. Exit Please select an option

Fig. 6.13(Final tour construction submenu)

In this research work, the optimisation of the network actually ends with the construction of the initial tour, since the network being optimised are usually fully connected networks without any hanging nodes. Option 2, has however, been added to the software for completeness. Should there be networks that are not optimised in the first phase, option 2 provides the facilities for displaying the edge and the edge costs from the database files provided. It also facilitates a deletion and addition of edges to the sub tours that need to be reconstructed into Hamiltonian cycles. Finally it provides the facilities for printing the output files where the results of the optimised tour which is generated is stored. Figure 6.14 shows the print sub menu.

The network graph showing the route constructed can also be printed directly by using the print screen command key on the key board. For this purpose, a color printer is recommended.

PRINT RESULT SUBMENU
1. Print Route 2. Exit Please Select an Option

Fig 6.14(Print submenu)

The third session of the system is activated when option 3 , that is, Define Graph Sub menu is selected from the KBSNET Main Menu. Selecting this option allows the current network graph plotted to be viewed on the screen. The cost of the tour is also displayed.

The software program was used in the Interactive mode to generate the feasible routes obtainable from the network graph of figure 6.1. Only three feasible routes were generated based on the heuristic algorithm coded. The linked list representation of these three routes generated by the software were:

a. FCT --> KD --> KW --> LA --> RV --> BO --> SO --> FCT
   with a cost of 416. (figure 6.3)

b. FCT --> KD --> KW --> LA --> RV --> SO --> BO --> FCT
   with a cost of 421.5 (figure 6.4)

c. FCT --> KD --> SO --> KW --> LA --> RV --> BO --> FCT
   with a cost of 416. (figure 6.2)

The routes generated in (a) and (c) give the minimum cost of 416. This is the same value obtained earlier in the illustration.

6.3 Case Study

An experimental study simulating an interconnection of computers located in the Nigerian State Capitals and the FCT(Abuja) is carried out using the software program developed. The network has 37 nodes. This would have resulted in an exhaustive search of $(n-1)!/2$, that is about 1.86×10^{41} different routes before the least cost routes could be determined. While it is not possible to show all the edges used in a single network graph diagram, it is however possible to represent the network by the data file used for the processing.

The linked list representation of the feasible routes are:

a. FCT -> NS --> BN --> EB --> EN --> AN --> DT --> IM --> AB
--> AK --> CR --> RV --> BY --> ED --> EK --> OD --> OS
--> KW --> OG --> LA --> OY --> KG --> NG --> KD --> ZM
--> KT --> KN --> JG --> BA --> PL --> TA --> GB --> AD
--> BO --> YB --> KB --> SO --> FCT

The cost of the route is 1227.5 and the graph of the linked list is presented in Appendix F.

b. FCT -> NS --> BN --> EB --> EN --> AN --> DT --> IM --> AB
--> AK --> CR --> RV --> BY --> ED --> OS --> EK --> OD
--> OY --> OG --> LA --> KW --> NG --> KG --> KD --> PL
--> BA --> JG --> KN --> KT --> ZM --> SO --> KB --> YB
--> BO --> AD --> TA --> GB --> FCT

The cost of the route is 1229.5 and the graph of the linked list is presented in Appendix G.

c. FCT -> NS --> BN --> EB --> EN --> AN --> DT --> IM --> AB

--> AK --> CR --> RV --> BY --> ED --> EK --> OD --> OS

--> OY --> OG --> LA --> KW --> NG --> KG --> PL --> KD

--> ZM --> SO --> KB --> KT --> KN --> JG --> BA --> GB

--> AD --> TA --> YB --> BO --> FCT

The cost of the route is 1241.5 and the graph of the linked list is presented in Appendix H.

d. FCT -> NS --> PL --> KD --> ZM --> SO --> KB --> KT --> KN

--> JG --> BA --> GB --> TA --> AD --> BO --> YB --> BN

--> EB --> EN --> AN --> DT --> IM --> AB --> AK --> CR

--> RV --> BY --> ED --> KG --> NG --> KW --> OS --> EK

--> OD --> OG --> LA --> OY --> FCT

The cost of the route is 1239.5 and the graph of the linked list is presented in Appendix I.

e. FCT-->NS-->KG->BN->EB->EN ->AN ->DT -->IM ->AB->AK>

CR-->RV-->BY-->ED -->EK -->OD -->OS -->KW-->OG

->LA ->OY -->KD ->ZM -->SO ->KB -->KT -->KN -->JG -->BA

->PL -->GB -->TA -->AD -->BO -->YB -->NG -->FCT

The cost of the route is 1248.5 and the graph of the linked list is presented in Appendix J.

f. FCT --> NS -->KG --> DT --> AN --> EN --> EB --> AK --> CR ->IM --> AB --> RV -> BY --> ED --> OS --> EK --> OD--> KW --> OY--> OG --> LA --> NG --> KD --> ZM --> KT --> KN

--> JG --> BA --> PL --> GB --> TA --> AD --> BO --> YB --> KB-->

SO--> BN --> FCT

The cost of the route is 1250 and the graph of the linked list is presented in Appendix K.

g. FCT -> NS -->NG --> KD --> KN --> JG --> BA --> PL --> TA -->

GB --> AD --> BO --> YB --> KT --> ZM --> SO --> KB

--> KW --> OS --> EK --> OD --> OG --> LA --> OY --> KG

--> BN --> EN --> AN --> DT --> IM --> AB --> AK --> CR

--> EB --> RV --> BY --> ED --> FCT

The cost of the route is 1259.5 and the graph of the linked list is presented in Appendix L.

h. FCT -> NS -->KG --> EB --> EN --> AN --> DT --> IM --> AB -->

AK --> CR --> RV --> BY --> ED --> EK --> OD --> OS

--> OY --> OG --> LA --> KW --> NG --> KD --> PL --> BA

--> GB --> AD --> TA --> BN --> ZM --> KT --> KN --> JG

--> YB --> BO --> KB --> SO --> FCT

The cost of the route is 1269.5 and the graph of the linked list is presented in Appendix M.

i. FCT --> NS ->KG --> EB --> EN --> AN --> DT --> IM --> AB -->

AK --> CR --> RV --> BY --> ED --> EK --> OD --> OS

--> OY --> OG --> LA --> KW --> NG --> KD --> PL --> BA

--> GB --> AD --> TA --> BN --> ZM --> KT --> KN --> JG

--> YB --> BO --> KB --> SO --> FCT

The cost of the route is 1269.5 and the graph of the linked list is presented in Appendix N.

j. FCT --> NS -->BN --> EB --> EN --> AN --> DT --> IM --> AB --> AK --> CR --> RV --> BY --> ED --> EK --> OD --> OS --> KW --> OG --> OY --> LA -> KG --> NG --> KD --> KN --> JG --> BA --> PL --> ZM --> SO -> KB --> KT --> GB --> TA --> AD --> BO --> YB --> FCT

The cost of the route is 1276.5 and the graph of the linked list is presented in Appendix O.

k. FCT -> NS -->KG --> EB --> EN --> AN --> DT --> IM --> AB --> AK --> CR --> RV --> BY --> ED --> OD --> EK --> OS --> KW --> OY --> OG --> LA --> NG --> KD --> KN --> JG --> BA --> GB --> AD --> TA --> BN --> PL --> ZM --> SO --> KB --> KT --> YB --> BO --> FCT

The cost of the route is 1279 and the graph of the linked list is presented in Appendix P.

l. FCT -> NS -->PL --> BA --> JG --> KN --> KT --> ZM --> SO --> KB --> NG --> KD --> KG --> EK --> OD --> OS --> KW --> OG --> OY --> LA --> ED --> DT --> AN --> EN --> EB --> CR --> AK --> AB --> IM --> RV --> BY --> BN --> TA --> GB --> AD --> BO --> YB --> FCT

The cost of the route is 1279.5 and the graph of the linked list is presented in Appendix Q.

m. FCT -> NS --> BN --> EB --> EN --> AN --> DT --> IM --> AB --> AK --> CR --> RV --> BY --> ED --> EK --> OD --> OS --> OY --> OG --> LA --> KW --> NG --> KG --> PL --> BA --> JG --> KN --> KM --> SO --> KB --> KT --> KD --> TA --> AD --> GB --> YB --> BO --> FCT

The cost of the route is 1281.5 and the graph of the linked list is presented in Appendix R.

n. FCT -> NS --> NG --> KG --> OD --> BK --> OS --> OY --> OG --> LA --> ED --> DT --> AN --> EN --> EB --> AB --> IM --> RV --> BY --> AK --> CR --> BN --> TA --> AD --> GB --> BA --> JG --> KN --> KT --> ZM --> KD --> PL --> KW --> SO --> KB --> YB --> BO --> FCT

The cost of the route is 1284 and the graph of the linked list is presented in Appendix S.

o. FCT -> NS --> NG --> KD --> PL --> BA --> JG --> KN --> ZM --> KT --> SO --> KB --> OS --> EK --> OD --> OY --> OG --> LA --> ED --> DT --> AN --> EN --> EB --> IM --> AB --> AK --> CR --> RV --> BY --> KG --> BN --> TA --> AD --> GB --> BO --> YB --> KW --> FCT

The cost of the route is 1287.5 and the graph of the linked list is presented in

Appendix T.

p. FCT -> NS --> NG --> KD --> ZM --> KN --> JG --> BA --> GB --> TA --> AD --> BO --> YB --> BN --> EN --> AN --> DT --> IM --> AB --> AK --> CR --> EB --> KG --> ED --> OS --> EK --> OD --> KW --> OY --> OG --> LA --> RV --> BY --> SO --> KB --> KT --> PL --> FCT

The cost of the route is 1293 and the graph of the linked list is presented in Appendix U.

q. FCT -> NS --> NG --> KG --> ED --> DT --> AN --> EN --> EB --> AB --> IM --> RV --> BY --> AK --> CR --> BN --> PL --> BA --> GB --> TA --> AD --> BO --> YB --> KN --> JG --> KT --> ZM --> KD --> KB --> SO --> KW --> OS --> EK --> OD --> OG --> LA --> OY --> FCT

The cost of the route is 1294 and the graph of the linked list is presented in Appendix V.

r. FCT -> NS --> KG --> NG --> KD --> ZM --> KN --> JG --> BA --> PL --> TA --> GB --> AD -> BO --> YB --> OD -->EK --> OS --> KW --> OG --> LA --> OY --> ED --> DT --> AN --> EN --> EB --> BN --> AB --> IM --> RV --> BY --> AK --> CR --> KB --> SO --> KT --> FCT

The cost of the route is 1297 and the graph of the linked list is presented in Appendix W.

s. FCT -> NS --> KG --> OD --> EK --> OS --> OY --> OG --> LA --> ED --> DT --> AN --> EN --> EB --> AB --> IM --> RV --> BY --> AK --> CR --> BN --> TA --> AD --> GB --> BA --> JG --> KN --> KT --> ZM --> KD --> NG --> KW --> PL --> BO --> YB --> SO --> KT --> FCT

The cost of the route is 1298.5 and the graph of the linked list is presented in Appendix X.

t. FCT -> NS --> NG --> KD --> KN --> JG --> BA --> PL --> TA --> GB --> AD --> BO --> YB --> OY --> OG --> LA --> OS --> EK --> OD --> KW --> DT --> AN --> EN --> EB --> AB --> IM --> RV --> BY --> AK --> CR --> BN --> KG --> ED --> SO --> ZM --> KT --> KB --> FCT

The cost of the route is 1309 and the graph of the linked list is presented in Appendix Y.

u. FCT -> NS --> KG --> AN --> DT --> IM --> AB --> AK --> CR --> RV --> BY --> ED --> EN --> EB --> BN --> KD --> ZM --> SO --> KB --> KW --> OS --> EK --> OD --> OY --> OG --> LA --> NG --> KN --> JG --> BA --> GB --> TA --> AD --> BO --> YB --> PL --> KT --> FCT

The cost of the route is 1319.5 and the graph of the linked list is presented in Appendix Z.

The result of the case study shows clearly the relative advantage of the Knowledge Based processing technique over the purely Automated techniques. Using the automated technique only one solution can be obtained. This solution is dependent on the arrangement of the data in the data file used. With the present data set the only solution that can be obtained with the automated processing mode of the software program is the route shown in Appendix V. When the Interactive mode is used however, up to two hundred different routes can be generated. Comparing the results it is also observed that the result generated by the Automated processing technique is not the minimum possible, although it is within an acceptable range in the solution space.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

This chapter presents the Conclusions drawn from the research work. The Recommendations are also presented.

7.1 Conclusion

In this research work it had been proposed that the topology that is most suited for connecting computers in a communications network for distributed processing is a Star/Ring topology. This topology is especially useful since most networking applications require some form of central control, enforcement of standards, data integrity, compatibility and accuracy. Besides there is the continual need to ensure that the attendant problems of data redundancy and generation of conflicting statistics are eliminated.

All these have been highlighted in [Akinyokun,1987], where a three level architecture for the Design and Implementation of a Road safety Relational Database had been proposed. The driving force behind this and other proposed and existing distributed systems is telecommunications technology. In developing countries where these facilities are substandard, the proposed topology allows the routing of data along alternate least cost and most reliable paths through the common carrier networks, while not compromising the data.

It is being proposed here that the routing of data in the proposed Star/Ring hybrid network can be modelled by a Hamiltonian cycle. An experimental study of the model proposed has been carried out using a hypothetical computer networking environment that is based on the Nigerian State Capitals and the Federal Capital Territory (Abuja).

The nodes of the conceptual network graph were the State Capital cities and the

FCT, while the weights attached to the edges of the network graph is the cost of processing a call from one node to another using NITEL call-office rates.

The routing algorithm is coded to allow for the following features.

a. Menu driven

b. User-friendliness

c. Interative

The algorithm allows for the generation of all the feasible routes. In the Ring topology networks, data packets sent out circulates round the ring until it ends up back at the transmitting node where it is then recovered or removed from ciculation. The routing algorithm implemented for the Star/Ring hybid network proposed has also retained this feature. For a tour to be a Hamiltonian cycle it must end at the starting node also. The proposed algorithm therefore, guarantees the automatic acknowledgement of data sent in the network.

The proposed routing algorithm supports real time processing of data and finds ready application in the transmission of messages in any network that is based on the Mesh topology architecture. It is noted that the Internet which is an interconnection of thousands of computers which spans the globe is actually a Mesh topology network. The Internet is based on telephone line connections.

7.2 Recommendations

During the course of this research, quite a number of literary publications on communications systems modelling were consulted. It is observed that there is a dearth of information on the application of the Travelling Salesperson Problem as a possible model for designing least cost networks, or to any aspect of communications. This made it impossible to make adequate comparison of the present work with any other model of this nature.

Within the context of the framework proposed, the model designed is actually limited to the point-to-point cabled networks. The current trend in long distance communications is towards wireless communication systems via satellite, microwave or radio channels. The application of the routing model in wireless network environment has not been fully addressed in this research. It is felt that the model should be applicable to packet radio networks.

The routing algorithm developed will provide a reliable method for sending Broadcast or Multicast transmission packets from the source node to the other nodes in a cabled point-to-point network. Multicast transmissions were formerly limited to LANs, but in recent times has increasingly being used by applications on the Internet for Multimedia conferencing and resourse discovery. While multicast file transfer is not a standard software, there are however many protocols devised for it. The routing algorithm developed in this research provides a viable alternative to those based on the Flooding techniques and the Spanning Tree techniques presently being used for multicast transmissions.

It is recommended that the proposed model should be futher researched and tested, so that a full-scale routing algorithm and communications protocol can be developed. This would be ideally suited to our local needs considering the state of our telecommunications facilities. Perhaps the package that may evolve can serve as a utility of MicroSoft Windows NT.

References

1. Akinyokun O.C.,(1987). The Design and Implementation of Road Safety Relational Database, International Journal of Information Technology for Development, Published by the Oxford University Press, United Kingdom, Vol2, No2 ,pp 147-156.

2. Akinyokun O.C.,(1990). Interactive and Menu Driven Heuristics for Travelling Salesperson Problem, Nigerian Journal of Science, Published by the Science Asssociation of Nigeria,20 pages; Proceedngs of the International Conference on SystemsManagement '90 Hong Kong.

3. Akinyokun O.C.,(1990). Query Optimization in a Database Environment, Nigerian Journal of Science, Vol24, No1&2, pp 174-180

4. Akinyokun O.C.,(1994). Computers and Programming Using Fortran, Second Edition. Ondo State New Era Press(Publishers).

5. Akinyokun O.C.,(1994). Extracts from Inroduction to Computing, Database Systems lecture notes, F.U.T.A.

6. Akinyokun O.C., Uzoka F.M.E., Sunmola F. (1996). Programming Computer in a Unix Operating System Environment. HTRDG Computing Centre (Publishers).

7. Christofides N.,(1976). Worst-case analysis of a new heuristics fot the travelling salesman problem, Management Science Research Report No 388, Carnegie Mellon University, U.S.A.

8. Durr M.,Gibbs M.,(1989). Networking Personal Computers, Que Corporation (Publishers)

9. Elmaghraby S.E.,(1971). Operations Research, Industrial Engineering Handbook, McGraw-Hill (Publishers).

10. Furth E.,(1967). Communications Systems Modelling, Communcations System Engineering Handbook, McGraw-Hill (Publishers)

11. Golden B.,(1980). A Statistical approach to the TSP, Networks, Vol 7, pp209-225.

12. Golden et al,(1980). Approximate travelling salesman algorithms, Operations Research, vol. 28, No 3, pp694-711.

13. Hopper A., Temple S., Williamson R.(1986). Area Network Design, Addison-Wesley Publishing Co, Inc.

14. Horowitz E.,Sahni S.,(1978). Fundamentals of Computer Algorithms, Pitman Publishing Limited, U.K.

15. Huitema C.,(1995). Routing in the Internet, Prentice-Hall Inc. (Publishers)

16. Lithe J.D.,(1984). An improved solution to the travelling salesperson problem with thousands of nodes,Communications of the ACM, vol. 27, No 12, pp1227-1236.

17. Nitel plc,(1990). National Telephone Directory, Sixth Edition.

18. Nitel plc, (1994). Services Tariff Book

19. Federal Surveys (1985). Road Map of Nigeria showing Federal Trunk Roads

20. Savory S.,(1988). Artificial Intelligence and Expert Systems,Ellis Horwood Ltd. (Publishers)

21. Sedgewick R.,(1988). Algorithms, Addison-Wesley Publishing Co., Second Edition.

22. Sheldon T.,(1994). LAN TIMES Encyclopedia of Networking, Osborne McGraw-Hill (Publishers)

23. Stallings W.,(1994) Data and Computer Commmunications, Mcmillian Publishing Co. , New York, Fourth Edition.

24. Tanenbaum A.S.,(1996) Computer Networks, Prentice-Hall PTR (Publishers), Third edition.

25. Tilley E.,(1995) Windows 95 Unleashed, SAMS publishing Co., U.S.A

Appendix A
Coding convention used for the labelling of network nodes

STATE	CAPITAL	STATE CODE	NODE CODE
ONDO	AKURE	OD	1
OYO	IBADAN	OY	2
OSUN	OSOGBO	OS	3
OGUN	ABEOKUTA	OG	4
LAGOS	IKEJA	LA	5
EKITI	ADO-EKITI	EK	6
EDO	BENIN	ED	7
DELTA	ASABA	DT	8
KWARA	ILORIN	KW	9
KOGI	LOKOJA	KG	10
ABUJA	ABUJA	FCT	11
ABIA	UMUAHIA	AB	12
ANAMBRA	AWKA	AN	13
ENUGU	ENUGU	EN	14
EBOINYI	ABAKALIKI	EB	15
IMO	OWERRI	IM	16
BAYELSA	YENAGOA	BY	17
RIVERS	PORT-HARCOURT	RV	18
AKWA-IBOM	UYO	AK	19
CROSS-RIVERS	CALABAR	CR	20
JIGAWA	DUTSE	JG	21

ADAMAWA	YOLA	AD	22
TARABA	JALINGO	TA	23
NASARAWA	NASARAWA	NS	24
YOBE	DAMATURU	YB	25
NIGER	MINNA	NG	26
BORNO	MAIDUGURI	BO	27
GOMBE	GOMBE	GB	28
BAUCHI	BAUCHI	BA	29
BENUE	MARKURDI	BN	30
PLATEAU	JOS	PL	31
KANO	KANO	KN	32
KATSINA	KATSINA	KT	33
KADUNA	KADUNA	KD	34
SOKOTO	SOKOTO	SO	35
KEBBI	BIRNIN-KEBBI	KB	36
ZAMFARA	GUSAU	ZM	37

Appendix B

Nitel call office cost/separation distance

LOCATION	SEPARATION DISTANCE (KM)	COST/THREE MINUTE CALL (#)
OD,OD>	0.0	10
<OD,EK>	41.2	17
<OD,IKOLE>	71.3	21
<OD,IFON>	72.9	21
<OD,OS>	88.8	30
<OD,ED>	114.1	35
<OD,OY>	142.7	35
<OD,KW>	155.3	35
<OD,KG>	182.3	35
<OD,OG>	202.9	35
<OD,DT>	210.8	42
<OD,LA>	229.8	42
<OD,AN>	237.8	55
<OD,EN>	266.3	55
<OD,FCT>	277.4	55
<OD,BY>	280.5	55
<OD,IM>	280.5	55
<OD,NG>	298	55
<OD,NS>	312.2	55
<OD,AB>	317	55
<OD,EB>	334.4	55
<OD,RV>	339.2	55

<OD,BN>	369.3	63
<OD,AK>	388.3	63
<OD,CR>	428	63
<OD,KD>	432.7	63
<OD,PL>	496.1	63
<OD,ZM>	562.7	68.5
<OD,KB>	581.7	68.5
<OD,BA>	607.1	68.5
<OD,KN>	634	68.5
<OD,SO>	638.8	68.5
<OD,JG>	670.5	68.5
<OD,KT>	681.6	68.5
<OD,TA>	694.2	68.5
<OD,GB>	729.1	68.5
<OD,AD>	821	68.5
<OD,BO>	998.6	68.5
<OD,YB>	1050.9	68.5

Appendix C
Screen locations used for the network nodes

NODE CODE	STATE CODE	SCREEN MODE 0	SCREEN MODE 9
1	OD	(15,28)	(224,210)
2	OY	(15,20)	(160,210)
3	OS	(13,24)	(192,182)
4	OG	(16,16)	(128,224)
5	LA	(19,18)	(144,266)
6	EK	(13,30)	(240,182)
7	ED	(17,34)	(272,238)
8	DT	(19,38)	(304,266)
9	KW	(11,18)	(144,154)
10	KG	(14,38)	(304,196)
11	FCT	(11,38)	(304,154)
12	AB	(18,48)	(384,252)
13	AN	(17,40)	(320,238)
14	EN	(16,44)	(352,224)
15	EB	(16,50)	(400,224)
16	IM	(19,44)	(352,266)
17	BY	(21,36)	(288,294)
18	RV	(22,44)	(352,308)
19	AK	(22,52)	(416,308)
20	CR	(20,54)	(432,280)
21	JG	(4,48)	(384,56)
22	AD	(11,62)	(496,154)

23	TA	(12,52)	(416,168)
24	NS	(11,44)	(352,154)
25	YB	(5,58)	(464,70)
26	NG	(9,34)	(272,126)
27	BO	(6,64)	(512,84)
28	GB	(8,56)	(448,112)
29	BA	(8,50)	(400,112)
30	BN	(14,46)	(368,196)
31	PL	(9,46)	(368,126)
32	KN	(5,42)	(336,70)
33	KT	(6,36)	(288,84)
34	KD	(8,40)	(320,112)
35	SO	(4,24)	(192,56)
36	KB	(6,20)	(160,84)
37	ZM	(6,30)	(240,84)

Appendix D

Computed Nitel call office tariff

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<OD,OD>	0.0	10
<OD,OY>	142.7	35
<OD,OS>	88.8	30
<OD,OG>	202.9	35
<OD,LA>	229.8	42
<OD,EK>	41.2	17
<OD,ED>	114.1	35
<OD,DT>	210.8	42
<OD,KW>	155.3	35
<OD,KG>	182.3	35
<OD,FCT>	277.4	55
<OD,AB>	317.0	55
<OD,AN>	237.8	55
<OD,EN>	266.3	55
<OD,EB>	333.3	63
<OD,IM>	280.5	55
<OD,BY>	280.5	55
<OD,RV>	339.2	55
<OD,AK>	388.3	63
<OD,CR>	428.0	63
<OD,JG>	670.5	68.5
<OD,AD>	821.0	68.5
<OD,TA>	694.2	68.5
<OD,NS>	312.2	55
<OD,YB>	1050.9	68.5

<OD,NG>	298.O	55
<OD,BO>	998.3	68.5
<OD,GB>	729.1	68.5
<OD,BA>	607.1	68.5
<OD,BN>	369.3	63
<OD,PL>.	496.1	63
<OD,KN>	634.0	68.5
<OD,KT>	681.6	68.5
<OD,KD>	432.7	63
<OD,SO>	638.8	68.5
<OD,KB>	581.7	68.5
<OD,ZM>	562.7	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<OY,OD>	142.7	35
<OY,OY>	O.O	10
<OY,OS>	82.4	30
<OY,OG>	65.0	21
<OY,LA>	115.7	35
<OY,EK>	150.6	35
<OY,ED>	221.9	42
<OY,DT>	340.8	55
<OY,KW>	144.2	35
<OY,KG>	317.0	42
<OY,FCT>	391.5	63
<OY,AB>	442.2	63
<OY,AN>	367.7	63
<OY,EN>	404.2	63

<OY,EB>	475.5	63
<OY,IM>	399.4	63
<OY,BY>	372.5	63
<OY,RV>	44.8	63
<OY,AK>	512.0	63
<OY,CR>.	554.8	68.5
<OY,JG>	764.0	68.5
<OY,AD>	954.2	68.5
<OY,TA>	830.5	68.5
<OY,NS>	435.9	63
<OY,YB>	1158.6	68.5
<OY,NG>	3772	63
<OY,BO>	1117.4	68.5
<OY,GB>	851.2	68.5
<OY,BA>	721.2	68.5
<OY,BN>	507.2	63
<OY,PL>	610.2	68.5
<OY,KN>	713.3	68.5
<OY,KT>	733.9	68.5
<OY,KD>	516.7	63
<OY,SO>	642.0	68.5
<OY,KB>	559.5	68.5
<OY,ZM>	607.1	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<OS,OD>	88.8	30
<OS,OY>	82.4	30

<OS,OS>	0.0	10
<OS,OG>	149.0	35
<OS,LA>	193.4	35
<OS,EK>	77.7	21
<OS,ED>	198.1	35
<OS,DT>	298.0	55
<OS,KW>	82.4	30
<OS,KG>	240.9	55
<OS,FCT>	309.1	55
<OS,AB>	404.2	63
<OS,AN>	323.3	55
<OS,EN>	355.0	55
<OS,EB>	416.9	63
<OS,IM>	369.3	63
<OS,BY>	364.6	63
<OS,RV>	424.8	63
<OS,AK>	475.5	63
<OS,CR>	516.7	63
<OS,YG>	680.0	68.5
<OS,AD>	876.5	68.5
<OS,TA>	749.7	68.5
<OS,NS>	353.5	55
<OS,YB>	1077.8	68.5
<OS,NG>	298.0	55
<OS,BO>	1035.0	68.5
<OS,GB>	767.1	68.5
<OS,BA>	634.0	68.5
<OS,BN>	432.7	63

<OS,PL>	527.8	63
<OS,KN>	630.8	68.5
<OS,KT>	662.5	68.5
<OS,KD>	435.9	63
<OS,SO>	586.5	68.5
<OS,KB>	518.3	63
<OS,ZM	535.7	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<OG,OD>	202.9	35
<OG,OY>	65.0	21
<OG,OS>	149.0	35
<OG,OG>	O.O	10
<OG,LA>	77.7	21
<OG,EK>	214.0	42
<OG,ED>	269.5	55
<OG,DT>	393.1	63
<OG,KW>	198.1	35
<OG,KG>	380.4	63
<OG,FCT>	456.5	63
<OG,AB>	488.2	63
<OG,AN>	420.0	63
<OG,EN>	459.7	63
<OG,EB>	527.8	63
<OG,IM>	443.8	63
<OG,BY>	404.2	63
<OG,RV>	480.3	63
<OG,AK>	554.8	68.5

<OG,CR>	597.5	68.5
<OG,JG>	827.4	68.5
<OG,AD>	1022.3	68.5
<OG,TA>	895.5	68.5
<OG,NS>	602.3	68.5
<OG,YB>	1226.8	68.5
<OG,NG>	443.8	63
<OG,BO>	1185.6	68.5
<OG,GB>	914.5	68.5
<OG,BA>	787.7	68.5
<OG,BN>	570.6	68.5
<OG,PL>	673.6	68.5
<OG,KN>	773.5	68.5
<OG,KT>	789.3	68.5
<OG,KD>	578.5	68.5
<OG,SO>	678.4	68.5
<OG,KB>	586.5	68.5
<OG,ZM>	657.8	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<LA,OD>	229.8	42
<LA,OY>	115.7	35
<LA,OS>	193.4	35
<LA,OG>	77.7	21
<LA,LA>	0.0	10
<LA,EK>	237.8	55
<LA,ED>	253.6	55
<LA,DT>	367.7	63
<LA,KW>	258.4	55

<LA,KG>	396.2	63
<LA,FCT>	488.2	63
<LA,AB>	459.7	63
<LA,AN>	404.2	63
<LA,EN>	447.0	63
<LA,EB>	521.5	63
<LA,IM>	412.1	63
<LA,BY>	356.6	63
<LA,RV>	435.9	63
<LA,AK>	364.6	63
<LA,CR>	565.8	68.5
<LA,JG>	871.8	68.5
<LA,AD>	1035.0	68.5
<LA,TA>	905.0	68.5
<LA,NS>	523.1	63
<LA,YB>	1264.8	68.5
<LA,NG>	486.6	63
<LA,BO>	1214.1	68.5
<LA,GB>	941.5	68.5
<LA,BA>	819.4	68.5
<LA,BN>	576.9	69.5
<LA,PL>	705.3	68.5
<LA,KN>	824.2	68.5
<LA,KT>	851.1	68.5
<LA,KD>	626.1	68.5
<LA,SO>	751.3	68.5
<LA,KB>	664.1	68.5
<LA,ZM>	718.0	68.5

LOCATION	SEPARATION DISTANCE	COST (#)
<EK,OD>	41.2	17
<EK,OY>	150.6	35
<EK,OS>	77.7	21
<EK,OG>	214.0	42
<EK,LA>	237.8	55
<EK,EK>	0.0	10
<EK,ED>	149.0	35
<EK,DT>	229.8	42
<EK,KW>	125.2	35
<EK,KG>	166.4	35
<EK,FCT>	248.8	55
<EK,AB>	336.0	55
<EK,AN>	255.2	55
<EK,EN>	279.0	55
<EK,EB>	342.4	55
<EK,IM>	305.9	55
<EK,BY>	317.0	55
<EK,RV>	367.7	63
<EK,AK>	408.9	63
<EK,CR>	454.9	63
<EK,JG>	634.0	68.5
<EK,AD>	806.8	68.5
<EK,TA>	678.4	68.5
<EK,NS>	288.5	55
<EK,YB>	1022.3	68.5
<EK,NG>	261.5	55
<EK,BO>	974.8	68.5

<EK,GB>	705.3	68.5
<EK,BA>	578.5	68.5
<EK,BN>	358.2	63
<EK,PL>	467.6	63
<EK,KN>	5991.1	68.5
<EK,KT>	649.9	68.5
<EK,KD>	396.3	63
<EK,SO>	597.5	68.5
<EK,KB>	543.7	68.5
<EK,ZM>	523.1	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<ED,OD>	114.1	35
<ED,OY>	221.9	42
<ED,OS>	198.1	35
<ED,OG>	269.5	35
<ED,LA>	253.6	55
<ED,EK>	149.0	35
<ED,ED>	0.0	10
<ED,DT>	126.8	35
<ED,KW>	269.5	55
<ED,KG>	204.5	35
<ED,FCT>	324.9	55
<ED,AB>	221.9	42
<ED,AN>	158.5	35
<ED,EN>	199.7	35
<ED,EB>	269.5	55
<ED,IM>	179.1	35

<ED,BY>	169.6	35
<ED,RV>	386.7	63
<ED,AK>	290.1	55
<ED,CR>	332.9	55
<ED,JG>	719.6	68.5
<ED,AD>	808.4	68.5
<ED,TA>	684.7	68.5
<ED,NS>	334.4	55
<ED,YB>	1073.0	68.5
<ED,NG>	374.1	63
<ED,BO>	1014.4	68.50
<ED,GB>	741.8	68.5
<ED,BA>	629.2	68.5
<ED,BN>	353.5	55
<ED,PL>	527.8	63
<ED,KN>	694.2	68.5
<ED,KT>	760.8	68.5
<ED,KD>	499.3	63
<ED,SO>	741.8	68.5
<ED,KB>	692.6	68.5
<ED,ZM>	649.9	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<DT,OD>	210.8	42
<DT,OY>	340.8	55
<DT,OS>	298.0	55
<DT,OG>	393.1	63
<DT,LA>	367.7	63

<DT,EK>	229.8	42
<DT,ED>	126.8	35
<DT,DT>	0.0	10
<DT,KW>	351.9	55
<DT,KG>	177.5	35
<DT,FCT>	293.2	55
<DT,AB>	109.4	35
<DT,AN>	31.7	17
<DT,EN>	82.4	30
<DT,EB>	147.4	35
<DT,IM>	84.0	30
<DT,BY>	150.6	35
<DT,RV>	160.0	35
<DT,AK>	180.7	35
<DT,CR>	210.3	42
<DT,JG>	672.0	68.5
<DT,AD>	702.2	68.5
<DT,TA>	578.5	68.5
<DT,NS>	277.4	55
<DT,YB>	990.6	68.5
<DT,NG>	372.5	63
<DT,BO>	930.4	68.5
<DT,GB>	741.4	68.5
<DT,BA>	557.9	68.5
<DT,BN>	256.8	55
<DT,PL>	466.0	63
<DT,KN>	660.0	63
<DT,KT>	751.3	68.5

<DT,KD>	478.7	63
<DT,SO>	771.9	68.5
<DT,KB>	741.8	68.5
<DT,ZM>	653.0	68.5

LOCATION	SERARATION DISTANCE (KM)	COST (#)
<KW,OD>	155.3	35
<KW,OY>	144.2	35
<KW,OS>	82.4	30
<KW,OG>	198.1	35
<KW,LA>	254.8	55
<KW,EK>	125.2	35
<KW,ED>	269.5	55
<KW,DT>	351.9	55
<KW,KW>	0.0	10
<KW,KG>	253.6	55
<KW,FCT>	288.5	55
<KW,AP>	459.7	63
<KW,AN>	375.6	63
<KW,EN>	394.7	63
<KW,EB>	456.5	63
<KW,IM>	428.0	63
<KW,BY>	435.9	63
<KW,RV>	491.4	63
<KW,AK>	532.6	68.5
<KW,CR>	515.1	63
<KW,JG>	629.2	68.5

<KW,AD>	865.4	68.5
<KW,TA>	741.8	68.5
<KW,NS>	348.7	55
<KW,YB>	1042.9	68.5
<KW,NG>	250.4	42
<KW,BO>	1003.3	68.5
<KW,GB>	743.4	68.5
<KW,BA>	607.1	68.5
<KW,BN>	443.8	63
<KW,PL>	496.1	63
<KW,KN>	575.4	68.5
<KW,KT>	594.4	68.5
<KW,KD>	385.2	63
<KW,SO>	507.2	63
<KW,KB>	435.9	63
<KW,ZM>	464.4	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<KG,OD>	182.3	35
<KG,OY>	317.0	55
KG,OS>	240.9	55
<KG,OG>	380.4	63
<KG,LA>	396.2	63
<KG,EK>	166.4	35
<KG,ED>	204.5	35
<KG,DT>	177.5	35
<KG,KW>	253.6	55

<KG,KG>	0.0	10
<KG,FCT>	123.6	35
<KG,AB>	263.1	55
<KG,AN>	180.7	35
<KG,EN>	174.4	35
<KG,EB>	202.9	35
<KG,IM>	256.8	55
<KG,BY>	321.8	55
<KG,RV>	334.4	55
<KG,AK>	329.7	55
<KG,CR>	358.2	55
<KG,JG>	518.3	63
<KG,AD>	641.9	68.5
<KG,TA>	515.1	63
<KG,NS>	134.7	35
<KG,YB>	640.3	68.5
<KG,NG>	193.4	35
<KG,BO>	821.0	68.5
<KG,GB>	548.4	68.5
<KG,BA>	432.7	63
<KG,BN>	195.0	35
<KG,PL>	324.9	55
<KG,KN>	497.7	63
<KG,KT>	576.9	68.5
<KG,KD>	307.5	55
<KG,SO>	599.1	68.5
<KG,KB>	580.1	68.5
<KG,ZM>	475.5	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<FCT,OD>	277.4	55
<FCT,OY>	391.5	63
<FCT,OS>	309.1	55
<FCT,OG>	456.5	63
<FCT,LA>	488.2	63
<FCT,EK>	248.8	55
<FCT,ED>	324.9	55
<FCT,DT>	293.2	55
<FCT,KW>	288.5	55
<FCT,KG>	123.6	35
<FCT,FCT>	0.0	10
<FCT,AB>	366.1	63
<FCT,AN>	293.2	55
<FCT,EN>	269.5	55
<FCT,EB>	296.4	55
<FCT,IM>	369.3	63
<FCT,BY>	440.6	63
<FCT,RV>	448.6	63
<FCT,AK>	428.0	63
<FCT,CR>	447.0	63
<FCT,JG>	396.3	63
<FCT,AD>	578.5	68.5
<FCT,TA>	454.9	63
<FCT,NS>	69.7	21
<FCT,YB>	773.5	68.5
<FCT,NG>	106.2	35

<FCT,BO>	727.5	68.5
<FCT,GB>	461.2	63
<FCT,BA>	331.3	55
<FCT,BN>	193.4	35
<FCT,PL>	221.9	42
<FCT,KN>	375.6	63
<FCT,KT>	458.1	63
<FCT,KP>	187.0	35
<FCT,SO>	507.2	63
<FCT,KB>	512.0	63
<FCT,ZM>	366.1	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<AB,OD>	317.0	55
<AB,OY>	442.2	63
<AB,OS>	404.2	63
<AB,OG>	488.2	63
<AB,LA>	459.7	63
<AB,EK>	336.0	55
<AB,ED>	221.9	42
<AB,DT>	109.4	35
<AB,KW>	459.7	63
<AB,KG>	263.1	55
<AB,FCT>	366.1	63
<AB,AB>	0.0	10
<AB,AN>	85.6	30
<AB,EN>	95.1	30

<AB,EB>	107.8	35
<AB,IM>	52.3	17
<AB,BY>	150.6	35
<AB,RV>	99.9	30
<AB,AK>	66.6	21
<AB,CR>	112.5	35
<AB,JG>	713.3	68.5
<AB,AD>	676.8	68.5
<AB,TA>	554.8	68.5
<AB,NS>	331.3	55
<AB,YB>	995.4	68.5
<AB,NG>	459.7	63
<AB,BO>	925.6	68.5
<AB,GB>	656.2	68.5
<AB,BA>	583.3	68.5
<AB,BN>	266.3	55
<AB,PL>	504.0	63
<AB,KN>	718.0	68.5
<AB,KT>	819.4	68.5
<AB,KD>	546.8	68.5
<AB,SO>	862.2	68.5
<AB,KB>	843.2	68.5
<AB,ZM>	732.3	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<AN,OD>	237.8	55
<AN,OY>	367.7	63
<AN,OS>	323.3	55

<AN,OG>	420.0	63
<AN,LA>	404.2	63
<AN,EK>	255.2	55
<AN,ED>	158.5	35
<AN,DT>	31.7	17
<AN,KW>	375.6	63
<AN,KG>	180.7	35
<AN,FCT>	293.2	55
<AN,AB>	85.6	30
<AN,AN>	0.0	10
<AN,EN>	50.7	17
<AN,EB>	114.1	35
<AN,IM>	76.1	21
<AN,BY>	163.3	35
<AN,RV>	156.9	35
<AN,AK>	158.5	35
<AN,CR>	195.0	35
<AN,JG>	657.8	68.5
<AN,AD>	676.8	68.5
<AN,TA>	554.8	55
<AN,NS>	267.9	55
<AN,YB>	971.6	68.5
<AN,NG>	380.4	63
<AN,BO>	930.4	68.5
<AN,GB>	632.4	68.5
<AN,BA>	561.1	68.5
<AN,BN>	256.8	55
<AN,PL>	454.9	63

<AN,KN>	656.2	68.5
<AN,KT>	749.7	68.5
<AN,KD>	478.7	63
<AN,SO>	781.4	68.5
<AN,KB>	756.0	68.5
<AN,ZM>	657.8	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<EN,OD>	266.3	55
<EN,OY>	404.2	63
<EN,OS>	355.0	55
<EN,OG>	459.7	63
<EN,LA>	447.0	63
<EN,EK>	279.0	55
<EN,ED>	199.7	35
<EN,DT>	82.4	30
<EN,KW>	397.7	63
<EN,KG>	174.4	35
<EN,FCT>	269.5	55
<EN,AB>	95.1	30
<EN,AN>	50.7	17
<EN,EN>	0.0	1O
<EN,EB>	69.7	21
<EN,IM>	111.0	35
<EN,BY>	210.8	42
<EN,RV>	187.0	35
<EN,AK>	158.5	35
<EN,CR>	185.4	35

<EN,JG>	622.9	68.5
<EN,AD>	626.1	68.5
<EN,TA>	504.0	63
<EN,NS>	237.8	55
<EN,YB>	924.1	68.5
<EN,NG>.	364.6	63
<EN,BO>	859.0	68.5
<EN,GB>	583.3	68.5
<EN,BA>	499.3	63
<EN,BN>	187.0	35
<EN,PL>	413.7	63
<EN,KN>	622.9	68.5
<EN,KT>	722.8	68.5
<EN,KD>	451.7	63
<EN,SO>	768.7	68.5
<EN,KB>	754.5	68.5
<EN,ZM>	665.7	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<EB,OD>	334.4	55
<EB,OY>	475.5	63
<EB,OS>	416.9	63
<EB,OG>	527.8	63
<EB,LA>	521.5	63
<EB,EK>	342.4	55
<EB,ED>	269.5	55
<EB,DT>	147.4	35
<EB,KW>	456.5	63

<EB,KG>	202.9	35
<EB,FCT>	296.4	55
<EB,AB>	107.8	35
<EB,AN>	114.1	35
<EB,EN>	69.7	21
<EB,EB>	0.0	10
<EB,IM>	147.4	35
<EB,BY>	253.6	55
<EB,RV>	207.6	42
<EB,AK>	142.7	35
<EB,CR>	144.2	35
<EB,JG>	613.4	68.5
<EB,AD>	573.8	68.5
<EB,TA>	454.9	63
<EB,NS>	247.3	55
<EB,YB>	887.6	68.5
<EB,NG>	396.3	63
<EB,BO>	817.9	68.5
<EB,GB>	546.8	68.5
<EB,BA>	477.1	63
<EB,BN>	161.7	35
<EB,PL>	402.6	63
<EB,KN>	626.1	68.5
<EB,KT>	733.9	68.5
<EB,KD>	467.6	63
<EB,SO>	802.0	68.5
<EB,KB>	797.3	68.5
<EB,ZM>	659.4	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<IM,OD>	280.5	55
<IM,OY>	399.4	63
<IM,OS>	369.3	63
<IM,OG>	443.8	63
<IM,LA>	412.1	63
<IM,EK>	305.9	55
<IM,ED>	179.1	35
<IM,DT>	84.0	30
<IM,KW>	428.0	63
<IM,KG>	256.8	55
<IM,FCT>	369.3	63
<IM,AB>	52.3	17
<IM,AN>	76.1	21
<IM,EN>	111.0	35
<IM,EB>	147.4	35
<IM,IM>	0.0	10
<IM,BY>	104.6	35
<IM,RV>	79.3	21
<IM,AK>	112.5	35
<IM,CR>	155.3	35
<IM,JG>	733.9	68.5
<IM,AD>	721.2	68.5
<IM,TA>	602.3	68.5
<IM,NJ>	343.9	55
<IM,YB>	1033.4	68.5
<IM,NG>	454.9	63
<IM,BO>	963.7	68.5

<IM,GB>	691.1	68.5
<IM,BA>	610.2	68.5
<IM,BN>	296.4	55
<IM,PL>	526.2	63
<IM,KN>	732.3	68.5
<IM,KT>.	829.0	68.5
<IM,KD>	713.3	68.5
<IM,SO>	852.7	68.5
<IM,KB>	825.8	68.5
<IM,ZM>	733.9	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<BY,OD>	280.5	55
<BY,OY>	372.5	63
<BY,OS>	364.6	63
<BY,OG>	404.2	63
<BY,LA>	356.6	63
<BY,EK>	317.0	55
<BY,ED>	169.6	35
<BY,DT>	150.6	35
<BY,KW>	435.9	65
<BY,KG>	321.8	55
<BY,FCT>	440.6	63
<BY,AB>	150.6	35
<BY,AN>	163.3	35
<BY,EN>	210.8	42
<BY,EB>	253.6	55
<BY,IM>	104.6	35

<BY,BY>	0.0	10
<BY,RV>	84.0	30
<BY,AK>	185.4	35
<BY,CR>	228.2	42
<BY,JG>	822.6	68.5
<BY,AD>	825.8	68.5
<BY,TA>	705.3	68.5
<BY,NS>	428.0	63
<BY,YB>	1134.9	68.5
<BY,NG>	515.2	63
<BY,BO>	1068.3	68.5
<BY,GB>	792.5	68.5
<BY,BA>	706.9	68.5
<BY,BN>	396.3	63
<BY,PL>	616.6	68.5
<BY,KN>	973.2	68.5
<BY,KT>	898.7	68.5
<BY,KD>	787.7	68.5
<BY,SO>	900.3	68.5
<BY,KB>	859.1	68.5
<BY,ZM>	795.7	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<RV,OD>	339.2	55
<RV,OY>	443.8	63
<RV,OS>	424.8	63
<RV,OG>	480.3	63
<RV,LA>	435.9	63

<RV,EK>	367.7	63
<RV,ED>	386.7	63
<RV,DT>	160.1	35
<RV,KW>	491.1	63
<RV,KG>	334.4	55
<RV,FCT>.	448.6	63
<RV,AB>	99.9	30
<RV,AN>	156.9	35
<RV,EN>	187.0	35
<RV,EB>	207.6	42
<RV,IM>	79.3	21
<RV,BY>	84.0	30
<RV,RV>	0.0	10
<RV,AK>	107.8	35
<RV,CR>	149.0	35
<RV,JG>	808.4	68.5
<RV,AD>	768.7	68.5
<RV,TA>	656.2	68.5
<RV,NS>	420.0	63
<RV,YB>	1093.7	68.5
<RV,NG>	535.7	68.5
<RV,BO>	1025.5	68.5
<RV,GB>	754.5	68.5
<RV,BA>	681.6	68.5
<RV,BN>	366.1	63
<RV,PL>	599.1	68.5
<RV,KN>	809.9	68.5
<RV,KT>	905.0	68.5

<RV,KD>	634.0	68.5
<RV,SO>	932.0	68.5
<RV,KB>	898.7	68.5
<RV,ZM>	811.5	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<AK,OD>	388.3	63
<AK,OY>	512.0	63
<AK,OS>	475.5	63
<AK,OG>	554.8	68.5
<AK,LA>	364.6	63
<AK,EK>	408.9	63
<AK,ED>	290.1	55
<AK,DT>	180.7	35
<AK,KW>	532.6	68.5
<AK,KG>	329.7	55
<AK,FCT>	428.0	63
<AK,AB>	66.6	21
<AK,AN>	158.5	35
<AK,EN>	158.5	35
<AK,EB>	142.7	35
<AK,IM>	112.5	35
<AK,BY>	185.4	35
<AK,RV>	107.8	35
<AK,AK>	0.0	10
<AK,CR>	36.6	17
<AK,JG>	914.5	68.5
<AK,AD>	673.6	68.5

<AK,TA>	564.3	68.5
<AK,NS>	385.2	63
<AK,YB>	1011.2	68.5
<AK,NG>	923.1	63
<AK,BO>	939.9	68.5
<AK,GB>,	673.6	68.5
<AK,BA>	615.0	68.5
<AK,BN>	301.1	55
<AK,PL>	543.7	68.5
<AK,KN>	767.1	68.5
<AK,KT>	874.9	68.5
<AK,KD>	605.5	68.5
<AK,SO>	930.4	68.5
<AK,KB>	911.4	68.5
<AK,ZM>	795.7	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<CR,OD>	428.0	63
<CR,OY>	554.8	68.5
<CR,OS>	516.7	63
<CR,OG>	597.5	68.5
<CR,LA>	565.8	68.5
<CR,EK>	454.9	63
<CR,ED>	332.9	55
<CR,DT>	220.3	42
<CR,KW>	515.1	63
<CR,KG>	358.2	63

<CR,FCT>	447.0	63
<CR,AB>	112.5	35
<CR,AN>	195.0	35
<CR,EN>	185.4	35
<CR,EB>	144.2	35
<CR,IM>	155.3	35
<CR,BY>	228.2	42
<CR,RV>	149.0	35
<CR,AK>	36.5	17
<CR,CR>	0.0	10
<CR,JG>	756.0	68.5
<CR,AD>	649.9	68.5
<CR,TA>	545.2	68.5
<CR,NS>	399.4	63
<CR,YB>	997.0	68.5
<CR,NG>	546.8	68.5
<CR,BD>	919.3	68.5
<CR,GB>	657.8	68.5
<CR,BA>	608.6	68.5
<CR,BN>	305.9	55
<CR,PL>	705.3	68.5
<CR,KN>	773.5	68.5
<CR,KT>	887.6	68.5
<CR,KD>	618.2	68.5
<CR,SO>	952.6	68.5
<CR,KB>	939.5	68.5
<CR,ZM>	811.5	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<JG,OD>	670.5	68.5
<JG,OY>	764.0	68.5
<JG,OS>	680.0	68.5
<JG,OG>	827.4	68.5
<JG,LA>	871.8	68.5
<JG,EK>	634.0	68.5
<JG,ED>	719.6	68.5
<JG,DT>	672.0	68.5
<JG,KW>	629.2	68.5
<JG,KG>	518.2	63
<JG,FCT>	396.3	55
<JG,AB>	713.3	68.5
<JG,AN>	657.8	68.5
<JG,EN>	622.9	68.5
<JG,BN>	613.4	68.5
<JG,IM>	733.9	68.5
<JG,BY>	822.6	68.5
<JG,RV>	808.4	68.5
<JG,AK>	114.5	68.5
<JG,CR>	756.0	68.5
<JG,JG>	0.0	10
<JG,AD>	443.8	63
<JG,TA>	383.6	63
<JG,NS>	396.3	63
<JG,YB>	428.0	63
<JG,NG>	380.4	63
<JG,BO>	412.1	63

<JG,GB>	258.4	55
<JG,BA>	169.6	35
<JG,BN>	453.3	63
<JG,PL>	210.8	42
<JG,KN>	93.5	30
<JG,KT>	229.8	42
<JG,KD>	247.3	55
<JG,SO>	464.4	63
<JG,KB>	562.7	68.5
<JG,ZM>	290.0	55

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<AD,OD>	821.0	68.5
<AD,OY>	954.2	68.5
<AD,OS>	876.5	68.5
<AD,OG>	1022.3	68.5
<AD,LA>	1035.0	68.5
<AD,EK>	806.8	68.5
<AD,ED>	808.4	68.5
<AD,DT>	702.2	68.5
<AD,KW>	865.4	68.5
<AD,KG>	641.9	68.5
<AD,FCT>	578.5	68.5
<AD,AB>	676.8	68.5
<AD,AN>	676.8	68.5
<AD,EN>	626.1	68.5
<AD,EB>	573.8	68.5

<AD,IM>	721.2	68.5
<AD,BY>	825.8	68.5
<AD,RV>	768.7	68.5
<AD,AK>	673.6	68.5
<AD,CR>	649.9	68.5
<AD,JG>	443.8	63
<AD,AD>	0.0	10
<AD,TA>	130.0	35
<AD,NS>	523.1	63
<AD,YB>	385.2	63
<AD,NG>	745.0	68.5
<AD,BO>	299.6	55
<AD,GB>	185.4	35
<AD,BA>	312.2	55
<AD,BN>	459.7	63
<AD,PL>	397.8	63
<AD,KN>	529.4	63
<AD,KT>	672.0	68.5
<AD,KD>	565.8	68.5
<AD,SO>	890.8	68.5
<AD,KB>	966.9	68.5
<AD,ZM>	708.5	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<TA,OD>	694.2	68.5
<TA,OY>	830.5	68.5
<TA,OS>	749.7	68.5
<TA,OG>	895.5	68.5

<TA,LA>	905.0	68.5
<TA,EK>	678.4	68.5
<TA,ED>	684.7	68.5
<TA,DT>	578.5	68.5
<TA,KW>	741.8	68.5
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<TA,FCT>	454.9	63
<TA,AB>	554.8	68.5
<TA,AN>	554.8	68.5
<TA,EN>	504.0	63
<TA,EB>	454.9	63
<TA,IM>	602.3	68.5
<TA,BY>	705.3	68.5
<TA,RV>	656.2	68.5
<TA,AK>	564.3	68.5
<TA,CR>	545.2	68.5
<TA,JG>	383.6	63
<TA,AD>	130.0	35
<TA,TA>	0.0	10
<TA,NS>	396.3	63
<TA,YB>	454.9	63
<TA,NG>	526.2	63
<TA,BO>	378.8	63
<TA,GB>	153.7	35
<TA,BA>	226.7	42
<TA,BN>	332.9	55
<TA,PL>	290.1	55
<TA,KN>	459.7	63

<TA,KT>	603.9	68.5
<TA,KD>	459.7	63
<TA,SO>	803.6	68.5
<TA,KB>	868.6	68.5
<TA,ZM>	619.7	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<NS,OD>	312.2	55
<NS,OY>	435.9	63
<NS,OS>	353.5	55
<NS,OG>	602.3	68.5
<NS,LA>	523.1	63
<NS,EK>	288.5	55
<NS,ED>	334.4	55
<NS,DT>	277.4	55
<NS,KW>	348.7	55
<NS,KG>	134.7	35
<NS,FCT>	69.7	21
<NS,AB>	331.3	55
<NS,AN>	267.9	55
<NS,EN>	237.8	55
<NS,EB>	247.3	55
<NS,IM>	343.9	55
<NS,BY>	428.0	63
<NS,RV>	420.0	63
<NS,AK>	385.2	63
<NS,CR>	399.4	63

<NS,JG>	396.3	63
<NS,AD>	523.1	63
<NS,TA>	396.3	63
<NS,NS>	0.0	10
<NS,YB>	743.4	68.5
<NS,NG>	172.8	35
<NS,BO>	689.5	68.5
<NS,GB>	416.9	63
<NS,BA>	299.6	55
<NS,BN>	125.2	35
<NS,PL>	196.5	35
<NS,KN>	389.9	63
<NS,KT>	488.2	63
<NS,KD>	221.5	42
<NS,SO>	565.8	68.5
<NS,KB>	576.9	68.5
<NS,ZM>	415.3	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<YB,OD>	1050.9	68.5
<YB,OY>	1158.6	68.5
<YB,OS>	1077.8	68.5
<YB,OG>	1226.8	68.5
<YB,LA>	1264.8	68.5
<YB,EK>	1022.3	68.5
<YB,ED>	1073.0	68.5
<YB,DT>	990.6	68.5

<YB,KW>	1042.9	68.5
<YB,KG>	640.3	68.5
<YB,FCT>	773.5	68.5
<YB,AB>	995.4	68.5
<YB,AN>	971.6	68.5
<YB,EN>	924.1	68.5
<YB,EB>	887.6	68.5
<YB,IM>	1033.4	68.5
<YB,BY>	1134.9	68.5
<YB,RV>	1093.7	68.5
<YB,AK>	1011.2	68.5
<YB,CR>	997.0	68.5
<YB,JG>	428.0	63
<YB,AD>	385.2	63
<YB,TA>	454.9	63
<YB,NS>	743.4	68.5
<YB,YB>	0.0	10
<YB,NG>	792.5	68.5
<YB,BO>	87.2	30
<YB,GB>	340.8	55
<YB,BA>	443.8	63
<YB,BN>	740.2	68.5
<YB,PL>	554.8	68.5
<YB,KN>	512.0	63
<YB,KT>	605.5	68.5
<YB,KD>	664.1	68.5
<YB,SO>	862.2	68.5
<YB,KB>	974.8	68.5

<YB,ZM>	708.5	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<NG,OD>	298.0	55
<NG,OY>	377.2	63
<NG,OS>	298.0	55
<NG,OG>	443.8	63
<NG,LA>	486.6	63
<NG,EK>	261.5	55
<NG,ED>	374.1	63
<NG,DT>	372.5	63
<NG,KW>	250.4	55
<NG,KG>	193.4	35
<NG,FCT>	106.2	35
<NG,AB>	459.7	63
<NG,AN>	380.4	63
<NG,EN>	364.6	63
<NG,EB>	396.3	63
<NG,IM>	454.9	63
<NG,BY>	515.2	63
<NG,RV>	535.7	68.5
<NG,AK>	523.1	63
<NG,CR>	546.8	68.5
<NG,JG>	380.4	63
<NG,AD>	745.0	68.5
<NG,TA>	526.2	63
<NG,NS>	172.8	35

<NG,YB>	792.5	68.5
<NG,NG>	0.0	10
<NG,BO>	756.0	68.5
<NG,GB>	504.0	63
<NG,BA>	523.1	63
<NG,BN>	296.4	55
<NG,PL>	255.2	55
<NG,KN>	337.6	55
<NG,KT>	388.3	63
<NG,KD>	139.5	35
<NG,SO>	407.3	63
<NG,KB>	407.3	63
<NG,ZM>	282.1	55

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<BO,OD>	998.3	68.5
<BO,OY>	1117.4	68.5
<BO,OS>	1035.0	68.5
<BO,OG>	1185.6	68.5
<BO,LA>	1214.1	68.5
<BO,EK>	974.8	68.5
<BO,ED>	1014.4	68.5
<BO,DT>	930.4	68.5
<BO,KW>	1003.3	68.5
<BO,KG>	821.0	68.5
<BO,FCT>	727.5	68.5
<BO,AB>	925.6	68.5
<BO,AN>	930.4	68.5

<BO,EN>	859.0	68.5
BO,EB>	817.9	68.5
<BO,IM>	963.7	68.5
<BO,BY>	1068.3	68.5
<BO,RV>	1025.5	68.5
<BO,AK>	939.9	68.5
<BO,CR>	919.3	68.5
<BO,YG>	412.1	63
<BO,AD>	299.6	55
<BO,TA>	378.8	63
<BO,NJ>	689.5	68.50
<BO,YB>	87.2	30
<BO,NG>	756.0	68.50
<BO,BO>	0.0	10
<BO,GB>	275.8	55
<BO,BA>	396.3	63
<BO,BN>	675.2	68.5
<BO,PL>	508.8	63
<BO,KN>	500.9	63
<BO,KT>	610.2	68.5
<BO,KD>	634.0	68.5
<BO,SO>	863.8	68.5
<BO,KB>	973.2	68.5
<BO,ZM>	700.6	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<GB,OD>	729.1	68.5
<GB,OY>	851.2	68.5

<GB,OS>	767.1	68.5
<GB,OG>	914.5	68.5
<GB,LA>	941.5	68.5
<GB,EK>	705.3	68.5
<GB,ED>	741.8	68.5
<GB,DT>	741.4	68.5
<GB,KW>	743.4	68.5
<GB,KG>	548.4	68.5
<GB,FCT>	461.2	63
<GB,AB>	656.2	68.5
<GB,AN>	632.4	68.5
<GB,EN>	583.3	68.5
<GB,EB>	546.8	68.5
<GB,IM>	691.1	68.5
<GB,BY>	792.5	68.5
<GB,RV>	754.5	68.5
<GB,AK>	673.6	68.5
<GB,CR>	657.8	68.5
<GB,JG>	258.4	55
<GB,AD>	185.4	35
<GB,TA>	153.7	35
<GB,NS>	416.9	63
<GB,YB>	340.8	55
<GB,NG>	504.0	63
<GB,BO>	275.8	55
<GB,GB>	0.0	10
<GB,BA>	142.7	35
<GB,BN>	399.4	63

<GB,PL>	248.4	55
<GB,KN>	342.4	55
<GB,KT>	485.0	63
<GB,KD>	402.6	63
<GB,SO>	708.5	68.5
<GB,KB>	792.5	68.5
<GB,ZM>	526.2	68.5

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<BA,OD>	607.1	68.5
<BA,OY>	721.2	68.5
<BA,OS>	634.0	68.5
<BA,OG>	787.7	68.5
<BA,LA>	819.4	68.5
<BA,EK>	578.5	68.5
<BA,ED>	629.2	68.5
<BA,DT>	557.9	68.5
<BA,KW>	607.1	68.5
<BA,KG>	432.7	63
<BA,FCT>	331.3	55
<BA,AB>	583.3	68.5
<BA,AN>	561.1	68.5
<BA,EN>	499.3	63
<BA,EB>	477.1	63
<BA,IM>	610.2	68.5
<BA,BY>	706.9	68.5
<BA,RV>	681.6	68.5
<BA,AK>	615.0	68.5

<BA,CR>	608.6	68.5
<BA,JG>	169.6	35
<BA,AD>	312.2	55
<BA,TA>	226.7	42
<BA,NS>	299.6	55
<BA,YB>	443.8	63
<BA,NG>	523.1	63
<BA,BO>	396.3	63
<BA,GB>	142.7	35
<BA,BA>	0.0	10
<BA,BN>	317.0	55
<BA,PL>	112.5	35
<BA,KN>	233.0	42
<BA,KT>	380.4	63
<BA,KD>	259.9	55
<BA,SO>	581.7	68.5
<BA,KB>	654.6	68.5
<BA,ZM>	396.3	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<BN,OD>	369.3	63
<BN,OY>	507.2	63
<BN,OS>	432.7	63
<BN,OG>	570.6	68.5
<BN,LA>	576.9	68.5
<BN,EK>	358.2	63
<BN,ED>	353.5	55
<BN,DT>	256.8	55

<BN,KW>	443.8	63
<BN,KG>	195.0	35
<BN,FCT>	193.4	35
<BN,AB>	266.3	55
<BN,AN>	256.8	55
<BN,EN>	187.0	35
<BN,EB>	161.7	35
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<BN,BY>	396.3	63
<BN,RV>	366.1	63
<BN,AK>	301.1	55
<BN,CR>	305.9	55
<BN,JG>	453.3	63
<BN,AD>	459.7	63
<BN,TA>	332.9	55
<BN,NS>	125.2	35
<BN,YB>	740.2	68.5
<BN,NG>	296.4	55
<BN,BO>	675.2	68.5
<BN,GB>	399.4	63
<BN,BA>	317.0	55
<BN,BN>	0.0	10
<BN,PL>	242.5	55
<BN,KN>	467.6	63
<BN,KT>	586.5	68.5
<BN,KD>	328.1	55
<BN,SO>	686.3	68.5
<BN,KB>	700.6	68.5

<BN,ZM>	526.2	63

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<PL,OD>	496.1	63
<PL,OY>	610.2	68.5
<PL,OS>	527.8	63
<PL,OG>	673.6	68.5
<PL,LA>	705.3	68.5
<PL,EK>	467.6	63
<PL,ED>	527.8	63
<PL,DT>	466.0	63
<PL,KW>	496.1	63
<PL,KG>	324.9	55
<PL,FCT>	221.9	42
<PL,AB>	504.0	63
<PL,AN>	454.9	63
<PL,EN>	413.7	63
<PL,EB>	402.6	63
<PL,IM>	526.2	63
<PL,BY>	616.6	68.5
<PL,RV>	599.1	68.5
<PL,AK>	543.7	68.5
<PL,CR>	705.3	68.5
<PL,JG>	210.8	42
<PL,AD>	397.8	63
<PL,TA>	290.1	55
<PL,NS>	196.5	35
<PL,YB>	554.8	68.5

<PL,NG>	255.2	55
<PL,BO>	508.8	63
<PL,GB>	248.8	55
<PL,BA>	112.5	35
<PL,BN>	242.5	55
<PL,PL>	0.0	10
<PL,KN>	234.6	42
<PL,KT>	364.6	63
<PL,KD>	171.2	35
<PL,SO>	524.6	63
<PL,KB>	581.7	68.5
<PL,ZM>	343.9	55

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
<KN,OD>	634.0	68.5
<KN,OY>	713.3	68.5
<KN,OS>	630.8	68.5
<KN,OG>	773.5	68.5
<KN,LA>	824.2	68.5
<KN,EK>	599.1	68.5
<KN,ED>	694.2	68.5
<KN,DT>	660.9	68.5
<KN,KW>	575.4	68.5
<KN,KG>	497.7	63
<KN,FCT>	375.6	63
<KN,AB>	718.0	68.5
<KN,AN>	656.2	68.5
<KN,EN>	622.9	68.5

<KN,EB>	626.1	68.5
<KN,IM>	732.3	68.5
<KN,BY>	973.2	68.5
<KN,RV>	809.9	68.5
<KN,AK>	767.1	68.5
<KN,CR>	773.5	68.5
<KN,JG>	93.5	30
<KN,AD>	529.4	63
<KN,TA>	459.7	63
<KN,NS>	389.9	63
<KN,YB>	512.0	63
<KN,NG>	337.6	55
<KN,BO>	500.9	63
<KN,GB>	342.4	55
<KN,BA>	233.0	42
<KN,BN>	467.6	63
<KN,PL>	234.6	42
<KN,KN>	0.0	10
<KN,KT>	147.4	35
<KN,KD>	198.1	35
<KN,SO>	372.5	63
<KN,KB>	470.7	63
<KN,ZM>	199.7	35

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
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<KT,OG>	789.3	68.5
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<KT,EK>	649.9	68.5
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<KT,AN>	749.7	68.5
<KT,EN>	722.8	68.5
<KT,EB>	733.9	68.5
<KT,IM>	829.0	68.5
<KT,BY>	898.7	68.5
<KT,RV>	905.0	68.5
<KT,AK>	874.9	68.5
<KT,CR>	887.6	68.5
<KT,JG>	229.8	42
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<KT,NS>	488.2	63
<KT,YB>	605.5	68.5
<KT,NG>	388.3	63
<KT,BO>	610.2	68.5
<KT,GB>	485.0	63
<KT,BA>	380.4	63
<KT,BN>	586.5	68.5
<KT,PL>	364.6	63

<KT,KN>	147.4	35
<KT,KT>	0.0	10
<KT,KD>	269.5	55
<KT,SO>	256.8	55
<KT,KB>	375.6	63
<KT,ZM>	137.9	35

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
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<KD,OY>	516.7	63
<KD,OS>	435.9	63
<KD,OG>	578.5	68.5
<KD,LA>	626.1	68.5
<KD,EK>	396.3	63
<KD,ED>	499.3	63
<KD,DT>	478.7	63
<KD,KW>	385.2	63
<KD,KG>	307.5	55
<KD,FCT>	187.0	35
<KD,AB>	546.8	68.5
<KD,AN>	478.7	63
<KD,EN>	451.7	63
<KD,EB>	467.6	63
<KD,IM>	713.3	68.5
<KD,BY>	787.7	68.5
<KD,RV>	634.0	68.5
<KD,AK>	605.5	68.5
<KD,CR>	618.2	68.5

<KD,JG>	247.3	55
<KD,AD>	565.8	68.5
<KD,TA>	459.7	63
<KD,NS>	221.5	42
<KD,YB>	664.1	68.5
<KD,NG>	139.5	35
<KD,BO>	634.0	68.5
<KD,GB>	402.6	63
<KD,BA>	259.9	55
<KD,BN>	328.1	55
<KD,PL>	171.2	35
<KD,KN>	198.1	35
<KD,KT>	269.5	55
<KD,KD>	0.0	10
<KD,SO>	366.1	63
<KD,KB>	412.1	63
<KD,ZM>	196.5	35

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
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<SO,OS>	586.5	68.5
<SO,OG>	678.4	68.5
<SO,LA>	751.3	68.5
<SO,EK>	597.5	68.5
<SO,ED>	741.8	68.5
<SO,DT>	771.9	63
<SO,KW>	507.2	68.5

<SO,KG>	599.1	63
<SO,FCT>	507.2	68.5
<SO,AB>	862.2	68.5
<SO,AN>	781.4	68.5
<SO,EN>	768.7	68.5
<SO,EB>.	802.0	68.5
<SO,IM>	852.7	68.5
<SO,BY>	900.3	68.5
<SO,RV>	932.0	68.5
<SO,AK>	930.4	68.5
<SO,CR>	952.6	68.5
<SO,JG>	464.4	63
<SO,AD>	890.8	68.5
<SO,TA>	803.6	68.5
<SO,NS>	565.8	68.5
<SO,YB>	862.2	68.5
<SO,NG>	407.3	63
<SO,BO>	863.8	68.5
<SO,GB>	708.5	68.5
<SO,BA>	581.7	68.5
<SO,BN>	686.3	68.5
<SO,PL>	524.6	63
<SO,KN>	372.5	63
<SO,KT>	256.8	55
<SO,KD>	366.1	63
<SO,SO>	0.0	10
<SO,KB>	131.6	35
<SO,ZM>	185.4	35

LOCATION	SEPARATION DISTANCE (KM)	COST (#)
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<KB,OS>	518.3	63
<KB,OG>	586.5	68.5
<KB,LA>	664.1	68.5
<KB,EK>	543.7	68.5
<KB,ED>	692.6	68.5
<KB,DT>	741.8	68.5
<KB,KW>	435.9	63
<KB,KG>	580.1	68.5
<KB,FCT>	512.0	63
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<KB,AN>	756.0	68.5
<KB,EN>	754.5	68.5
<KB,EB>	797.3	68.5
<KB,IM>	825.8	68.5
<KB,BY>	859.1	68.5
<KB,RV>	898.7	68.5
<KB,AK>	911.4	68.5
<KB,CR>	939.5	68.5
<KB,JG>	562.7	68.5
<KB,AD>	966.9	68.5
<KB,TA>	868.6	68.5
<KB,NS>	576.9	68.5
<KB,YB>	974.8	68.5
<KB,NG>	407.3	63
<KB,BO>	973.2	68.5

<KB,GB>	792.5	68.5
<KB,BA>	654.6	68.5
<KB,BN>	700.6	68.5
<KB,PL>	581.7	68.5
<KB,KN>	470.7	63
<KB,KT>	375.6	63
<KB,KD>	412.1	63
<KB,SO>	131.6	35
<KB,KB>	0.0	10
<KB,ZM>	272.6	55

LOCATION	SEPARATION DISTANCE (KM)	COST(#)
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<ZM,OS>	535.7	68.5
<ZM,OG>	657.8	68.5
<ZM,LA>	718.0	68.5
<ZM,EK>	523.1	63
<ZM,ED>	649.9	68.5
<ZM,DT>	653.0	68.5
<ZM,KW>	464.4	63
<ZM,KG>	475.5	63
<ZM,FCT>	366.1	63
<ZM,AB>	732.3	68.5
<ZM,AN>	657.8	68.5
<ZM,EN>	665.7	68.5

<ZM,EB>	659.4	68.5
<ZM,IM>	733.9	68.5
<ZM,BY>	795.7	68.5
<ZM,RV>	811.5	68.5
<ZM,AK>	795.7	68.5
<ZM,CR>	811.5	68.5
<ZM,JG>	290.0	55
<ZM,AD>	708.5	68.5
<ZM,TA>	619.7	68.5
<ZM,NS>	415.3	63
<ZM,YB>	708.5	68.5
<ZM,NG>	282.1	55
<ZM,BO>	700.6	68.5
<ZM,GB>	526.2	63
<ZM,BA>	396.3	63
<ZM,BN>	526.2	63
<ZM,PL>	343.9	55
<ZM,KN>	199.7	35
<ZM,KT>	137.9	35
<ZM,KD>	196.5	35
<ZM,SO>	185.4	35
<ZM,KB>	272.6	55
<ZM,ZM>	0.0	10

Appendix E

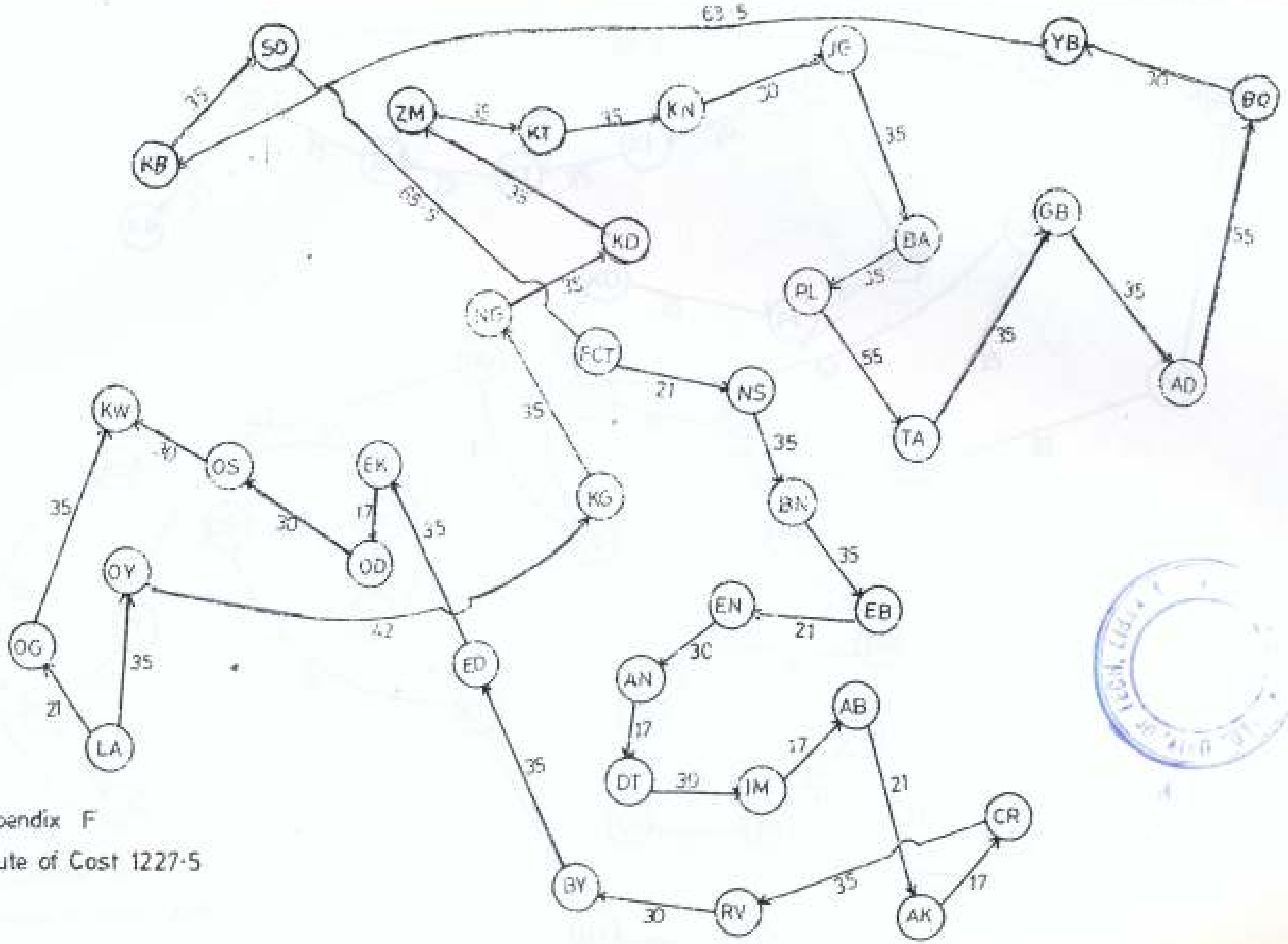
Result of manually generated least cost routes

ROUTE								COST
FCT	KD	KW	LA	RV	BO	SO	FCT	416
FCT	KD	KW	LA	RV	SO	BO	FCT	421.5
FCT	KD	KW	LA	BO	SO	RV	FCT	421.5
FCT	KD	KW	LA	SO	RV	BO	FCT	427
FCT	KD	KW	RV	BO	SO	LA	FCT	429.5
FCT	KD	KW	BO	SO	LA	RV	FCT	429.5
FCT	KD	KW	SO	LA	RV	BO	FCT	429.5
FCT	KD	LA	RV	BO	SO	KW	FCT	456.5
FCT	KD	RV	BO	SO	KW	LA	FCT	421.5
FCT	KD	BO	SO	KW	LA	RV	FCT	416
FCT	KD	SO	KW	LA	RV	BO	FCT	416
FCT	KW	LA	RV	BO	KD	SO	FCT	436
FCT	KW	LA	RV	SO	KD	BO	FCT	441.5
FCT	KW	LA	RV	KD	BO	SO	FCT	441.5
FCT	KW	LA	BO	SO	KD	RV	FCT	441.5
FCT	KW	LA	SO	KD	RV	BO	FCT	447
FCT	KW	LA	KD	RV	BO	SO	FCT	447

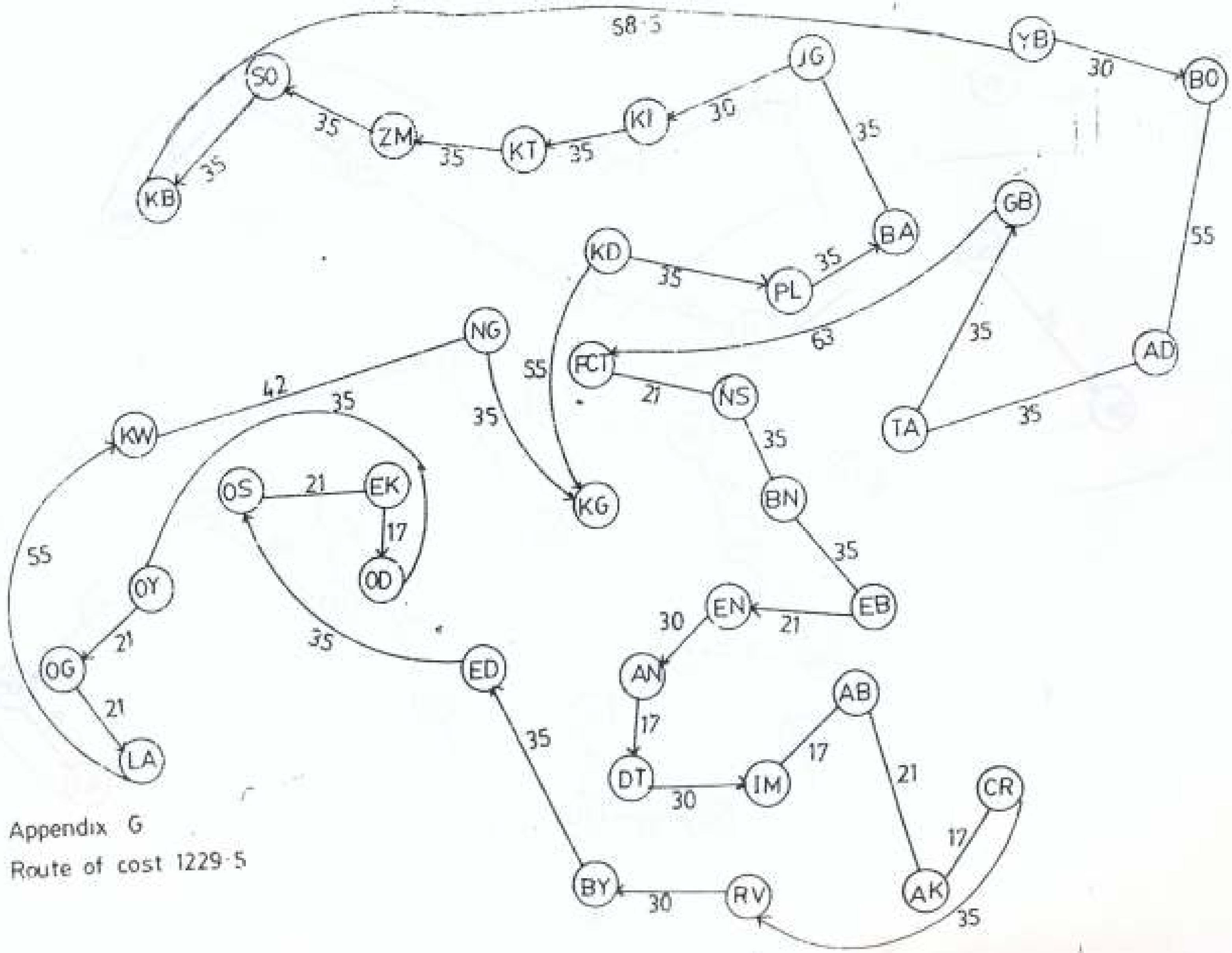
FCT	KW	RV	BO	SO	KD	LA	FCT	449.5
FCT	KW	BO	SO	KD	LA	RV	FCT	449.5
FCT	KW	SO	KD	LA	RV	BO	FCT	449.5
FCT	KW	KD	LA	RV	BO	SO	FCT	449.5
FCT	LA	RV	BO	SO	KD	KW	FCT	444
FCT	LA	RV	BO	SO	KW	KD	FCT	424
FCT	LA	RV	BO	KW	KD	SO	FCT	452
FCT	LA	RV	BO	KD	KW	SO	FCT	452
FCT	LA	RV	SO	KD	KW	BO	FCT	457.5
FCT	LA	RV	KD	KW	BO	SO	FCT	457.5
FCT	LA	RV	KW	BO	SO	KD	FCT	424
FCT	LA	BO	SO	KD	KW	RV	FCT	452
FCT	LA	SO	KD	KW	RV	BO	FCT	457.5
FCT	LA	KD	KW	RV	BO	SO	FCT	457.5
FCT	LA	KW	RV	BO	SO	KD	FCT	416
FCT	RV	BO	SO	KD	KW	LA	FCT	444
FCT	RV	BO	SO	KD	LA	KW	FCT	441.5
FCT	RV	BO	SO	KW	LA	KD	FCT	421.5
FCT	RV	BO	SO	LA	KD	KW	FCT	455

FCT	RV	BO	LA	KD	KW	SO	FCT	457.5
FCT	RV	BO	KD	KW	SO	LA	FCT	457.5
FCT	RV	BO	KW	SO	LA	KD	FCT	435
FCT	RV	SO	KD	KW	LA	BO	FCT	449.5
FCT	RV	KD	KW	LA	BO	SO	FCT	449.5
FCT	RV	KW	LA	BO	SO	KD	FCT	416
FCT	RV	LA	BO	SO	KD	KW	FCT	444
FCT	BO	SO	KD	KW	LA	RV	FCT	444
FCT	BO	SO	KD	KW	RV	LA	FCT	452
FCT	BO	SO	KD	RV	LA	KW	FCT	441.5
FCT	BO	SO	KD	LA	KW	RV	FCT	449.5
FCT	BO	SO	LA	KW	RV	KD	FCT	427
FCT	BO	SO	KW	RV	KD	LA	FCT	463
FCT	BO	SO	RV	KD	LA	KW	FCT	452.5
FCT	BO	RV	KD	LA	KW	SO	FCT	455
FCT	BO	KD	LA	KW	SO	RV	FCT	455
FCT	BO	LA	KW	SO	RV	KD	FCT	427
FCT	BO	KW	SO	RV	KD	LA	FCT	468.5
FCT	SO	KD	KW	LA	RV	BO	FCT	444

FCT	SO	KD	KW	LA	BO	RV	FCT	444
FCT	SO	KD	KW	BO	RV	LA	FCT	452
FCT	SO	KD	KW	RV	LA	BO	FCT	452
FCT	SO	KD	RV	LA	BO	KW	FCT	449.5
FCT	SO	KD	LA	BO	KW	RV	FCT	457.5
FCT	SO	KD	BO	KW	RV	LA	FCT	452
FCT	SO	BO	KW	RV	LA	KD	FCT	429.5
FCT	SO	KW	RV	LA	KD	BO	FCT	457.5
FCT	SO	RV	LA	KD	BO	KW	FCT	455
FCT	SO	LA	KD	BO	KW	RV	FCT	463

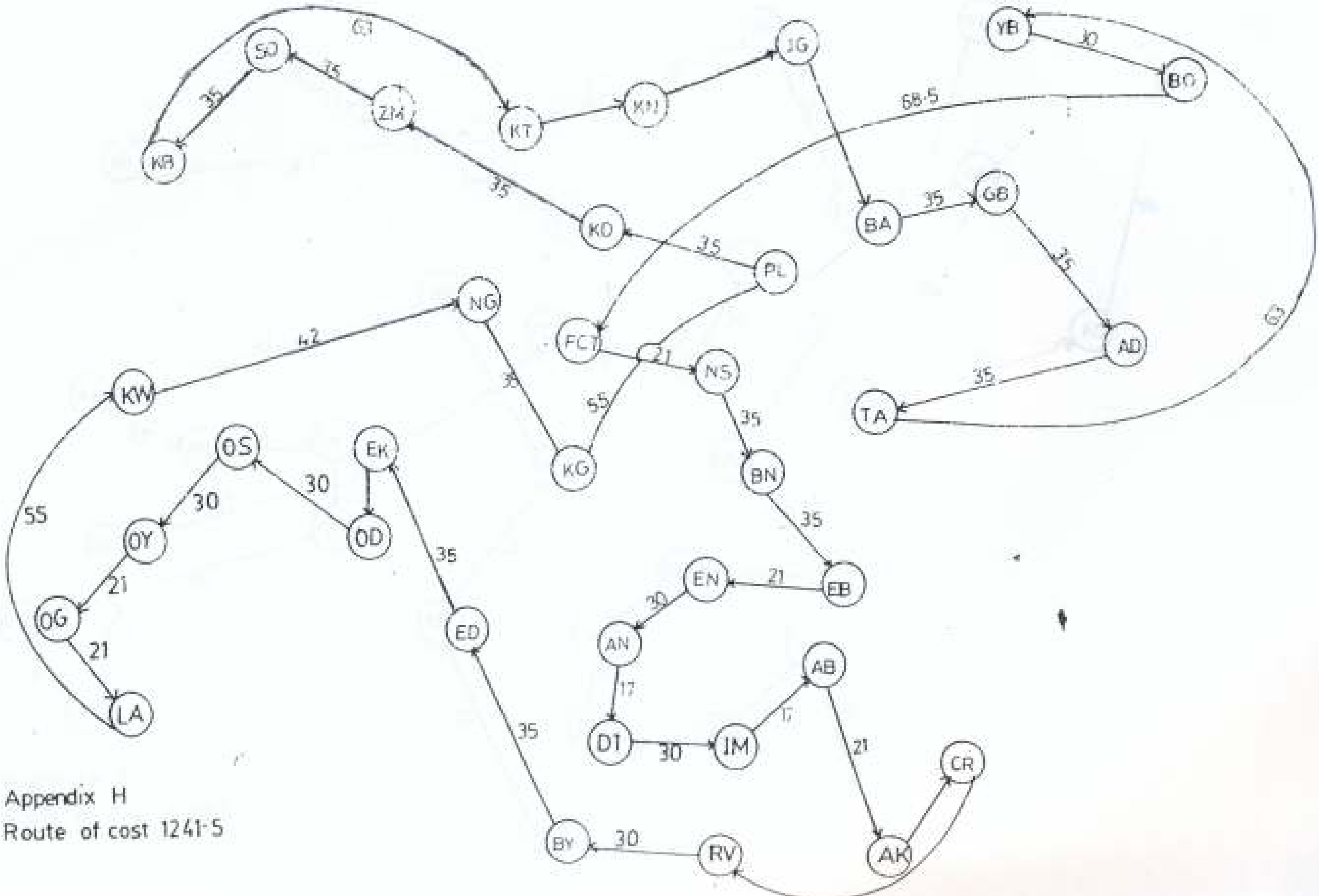


Appendix F
Route of Cost 1227·5

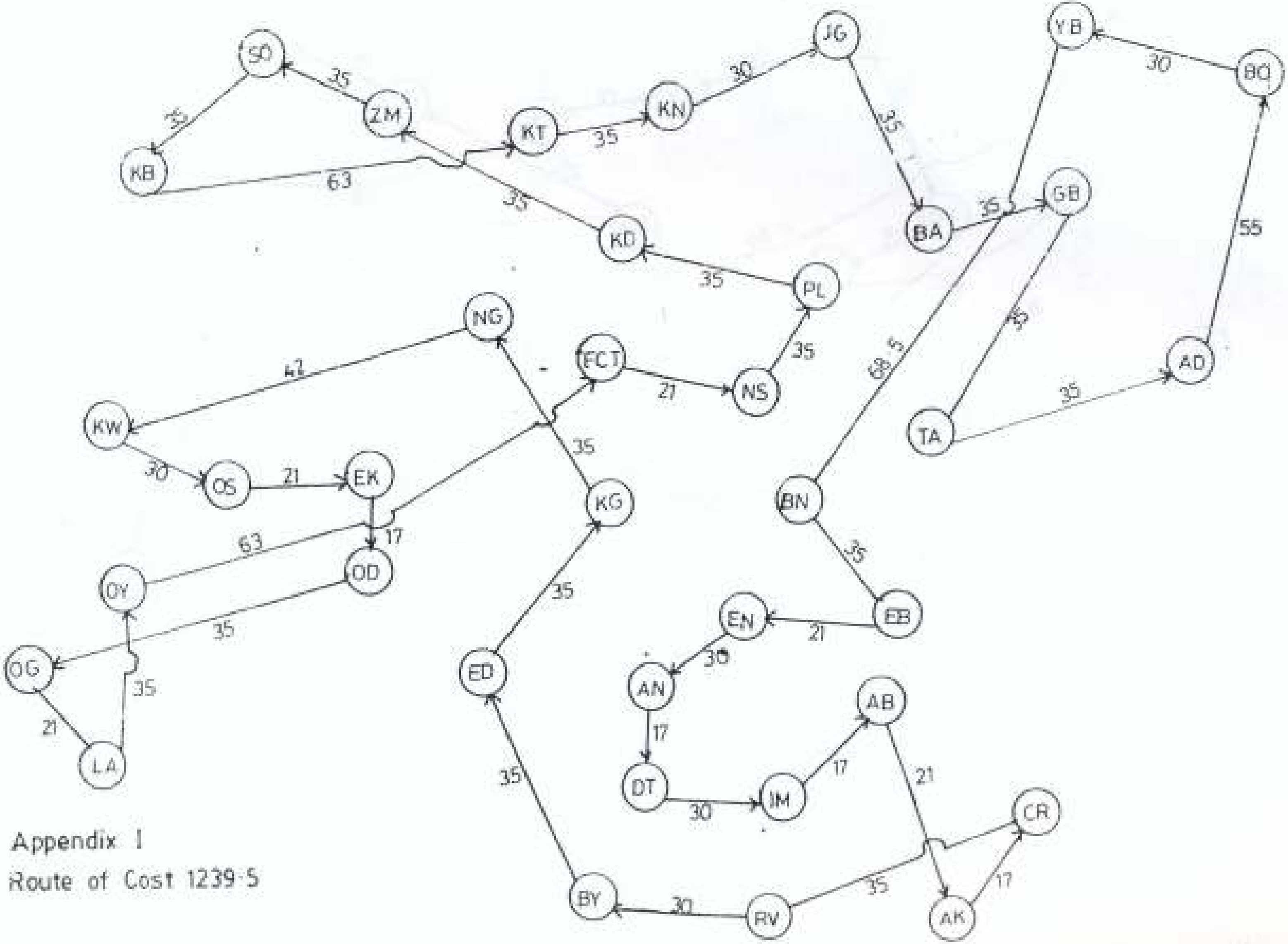


Appendix G

Route of cost 1229·5

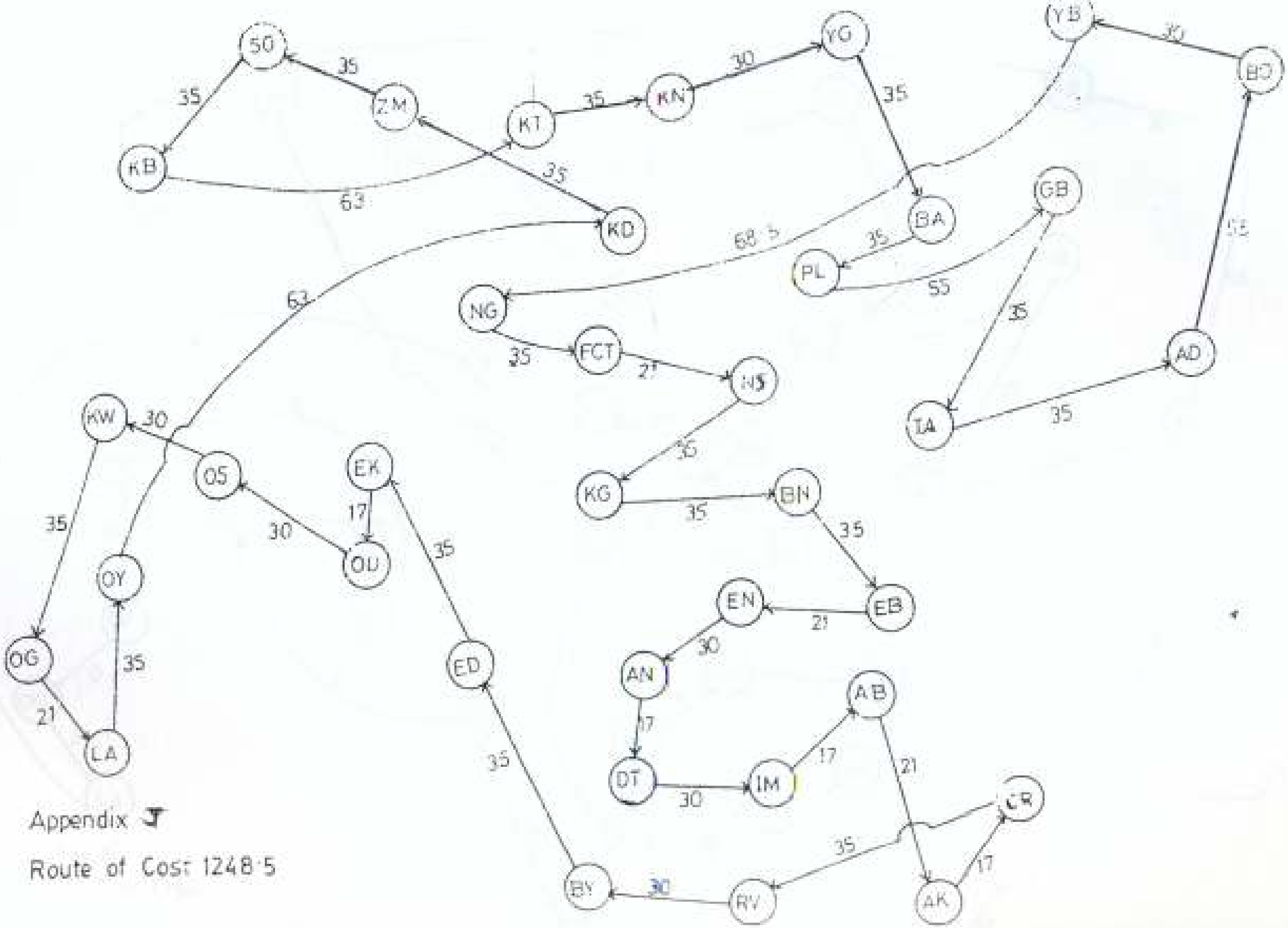


Appendix H
Route of cost 1241·5



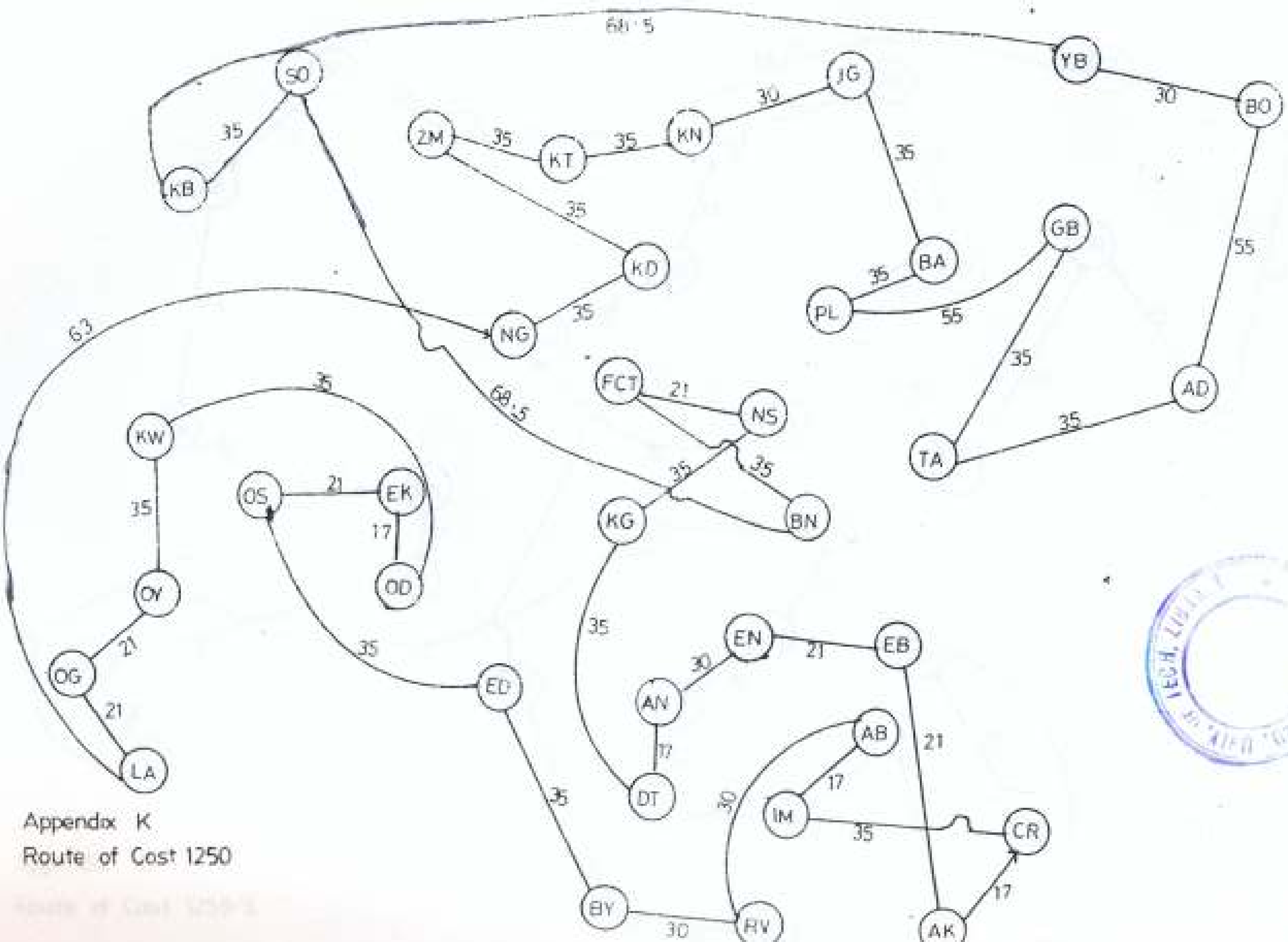
Appendix I

Route of Cost 1239·5

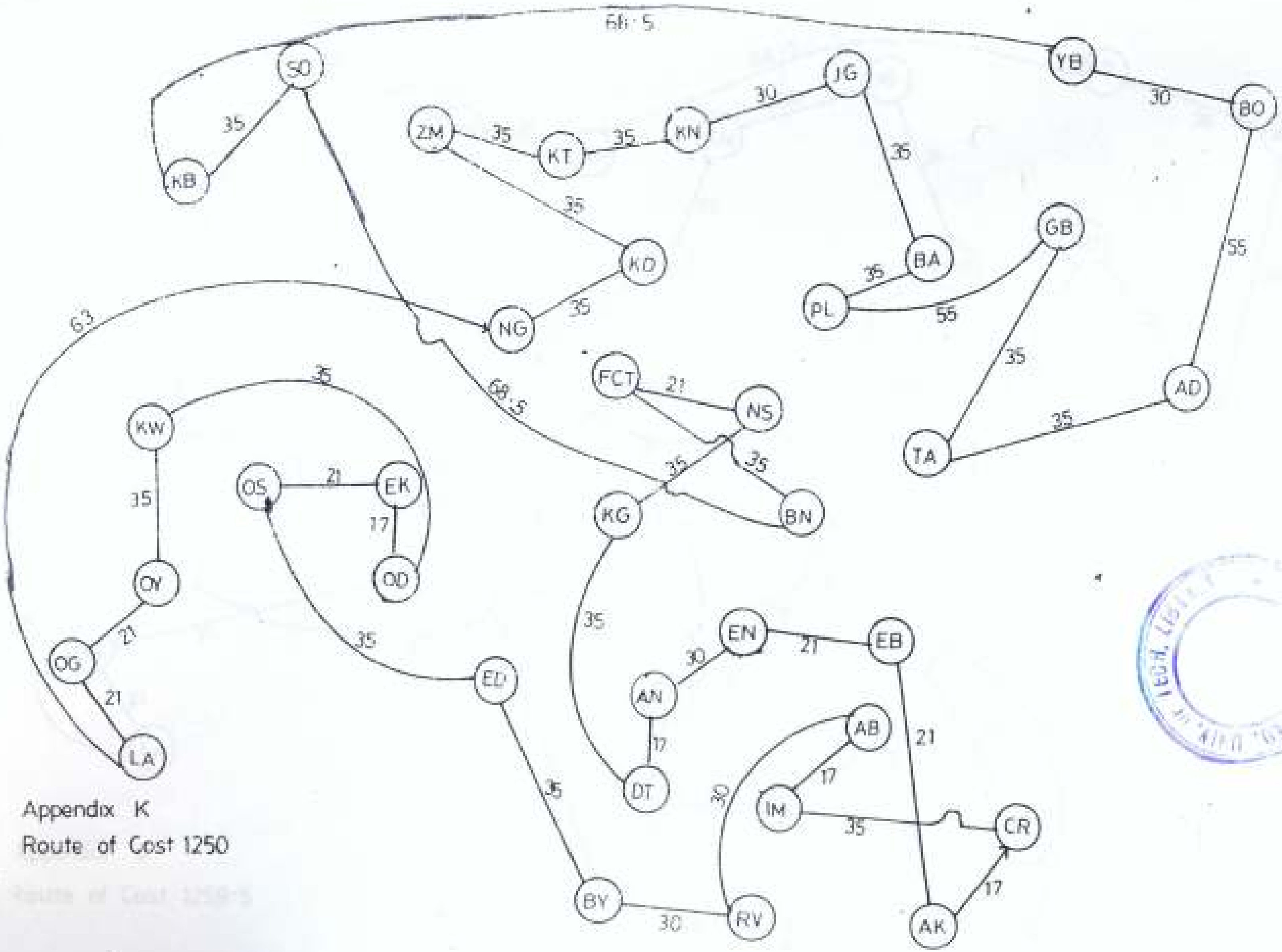


Appendix J

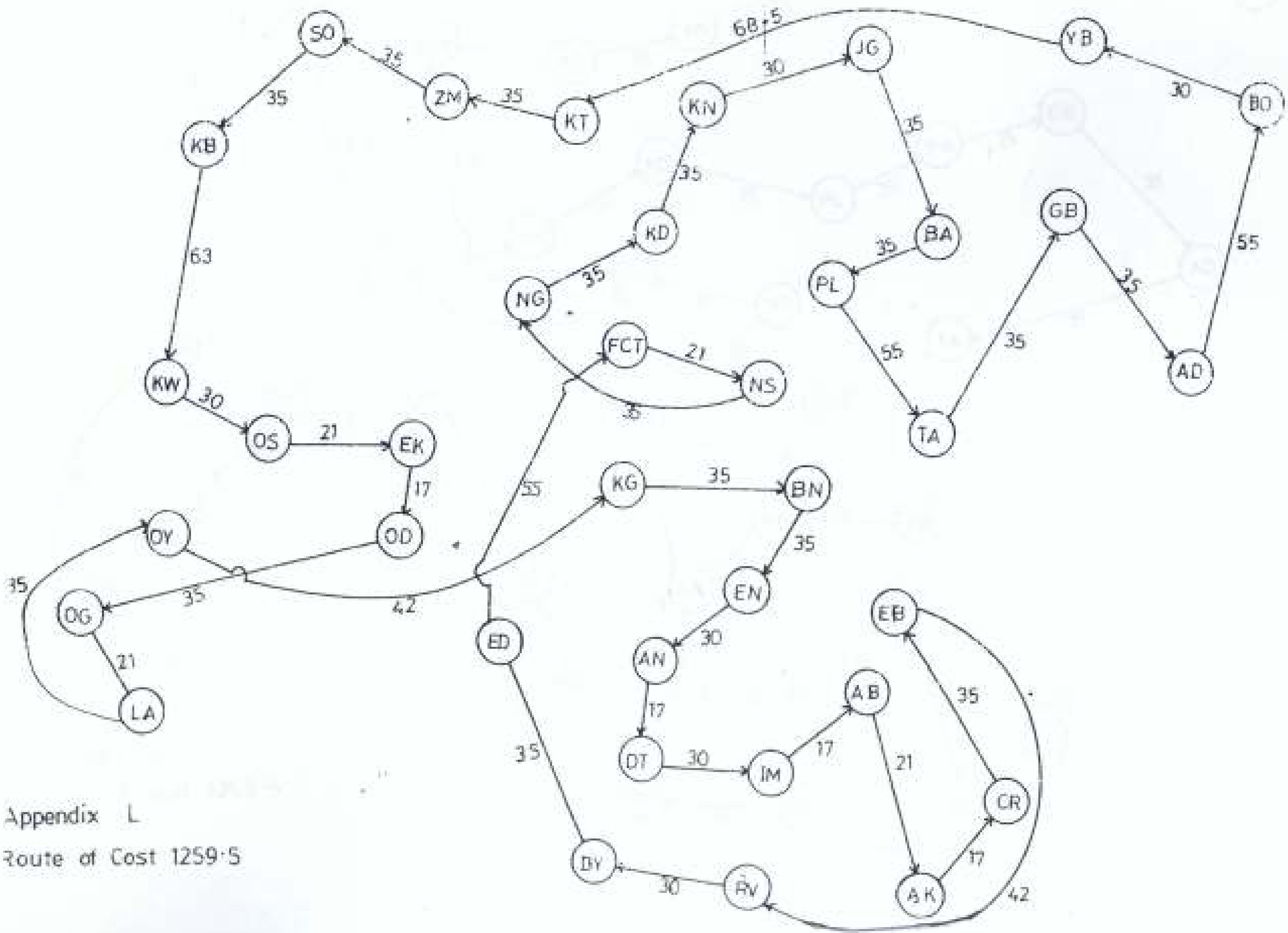
Route of Cost: 1248.5



Appendix K
Route of Cost 1250

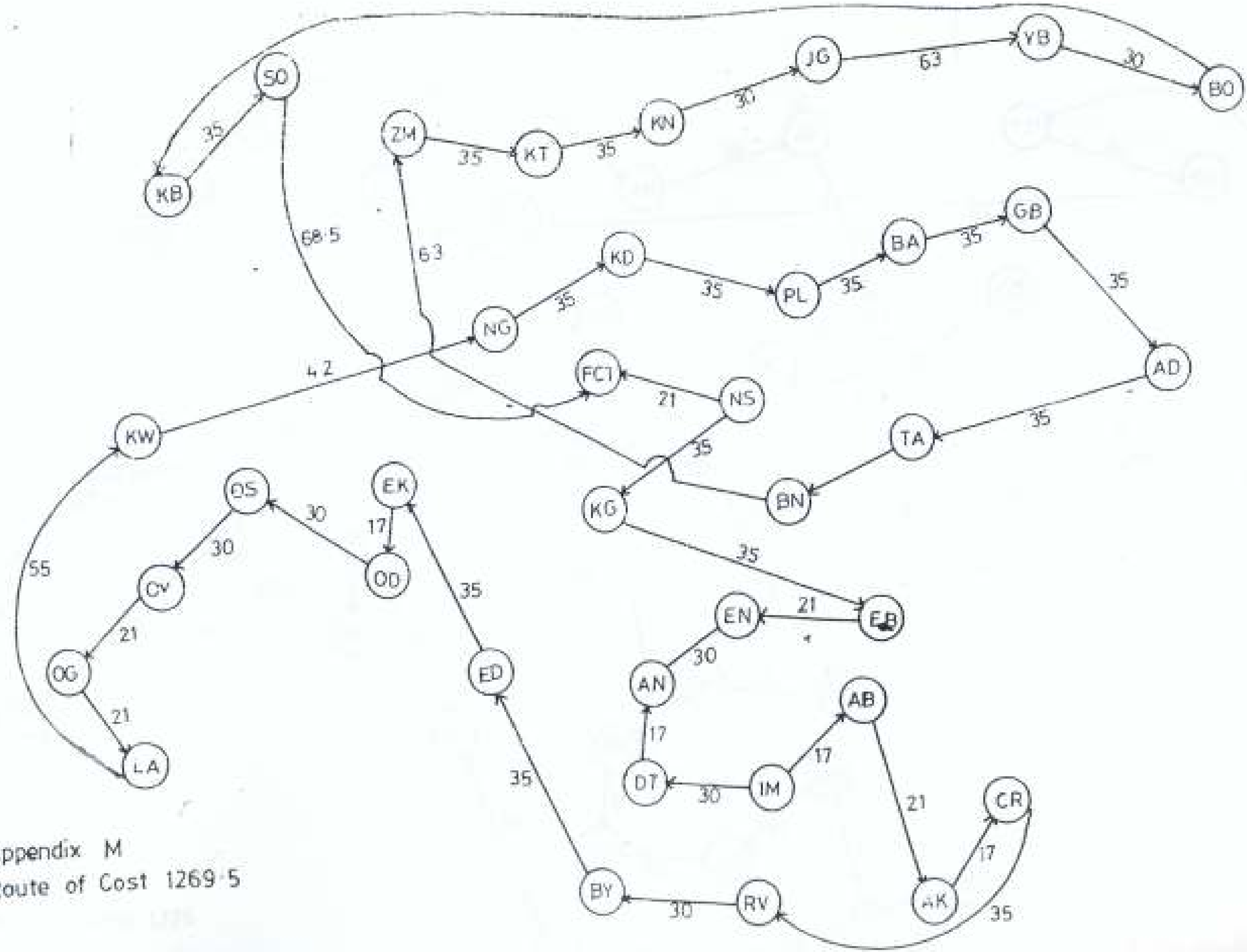


Appendix K
Route of Cost 1250

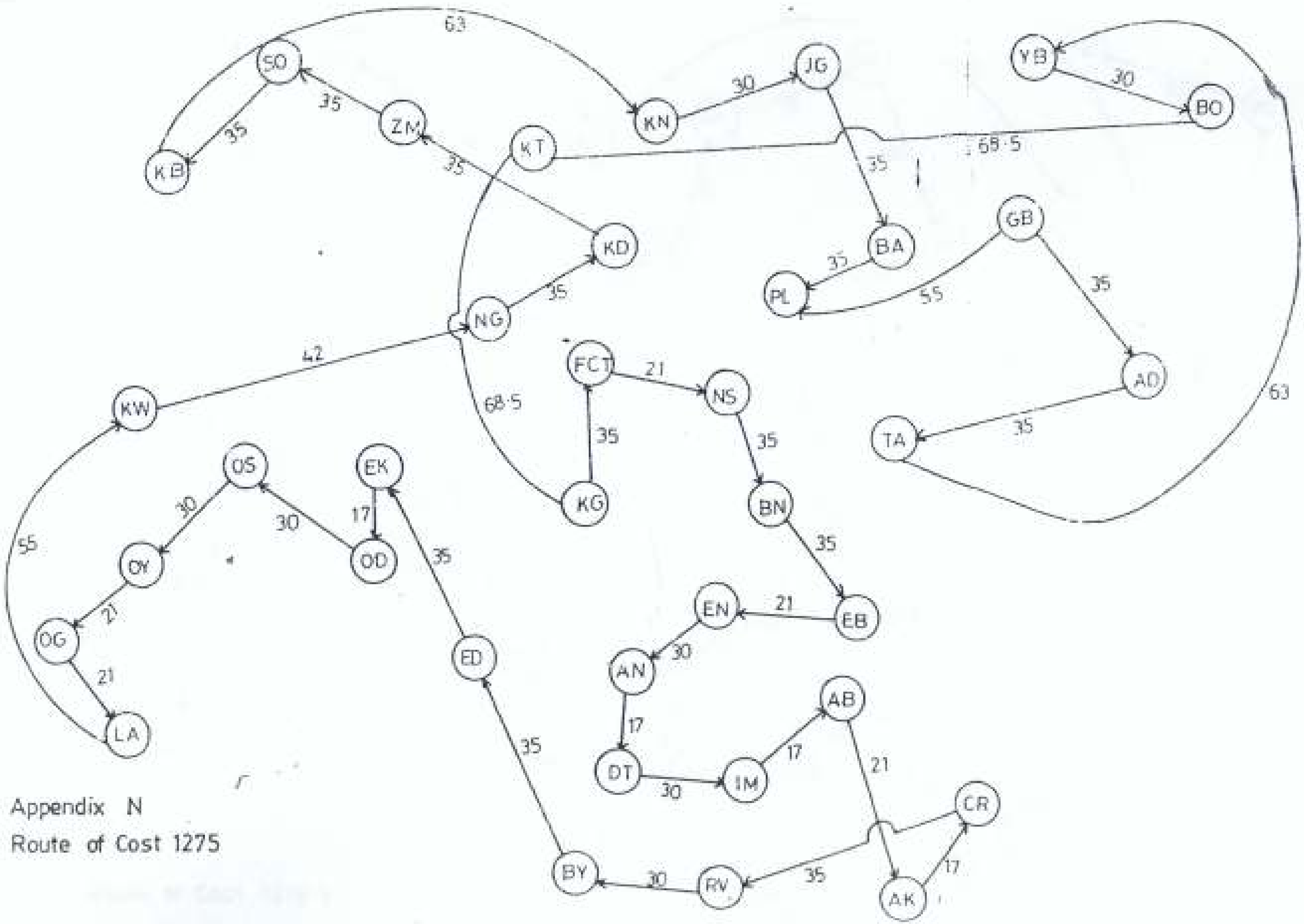


Appendix L

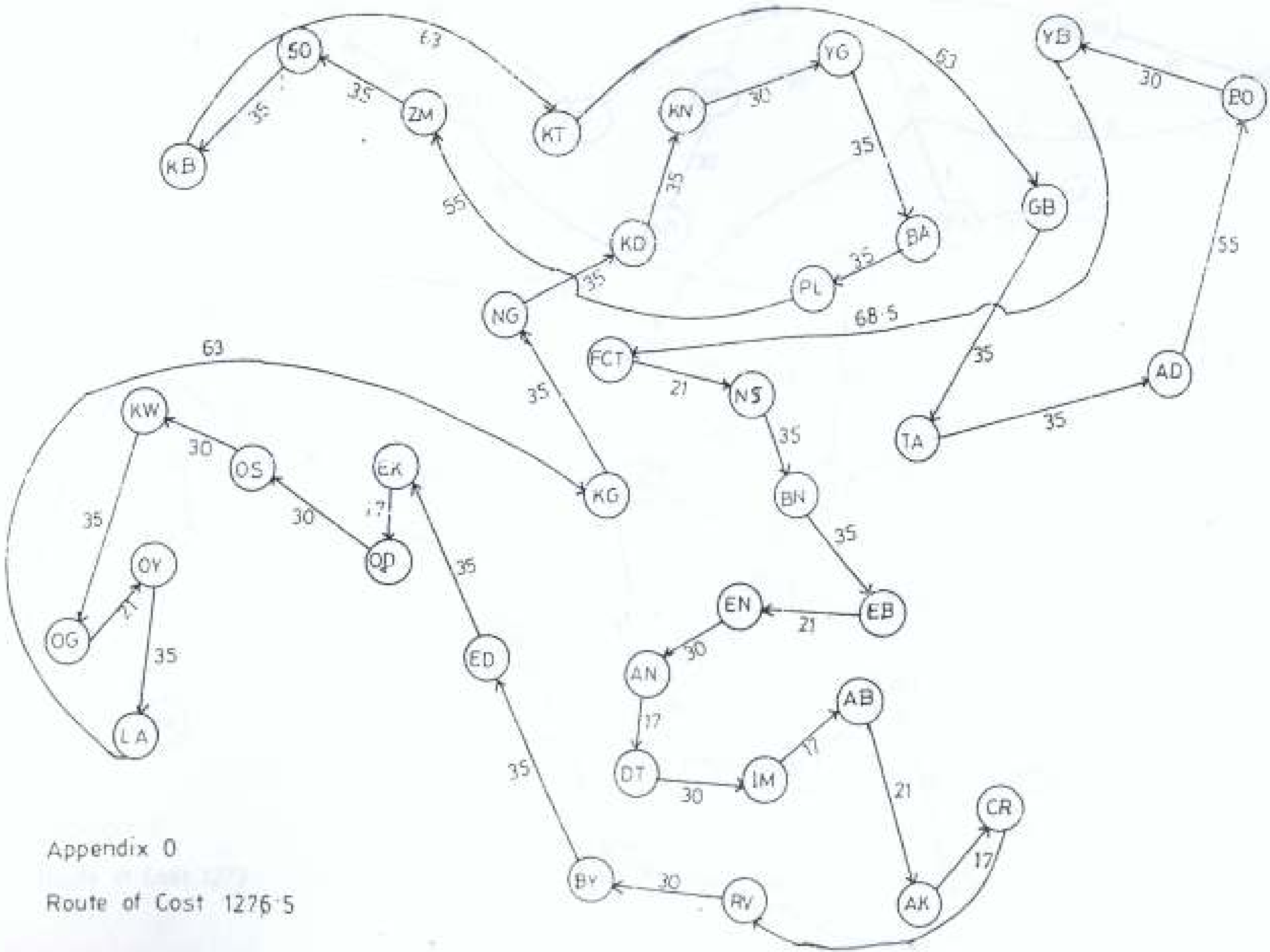
Route of Cost 1259·5



Appendix M
Route of Cost 1269·5

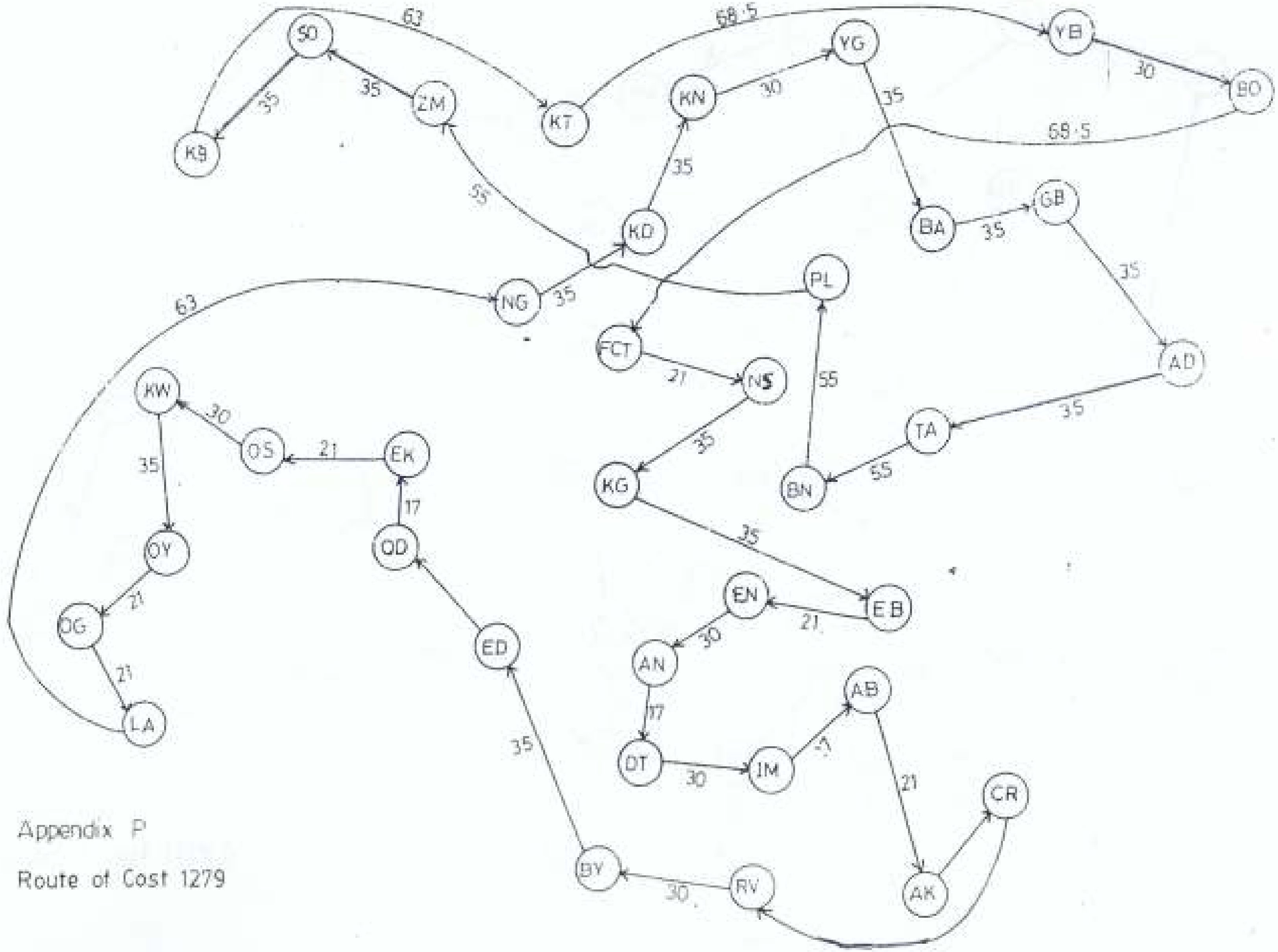


Appendix N
Route of Cost 1275



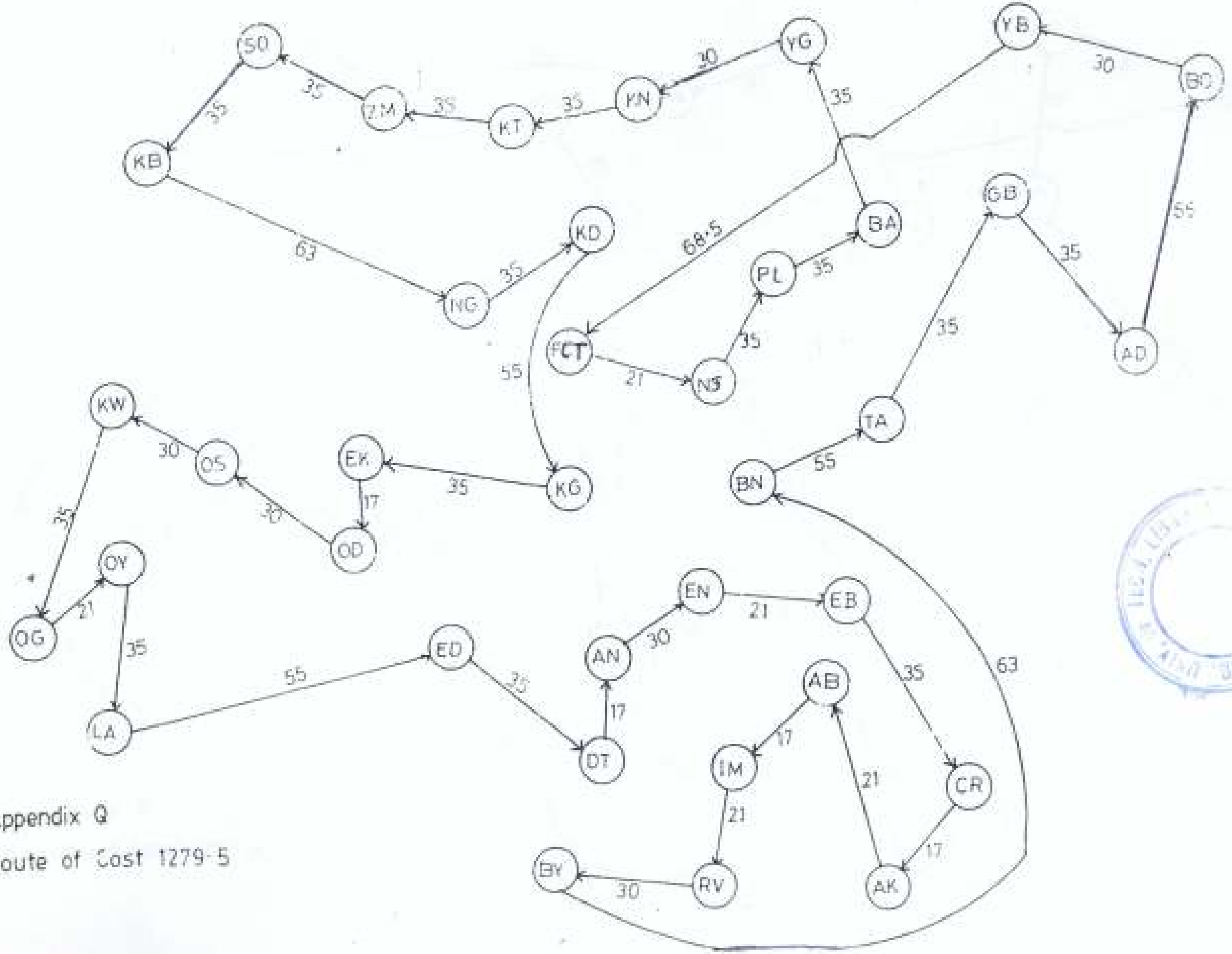
Appendix 0

Route of Cost 1276·5



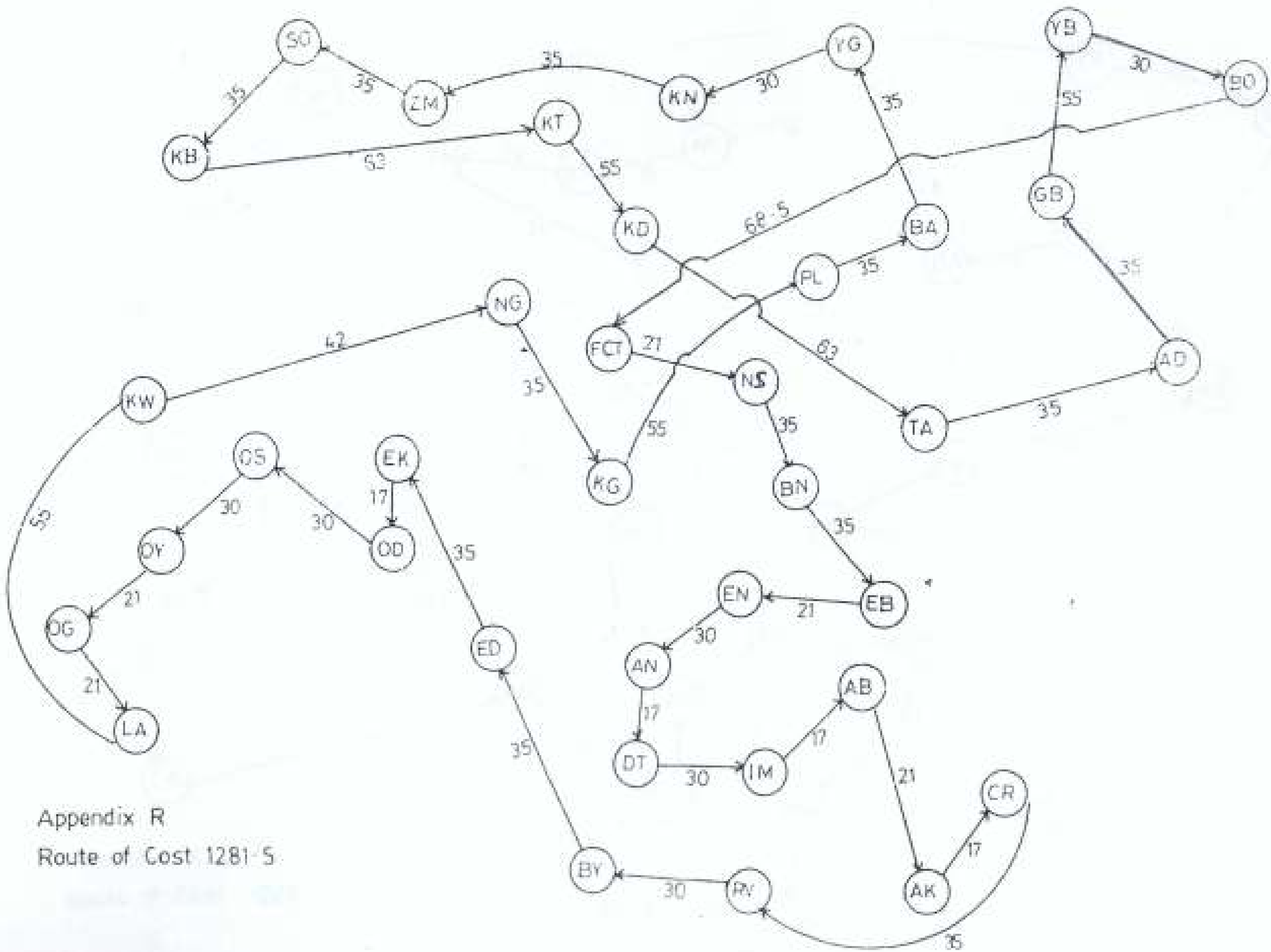
Appendix P

Route of Cost 1279



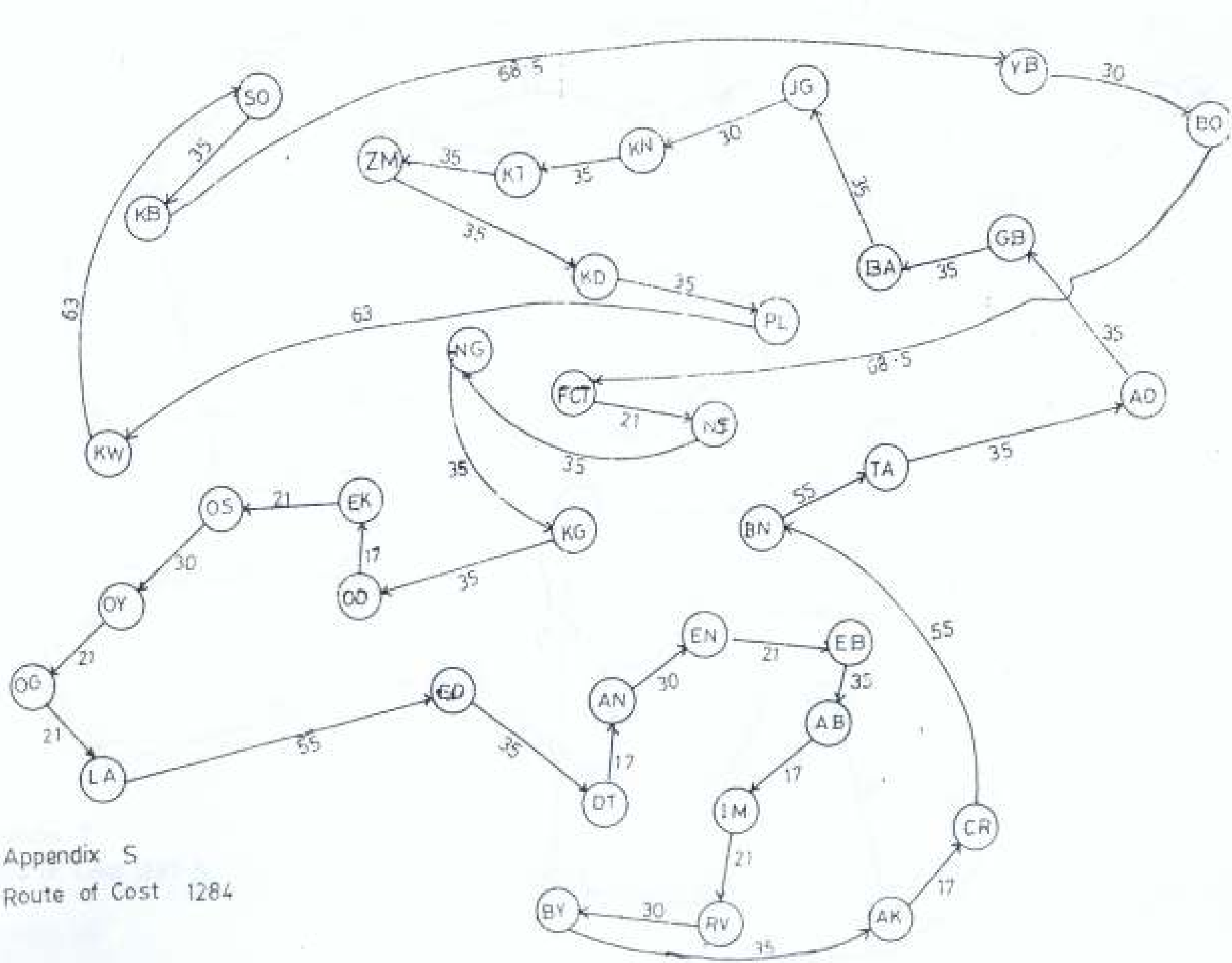
Appendix Q

Route of Cost 1279·5

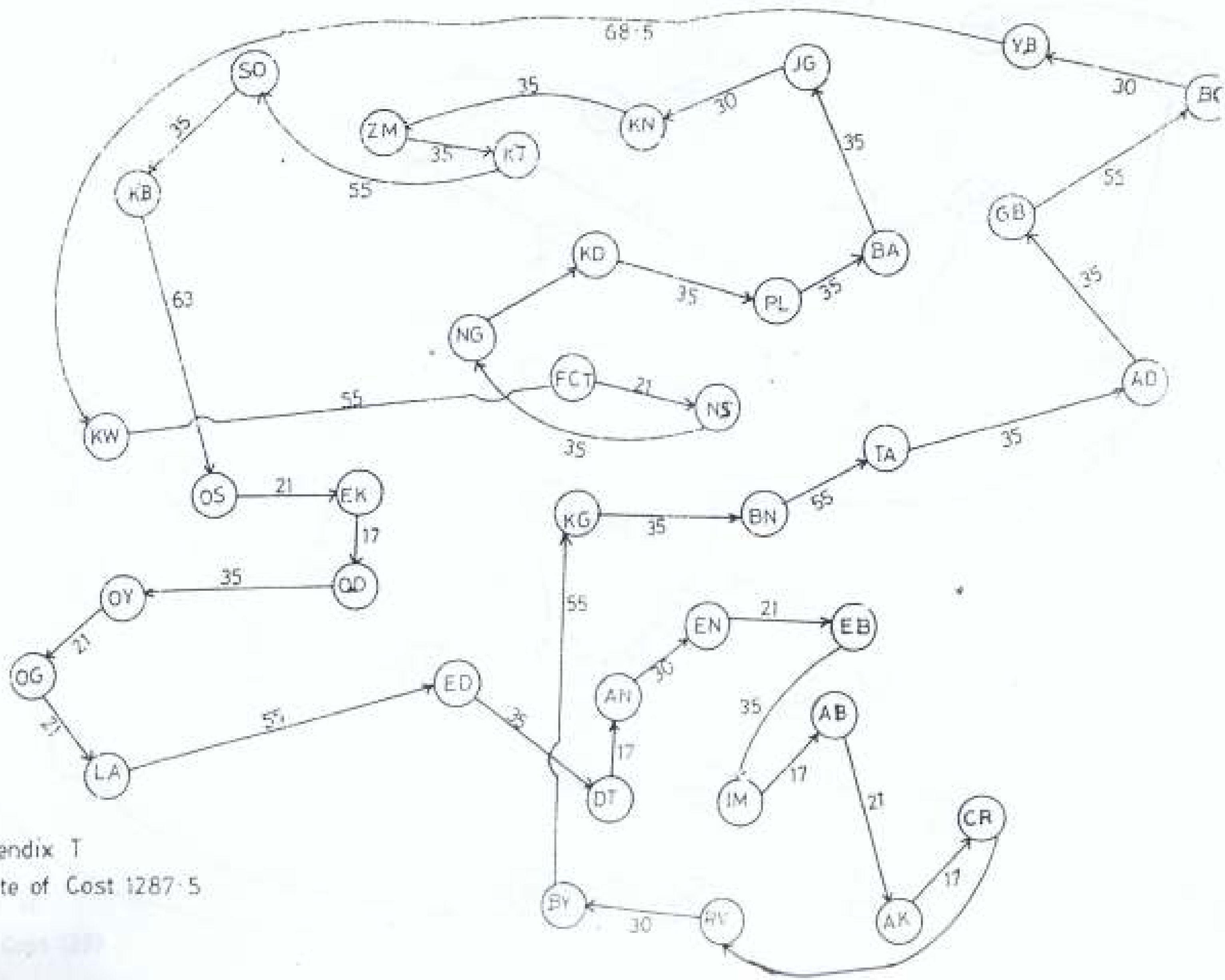


Appendix R

Route of Cost 1281·5

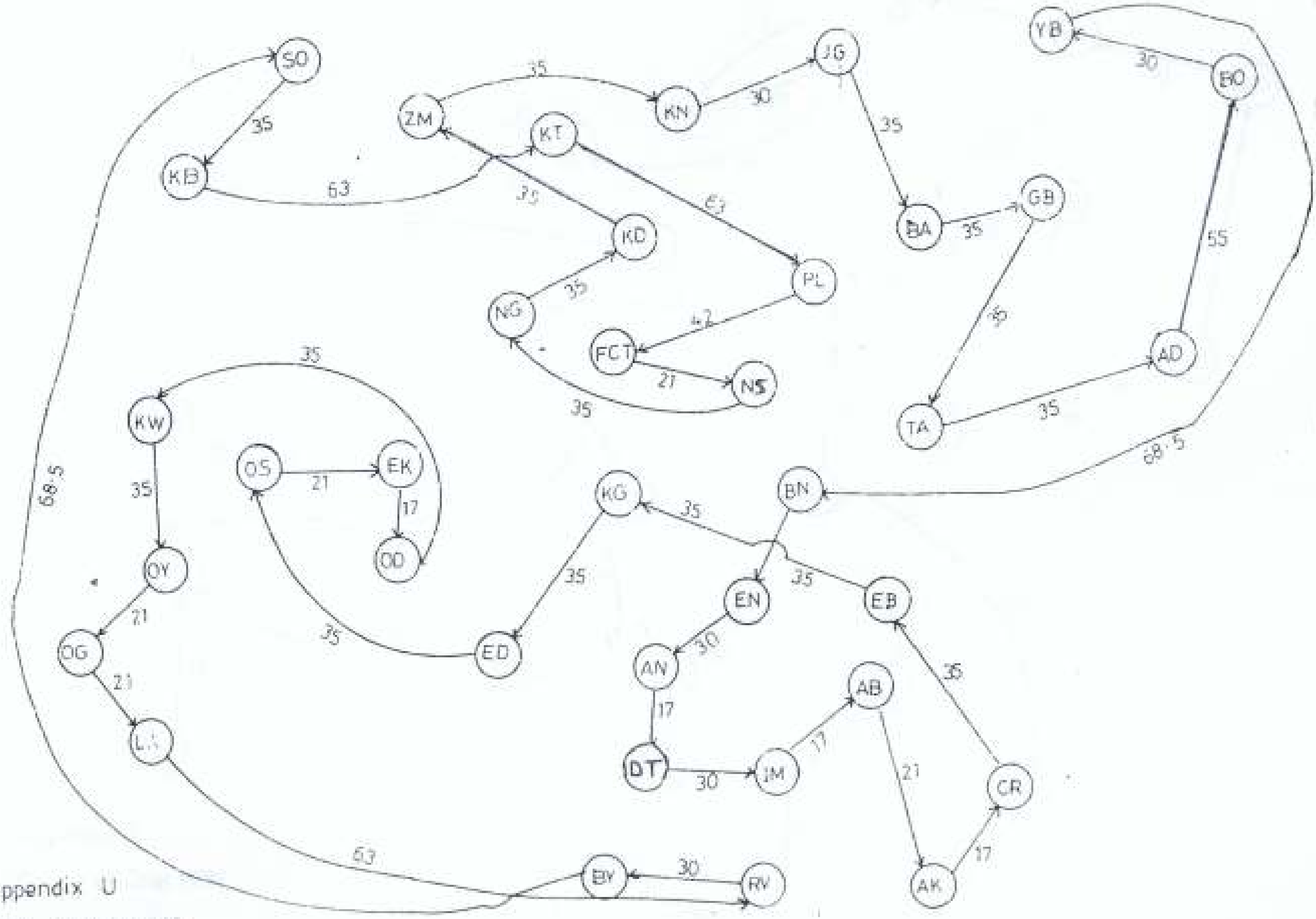


Appendix 5
Route of Cost 1284



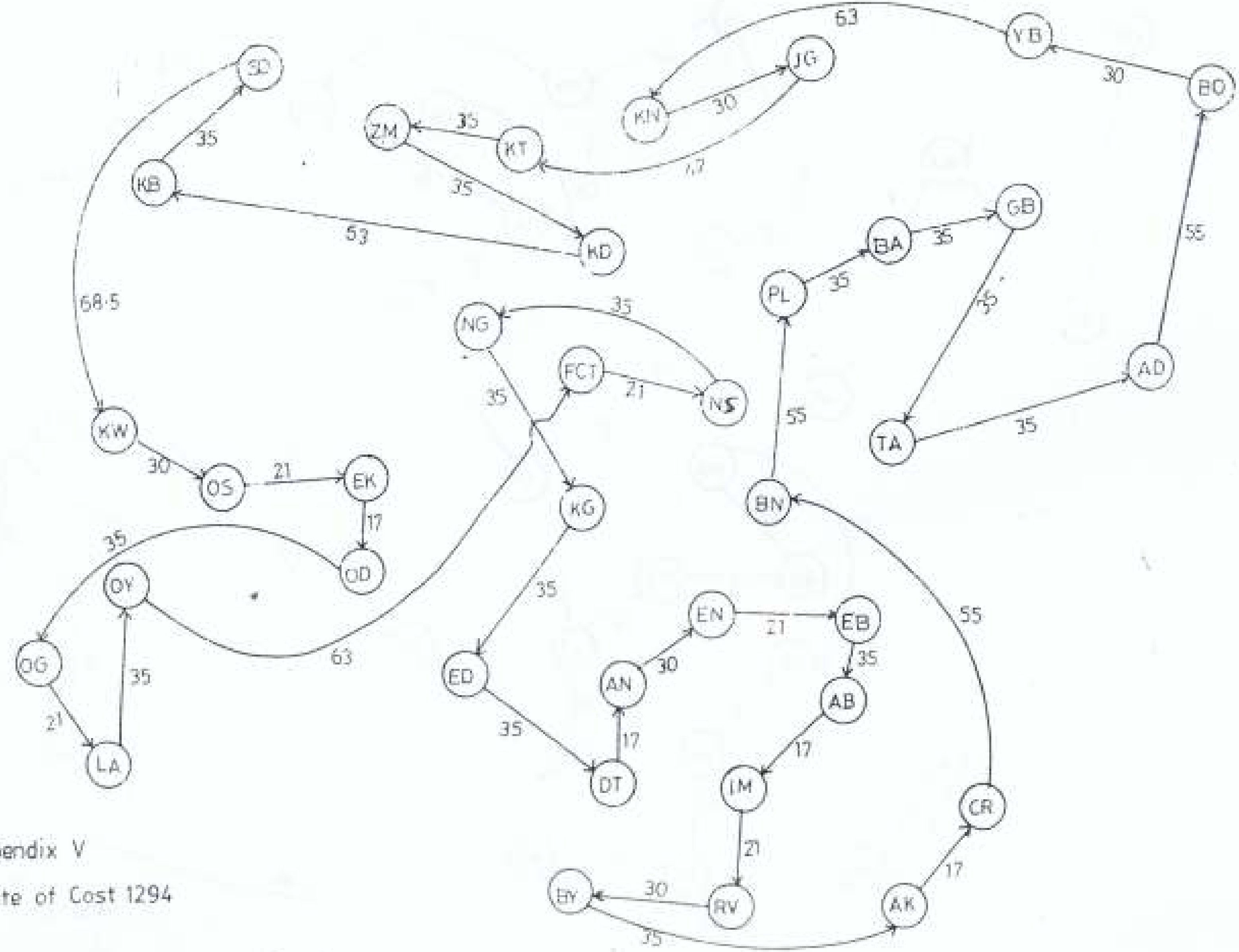
Appendix T

Route of Cost 1287·5



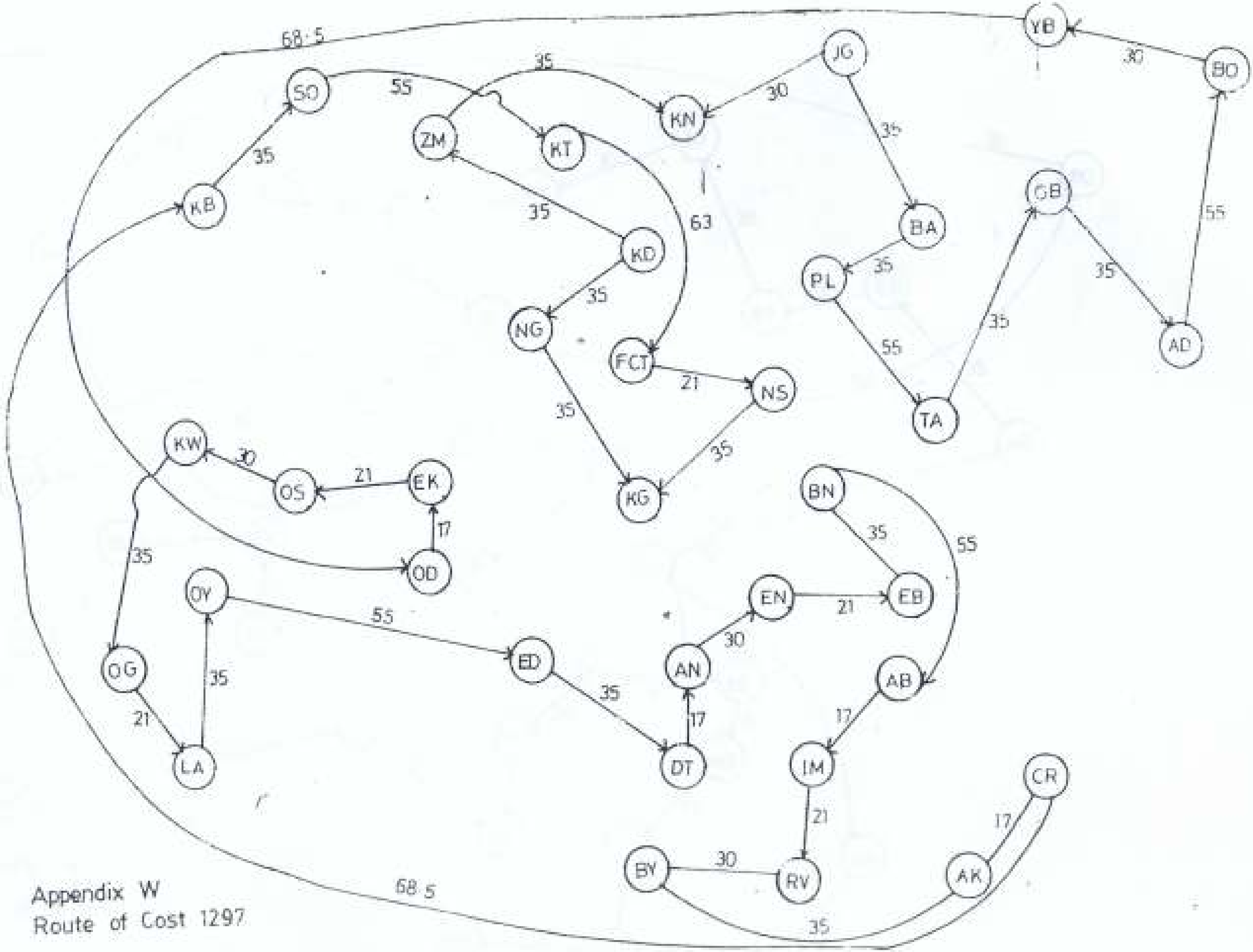
Appendix U

Route of Cost 1293

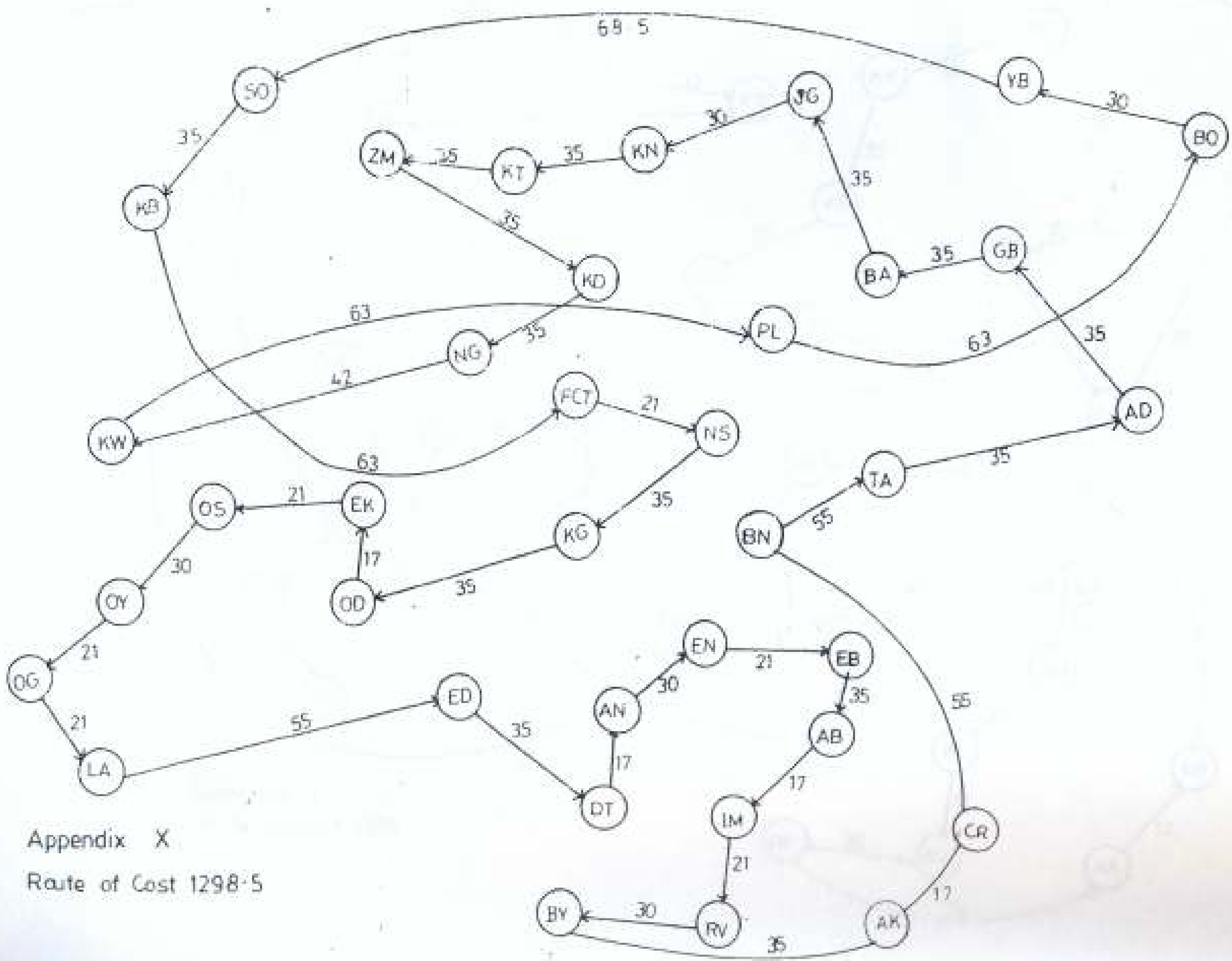


Appendix V

Route of Cost 1294

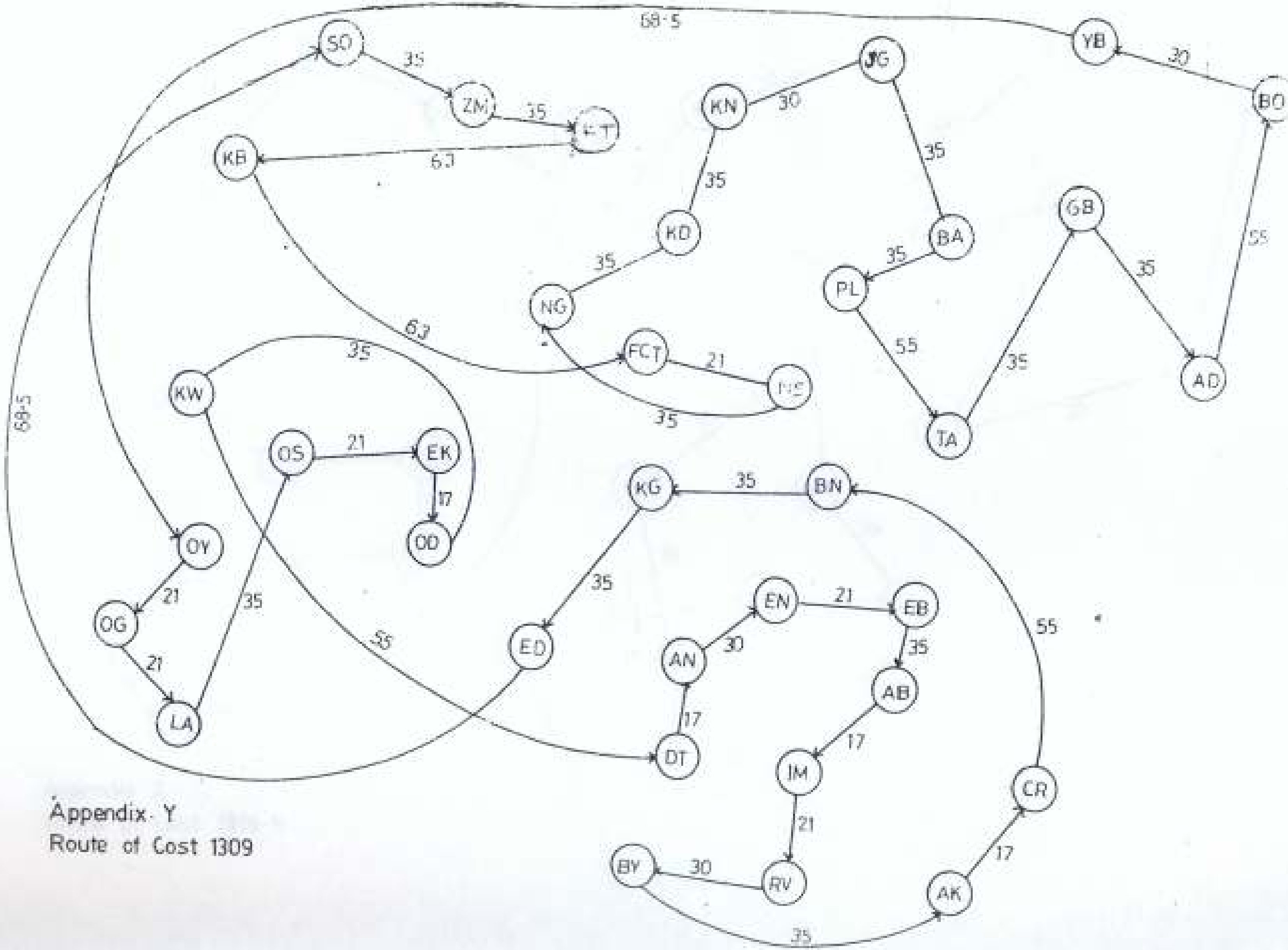


Appendix W
Route of Cost 1297

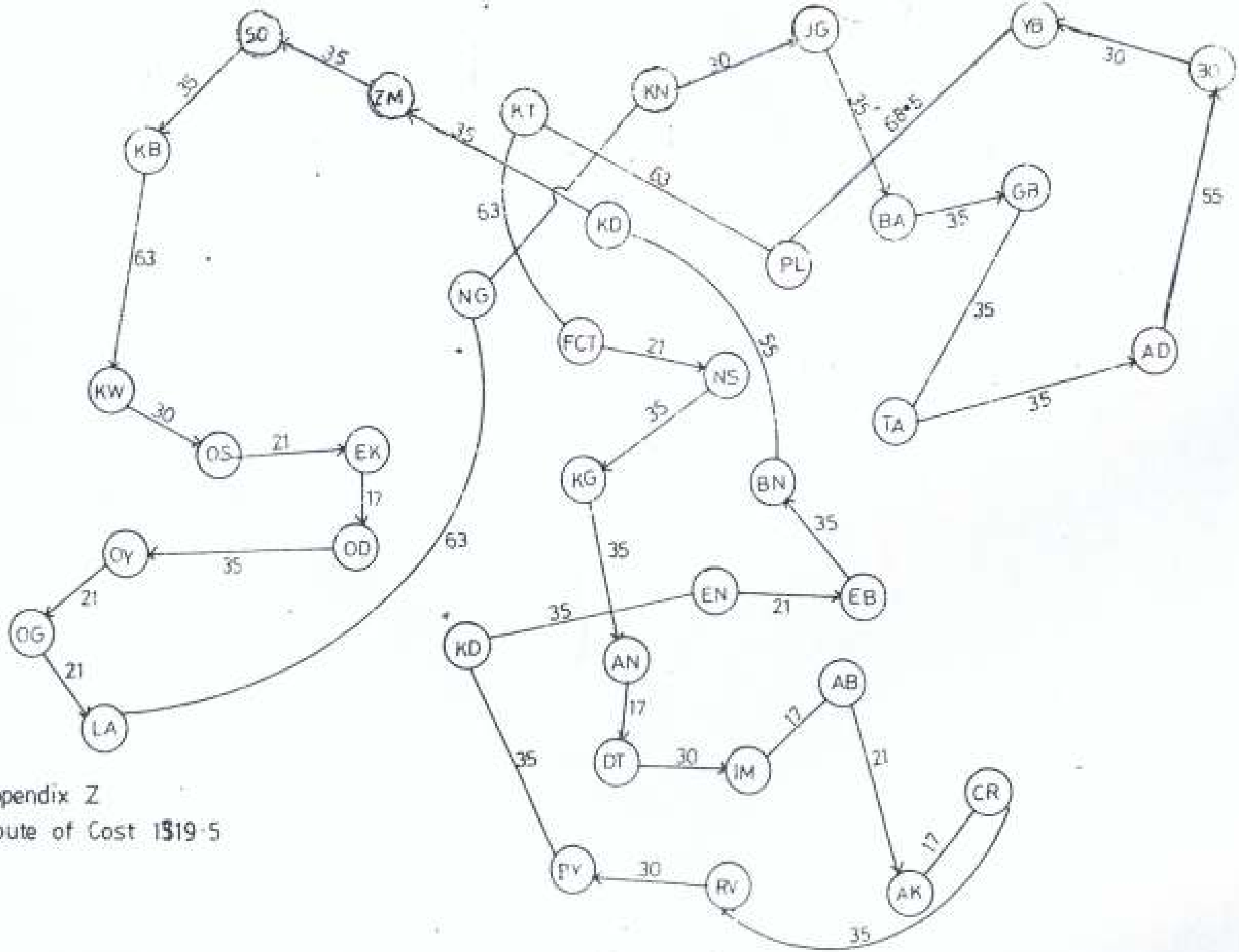


Appendix X

Route of Cost 1298·5



Appendix Y
Route of Cost 1309



Appendix Z
Route of Cost 1319·5