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# TRAFFIC CONGESTION, CONNECTIVITY AND OPTIMALITY

# IN

# NATIONAL NETWORKS

**BY**

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# ABSTRACT


## TRAFFIC CONGESTION, CONNECTIVITY AND OPTIMALITY IN NATIONAL NETWORKS

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Optimizing national telecommunication networks for developing countries is one of the most important issues in communication today. Developing countries are falling behind the developed countries because of connection delay and throughput bottleneck . This has a direct effect on worldwide communication because developed countries are competing to export their products and services to the third world. Competition in the telecommunication market and product compatibility promises attractive prices and availability for the developing countries .

In this dissertation the triangle relation between network traffic flow, connectivity, and grade of service in national network has been verified and their interdependability relationships has been measured and evaluated by cost analysis methodology.

This research generated a national network optimizing methodology which yields to the development of a software package to solve national networks existing

problems and to increase network performance and capacity with minimum cost and maximum profit. This includes providing methods for identifying the critical locations of high speed switches and presented the optimal topology for both switches and links throughout a cost effect analysis for both fixed cost and running cost of national networks.

The general plan in this study was broken into one, five, and ten years for more efficiency. This break-down makes the general plan more flexible to adapt to changes in telecommunication technology. The three plans can be combined and implemented in either a ten-year period or a sixteen-year period, depending on the availability of funds for these plans. The analysis of the data shows that increasing traffic intensity will reduce cost per minute when **SONET** is used as a backbone network for **ATM** switches.

The analysis and results suggested in the study can be used to create a national telecommunication network model for any developing country. Nevertheless, the results can be applied to other small countries, big cities, or sections of large countries.

This study is the first methodology of broadband networks on third world countries where there is a high demand for high speed transmission facilities.

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# CHAPTER 1

## INTRODUCTION

Telecommunication and Networking have developed more significantly than any other field in the past fifteen years because telecommunication is the most important factor driving our daily lives.

The great progress made in telecommunication could be measured by the huge number of books and papers published in the last decade. Most of the work done in the United States and other developed countries is a demand driven research. It is designed to handle specialized areas such as voice and data in limited environments utilizing LAN, MAN, or WAN to meet industrial competition and to reduce communication cost and time.

Little concern is given for national network studies. The reason lies in the high cost and complexity related to the time-consuming tasks needed for this type of analysis. Furthermore, in most cases, it is impossible to have access to real traffic data for the national network which makes any study just a lab model with applicable results in some cases. These observations apply to both public and private network systems.

Telecom 95, the seventh World Telecommunications Forum, was held at 1995 in Geneva, Switzerland. Sponsored by the International Telecommunications Union (ITU) and held once every four years, it is the only conference in the world that attracts virtually all the top executives from the world's telecom suppliers, carriers, and regulatory authorities.

Dr. Pekka Tarjanne, the secretary-general of the ITU, said in his opening address: "World leaders have realized that telecommunications is the most important industry in the world today, and that it holds the key of mankind future." As promising as this may be, there is a lot of uneasiness about the direction this information revolution is going and whether the benefits will be equally available to everyone.

Jacques Santer, president of the European Commission, pleaded for "generosity" in "transferring communications and information technology to developing countries and so helping spread liberty, democracy, and opportunity."

From that point of view, we can see that developing national networks for developing countries is one of the important issues which will open more opportunities for marketing the developed countries' products and services.

Designing an optimal telecommunication national network is influenced, as stated before, by traffic flow, connectivity, and level of congestion. These are demography dependent factors. In addition, traffic volume varies from one period to another. It varies between seasons, months, days, and even between minutes in the same hour.

Matching network capacity to demand will minimize network cost no matter what type of telecommunication service it provides. Both over-provision and under provision increase cost. Figure 1.1 shows a typical network operator's equipment provision schedule. The demand may represent the total (local and long distance) traffic originating in a given area. Each step in the capacity profile represents the provision of a local exchange extension or a new exchange. Alternatively, the demand curve could correspond to a particular type of traffic.

For a national network, matching capacity with demand is the major problem for network designers because there are many uncontrolled factors that have to be dealt with. It is, therefore, normal to use the fitted capacity graph 1.1 to ensure that the new equipment is on hand before the demand exceeds capacity. When a network slips into under-capacity, new exchanges often become congested on the day they are started. This is caused by the fact that forecasters tend to underestimate the amount of suppressed traffic in congested networks.

For purposes of exchange provision, the demand is normally quoted in terms of the highest instantaneous network throughput required. In circuit switched terms, the important parameters are the traffic intensity and the number of customer connections required. In packet switched networks, the equivalence of traffic intensity is the number of segments of data to be carried per hour.

To design an optimal national network with a forward provision, we need an overall analysis of the existing national networks including some actual traffic data. The analysis must also include the following factors to provide the required network topology:

1) Geographical and geological factors.
2) Population and density of telephone customers (demographic factor).
3) Volume of traffic generated by each customer.
4) Volume and proportion of traffic to other local, trunk, and international destinations.

5) The established network, its capacity for extension, its suitability for the support of new services, its state of repair, and its degree of obsolescence.

6) The reliability, optimum size, and service capabilities of contemporary equipment which may be used to extend or replace the established network.

Existing models for optimizing networks focus on network connectivity and traffic density with an assumed congestion. The result will be an optimum network applicable to various public and private networks. National networks must focus on all the factors listed above. Even though many models can be found in traffic studies, non of these models can be implemented as a complete model used for national networks. Nonetheless, some of them could be modified to become complete models.

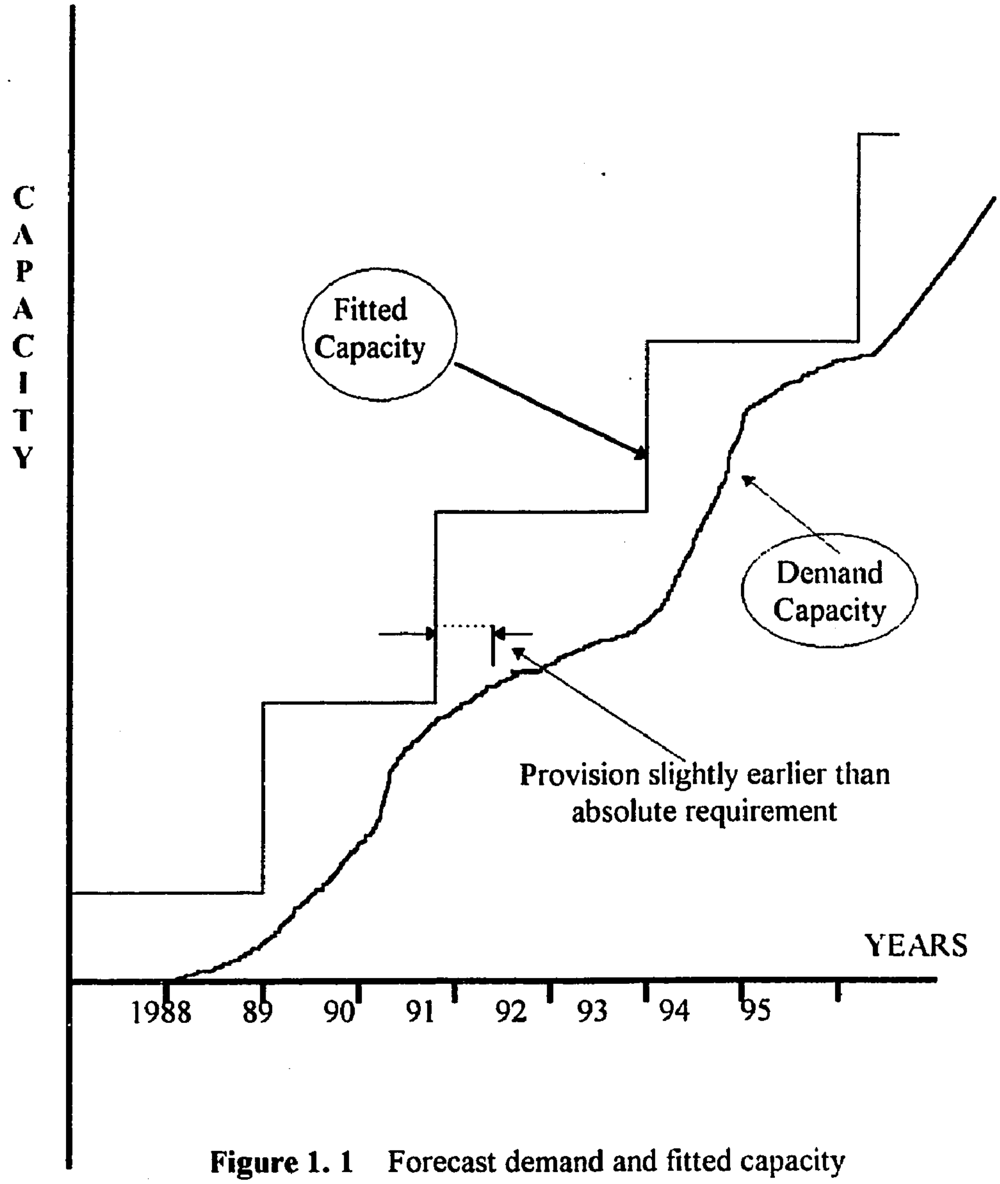



**Figure 1. 1** Forecast demand and fitted capacity

The complete model we need is the one which will output not only the optimal cost of connectivity for given traffic, but also the optimum national network including central office switching equipment.

Central office switching equipment plays a major role in network optimizing technology because it provides many products for open system interfaces which can be used and adapted for any existing network. This was not the case twenty years ago when any nation had to use the same suppliers for updating and modifying its network because of the incompatibility between switching systems of different manufacturers.

# CHAPTER 2

## NETWORK CONSTRAINTS

Network design today is an ongoing process due to the rapid changes in the technology. The communication industry is very competitive, and consequently, unpredictable which makes the network designer's job an uneasy one. Time is a very important factor here, so designing and implementing a network time table must be fast. Just when one thinks the optimal network design has been implemented, new services are introduced and price wars begin, forcing one to start over, or else the technology the person come to rely on suddenly becomes obsolete, to be replaced by something faster and more efficient.

The public and industrial demand for faster and cheaper reliable communication services forced communications carriers and manufacturers to form a competitive market all over the world.

The main components of telecommunication networks are generally classified as switching and transmission equipment. Switching equipment connects inlet and outlet termination to each other and to the service circuits. They have taken various forms from simple manual cardboard's to modern electronic stored-program common-control systems. Transmission equipment interconnects the switches to each other and to their terminal equipment. The trunk groups that provide the interswitch transmission paths may be as simple as wire pairs or as complex as time-multiplexed radio and optical links.

Traffic performance is one of the many categories of performance that determine the overall quality of telecommunication services as perceived by end-users. The various user-oriented performance categories defined by the International Telegraph and Telephone Consultative Committee(CCITT) are shown in figure 2. The five user-oriented categories are: [8]

*Service Support*. The ability to provide a service and assist to its use.

*Service Operability.* The ability to easily use and successfully handle a service when needed.

*Service Accessibility.* The ability of service to be obtained when requested. This aspect of performance deals with the access of the communication process, and is governed mainly by traffic consideration. It relates to the functions of connection establishment (such as voice calls and data sessions) and associated data base access, protocol conversion, etc., as required to support a particular service. This user oriented service corresponds to network oriented traffic performances.

**Service Integrity.** User's general opinion of, or level of satisfaction with, a service after gaining access to it. This aspect of performance relates to the transfer phase of the communication process, and is governed mainly by transmission considerations.

**Service Retainability** (Robustness). The ability of the communication service to remain functional for the duration required by users. This aspect of performance relates to all phases of the communication process (access phase, information transfer phase, and disengagement phase), and is governed mainly by availability considerations.

There are dependencies among the service accessibility (traffic), integrity (transmission), and Retainability (availability) categories, like the effect of severe and persistent traffic and transmission performance degradation on availability. Furthermore, packet-oriented services and congestion (a traffic aspect of performance) can be manifested not only during the access and disengagement phase, but also during the information transfer phase, and thereby affecting the integrity of information transfer.

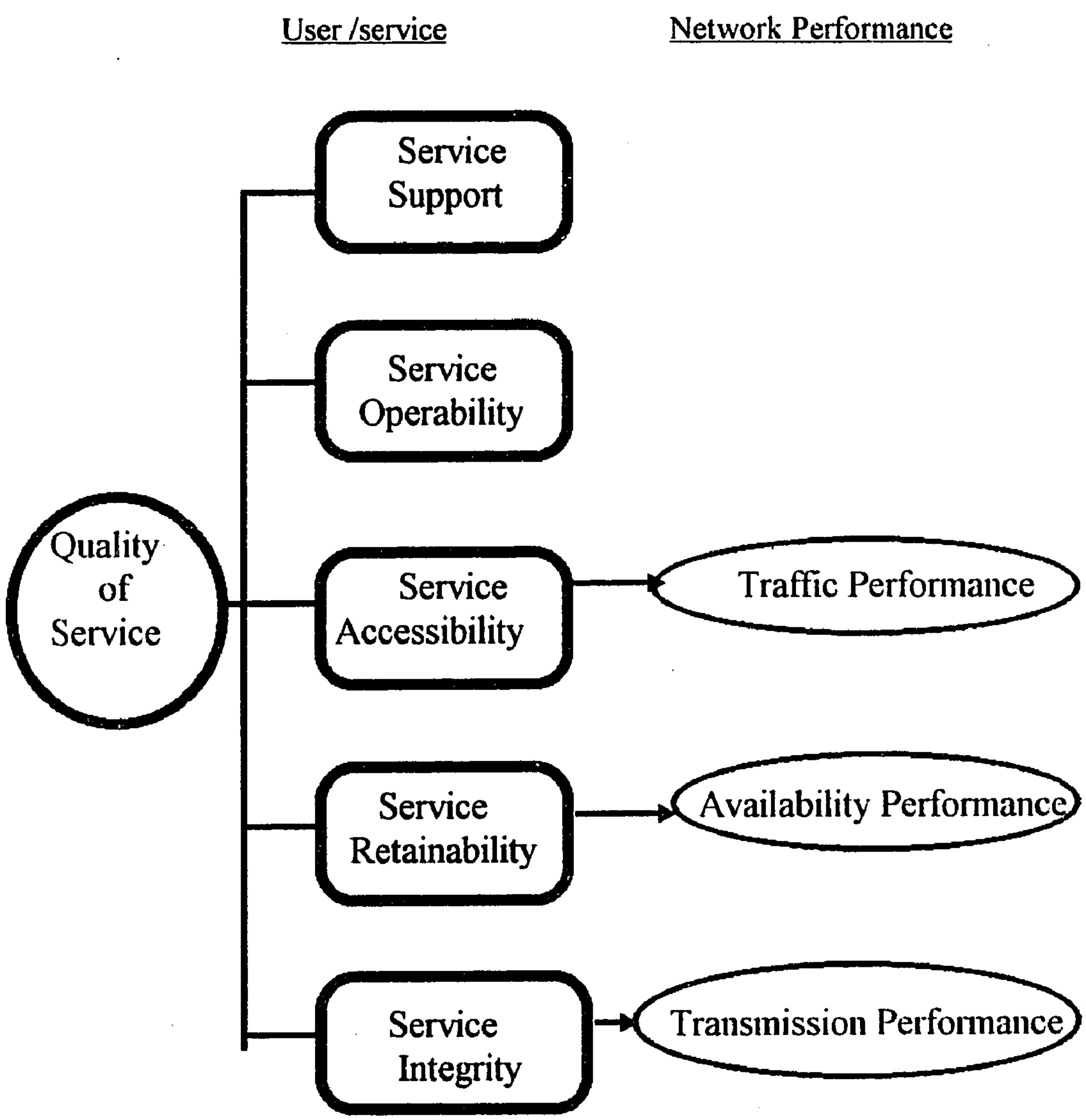



**Figure 2.1** Main User-and Network Oriented Performance Categories.

## 2.1 Traffic Concept

All networks are created to satisfy the communications needs of an organization. Some networks provide good service at relatively low cost, whereas others are inefficient and expensive. Whatever the design is, all networks are designed to meet a certain demand for communications resources. This demand is called traffic.

In processing traffic through the network, we must ensure that an accurate number of appropriate facilities are in the right place at the right time to get effective performance. The basic factors affecting traffic performance are the volume and nature of traffic to be handled, the facilities to serve the demand, and the grade of service desired. These three factors can be seen as the three sides of a triangle as shown in figure 2.2, where any change in one or two sides will affect the others. For example, adding more subscribers to an existing network (i.e. increasing traffic flow in the same facilities) will increase the level of congestion.

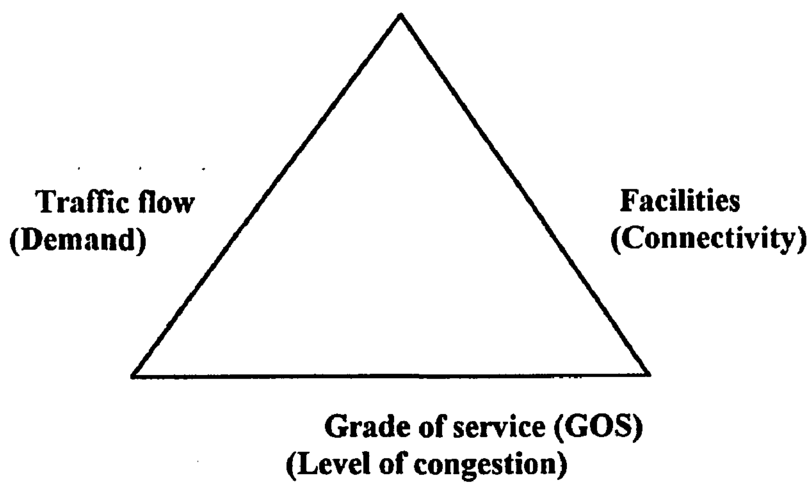



**Figure 2.2** The three sides of the traffic problem

### 2.1.1 Concepts of Traffic Flow

A network system exists primarily to provide useful services to a set of subscribers. These services involve many forms of information exchange between network service nodes and subscriber nodes.

Traffic flow is defined as the product of the number of calls through a switching office during a period of time and their average duration. Most well-designed network systems provide some traffic flow control to prevent congestion which may result in system failure. Two of the popular ways to achieve flow control are access limiting and dynamic routing of traffic. Traffic intensity is the average number of calls simultaneously in progress during a particular period of time. It is measured by (***Erlangs***) in voice network, and by bits per second (***bps***) in data networks. These two traffic intensity units can be converted into each other, specially in voice networks which utilize digital carriers by using pulse code modulation technology (**PCM**). The traffic intensity on any route between two exchanges can also be quoted in ***Erlangs*** or ***bps***.

***Erlang*** (ERL), named after A.K. Erlang (1878 to 1929), is the basic unit of traffic intensity. Thus, an average of one call in progress during a particular period would represent the traffic intensity of one Erlang.

Another traffic unit used in the United States is the *CCS* (hundred call seconds per hour). It relates to ***Erlang*** as follows:

one ***Erlang*** = **3600** call seconds = **36 *CCS***

If **A** is the traffic intensity in ***Erlangs***, **L** is the call arrival rate, and **H** is the average call holding time (the length of time during which a traffic source is engaged in a traffic path or channel), then

**A = L * H**

Thus **A** is the average number of calls arriving during the average holding time.

The definition of traffic intensity is not restricted to traffic between exchanges. Even intra-exchange traffic that passes across an exchange from incoming ports to outgoing ports can be measured and quoted in erlangs.

There are four traffic concepts of interest to us in the design of a network system:

***Demand traffic:*** The traffic load as seen by an ideal network system with no obstruction in the path.

***Offered Traffic:*** A theoretical concept. It is a measure of the traffic intensity that would occur if all traffic submitted to a group of circuits could be processed by the group without congestion.

***Offered Traffic*** = successful attempts + unsuccessful attempts

***Carried Traffic:*** The traffic intensity actually handled by the group. Traffic carried may or may not result in conversation. For a network without congestion, the ***carried traffic*** is equal to the offered traffic. Based on the degree of congestion, ***offered traffic*** will be higher than ***carried traffic***.

Teletraffic theory leads to a set of tables and graphs which enable the required network circuit numbers to be related to the ***offered traffic*** demand as we will see later in this dissertation.

***Blocked Traffic*** (congestion): The portion of traffic that cannot be processed by the group.

***Blocked Traffic = Offered Traffic - Carried Traffic***

## 2.1.2 Traffic Intensity Measurement

Traffic intensity in a given route may be measured using one of two main methods: sampling measurement and absolute measurement.

### 2.1.2.1 Sampling Measurement

By looking at the instantaneous states of the circuits at a number of sample points in time, we can get an estimate of the total circuit holding time. Error arises from the fact that we are only sampling the circuit usage rather than using exact measurements. The error can be reduced by increasing the frequency of samples. A good sample period length is about one third the average call holding time, i.e., the minimum monitoring period should be about three times the average call holding time.

### 2.1.2.2 Absolute Measurement

This method continuously monitors the traffic intensity for a specific period of time. This involves a large number of calculations which makes the first method more acceptable for network analysis. This problem is solved by introducing the stored program control

(SPC) exchanges which make the absolute measurement of call holding times relatively easy. Therefore, many exchanges today can produce exact measurements of traffic intensity.

### 2.1.3 The Busy Hour

It is a continuos sixty-minute period of the day during which the highest usage occurs. Traffic theory is generally based on the conditions observed during the busy hour. **CCITT** recommends measuring the highest busy hours during the year and using the average for a busy hour model.

In more recent times, it has been found that exchanges are developing more than one busy hour, for example, morning and afternoon busy hours which are usually the result of business traffic. An evening busy hour may result from residential and international traffic due to time zone variation. For huge traffic countries like the United States, it is not enough to use one busy hour for national network analysis. We may even need to redefine the busy hour to be less than 60 minute duration. For small countries like the one in this study, a 60 minute busy hour will be sufficient.

## 2.2 Topological Organization of the National Network

As mentioned earlier, network connectivity is the second side of the traffic problem. Enhancing the topological structure and connectivity of a network will have a direct effect on traffic performance.

choosing the right topology for a national network is not an easy task. To design an optimal network topology, the geographical structure, size of the national network, type of transmission media, and many other factors must be studied. Some of the basic topologies that have proven useful in telecommunication networking are classified as follows:

### 2.2.1 Mesh Topology

A fully connected mesh topology like the one shown in figure 2.3 provides a direct link path between every pair of network nodes. Such a topology is economically feasible only when the number of nodes in a given network is very small.

This type of topology would be very expensive if it was used to connect the entire national network, but it could be useful in connecting high level nodes in the national network hierarchy to reduce congestion. A partially connected topology is recommended when the traffic flow between certain nodes is negligible and can be switched on a longer path while resulting in lower cost.

The country used in this study used Mesh topology as a part of its hierarchical structure. Using the results of the national network analysis, we will compare mesh toplolgy with partialy connected topologies and come up with the optimal connectivity.

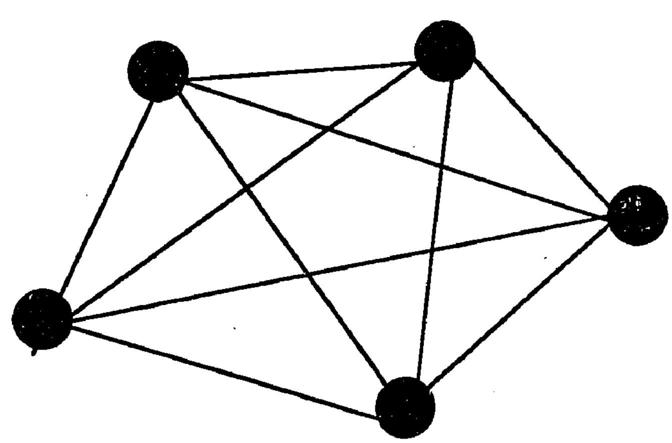


**Figure 2.3** Mesh Topology

## 2.2.2 Star Topology

It is a network which has one main switch or hub where all other nodes have a direct link only to that switch. Such topology is commonly used for connecting all the subscribers in a building or a campus to a voice switch known as the **PBX** or data switch. Star topology is also used for connecting the local subscribers to a central office or a concentrator.

In this study, we will see this topology used on a larger scale to connect central exchanges to the national nodal exchange, and also to the international one.

## 2.2.3 Hierarchical Topology

This topology is a subset of the generalized tree or multidrop topology, designed with the constraint that the sum of all link lengths in the network is minimal. The size of the national telecommunication network plays the major factor in choosing the degree of this topological structure. For small nations the minimum size will be a three level hierarchy: international, national, and end offices. On the end users level, we can use this structure with multiplexors and concentrators.

Hierarchical structure is especially common in national networks in which a large number of local exchanges or end offices route their trunk traffic via a small number of trunks or toll exchanges. At the highest level in the hierarchy, there is probably just one or two international exchanges. Each lower level has a greater number of exchanges, but each with only a restricted degree of long haul interconnection. Figure 2.4 illustrate a typical national hierarchy for a large country.

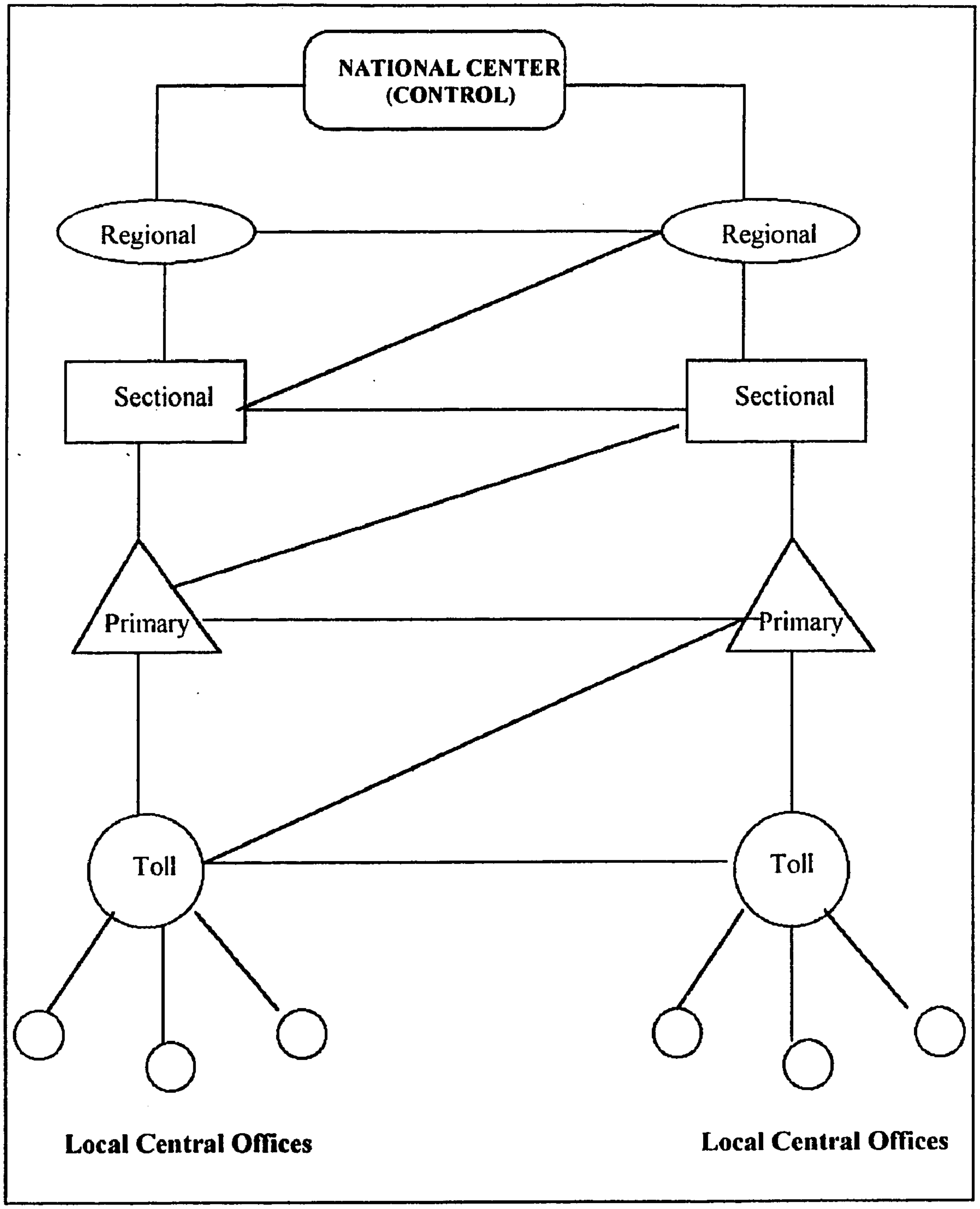



**Figure 2.4** The switching and routing hierarchy of a public network

The main advantage in hierarchical networks lies in their ability to get the most out of their circuits when the busy hours of various transmission routes do not coincide. For example, when one rout is busy in the morning while another rout in the same level is busy in the afternoon, both circuits can be used for the two traffic streams. On the other hand, separate direct circuit groups would be inefficient since at least one group will always be idle.

A disadvantage of hierarchical networks when compared to direct-circuited networks is their greater susceptibility to congestion under network overload. There are two causes for this disadvantage:

1. The total number of circuits available is less than the number of directly connected networks.
2. Congestion between any pair of exchanges will result in congestion on all other routs. Congestion in the higher levels may block the entire network.

### 2.2.4 Multicenter, Multidrop Topology

This is one of the most mixed topologies used in national networks. The backbone network with the higher traffic intensity is connected using Mesh structure, while subscribers and concentrators are connected to one or more backbone nodes using star topology. This structure is also used in data communication networks. Figure 2.5 shows a Part of the Jordanian national network multidrop Multicenter topology with cables and microwave links.

## 2.3 Routing Techniques

To minimize the circuit penalty which arises on small routes in direct structured networks is to adopt a hierarchical network structure as shown in figure 2.4. In this structure, a small number of main exchanges are fully connected with one another, while various tiers of less important exchanges have progressively less direct connections to other exchanges. By using this structure, we can reduce the number of circuits on long-haul routes.

Purely hierarchical networks have a greater susceptibility to congestion under network overload. This due to the fact that there is a fewer available overall circuits compared to direct-circuited networks. In addition, any congestion within any pair of exchanges will result in congestion on all other routes since all calls have to compete for the same circuits. This can rapidly lead to further congestion when customers keep re-dialing, as shown in figure 2.8.

Re-routing techniques can be used to handle overflow traffic and reduce the network congestion. Allowing the traffic to flow on alternate routes, as seen in figure 2.6, results in better use of network facilities and better performance for subscribers. Some of the generally employed techniques for traffic routing are:

### 2.3.1 Deterministic Routing

This method is also called Successive Node Routing Control (SNRC). This is the simplest routing method which allows a fixed primary route and one or more alternate

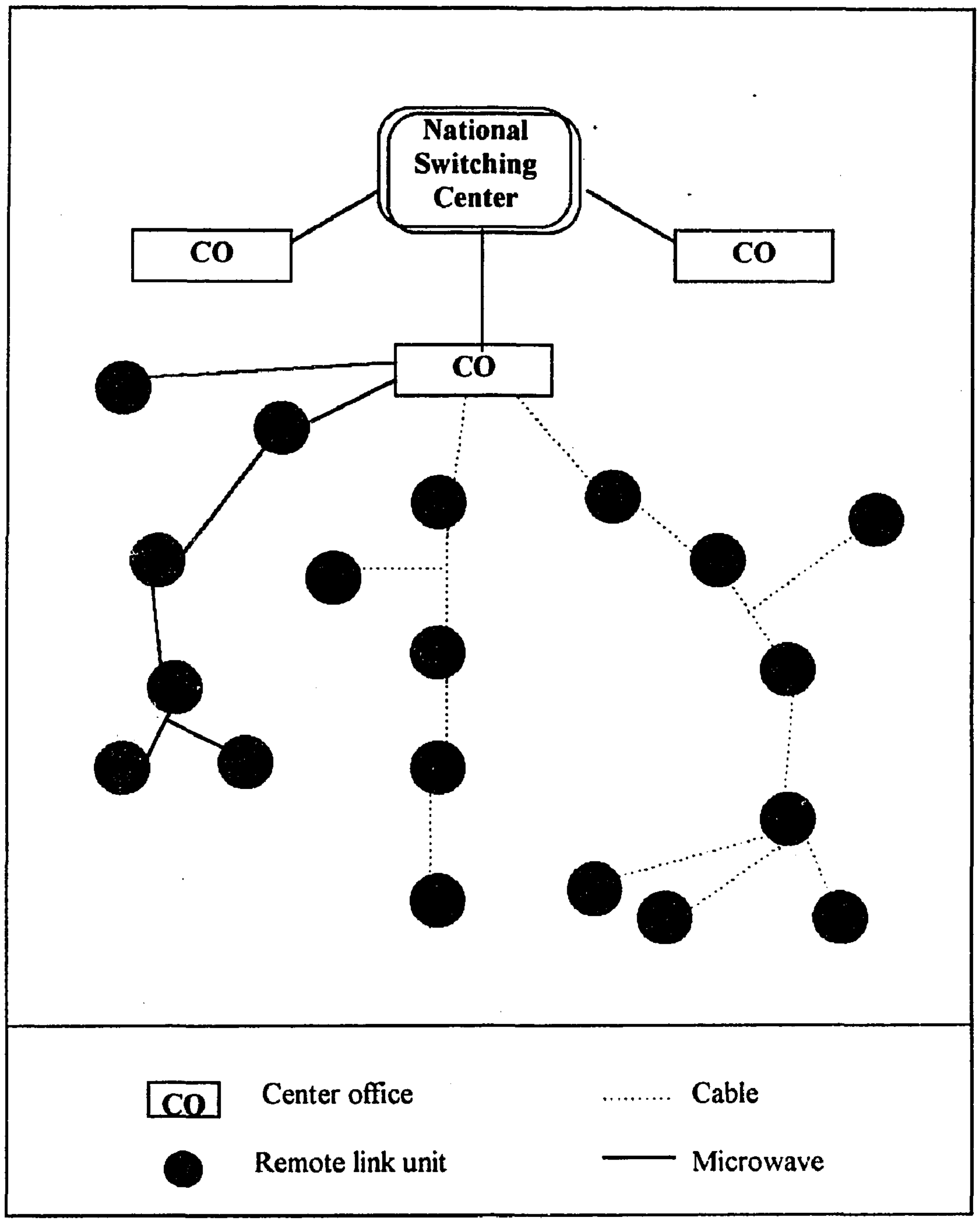
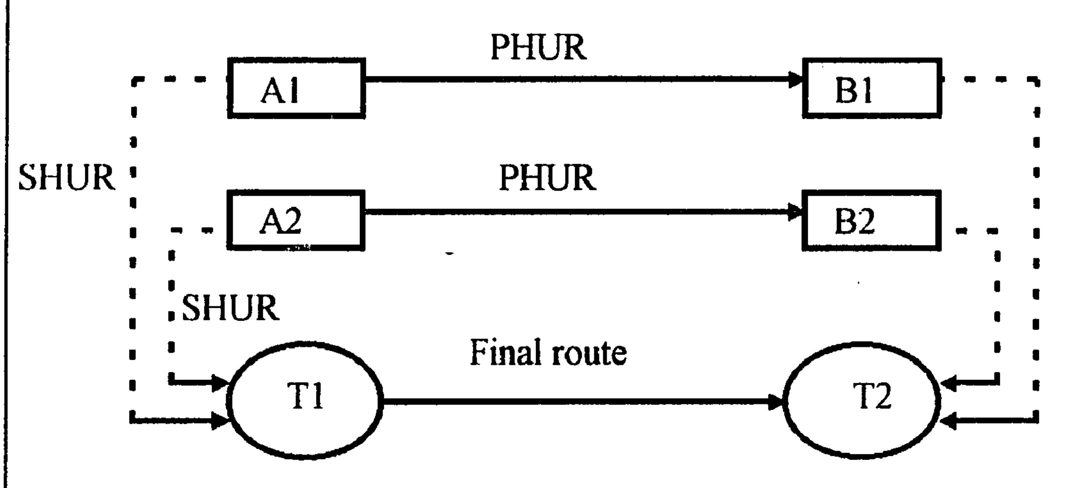



**Figure 2.5** Multidrop, Multicenter (Jordanian local network)

routes between two networks [figure 2.6]. The routing information is stored in hardware. Most public voice networks have employed this method until common channel signaling (CCS) was introduced.




PHUR: Primary High Usage Route
SHUR: Secondary High Usage Route

**Figure 2.6** Deterministic routing

## 2.3.2 Priority Routing

This method is based on stored program control (SPC) which provides a method of priority ranking traffic streams and can be particularly useful in conjunction with overflow network schemes. The network manager has control over his network to give higher priority to first offered traffic than overflow traffic. Each traffic stream competing

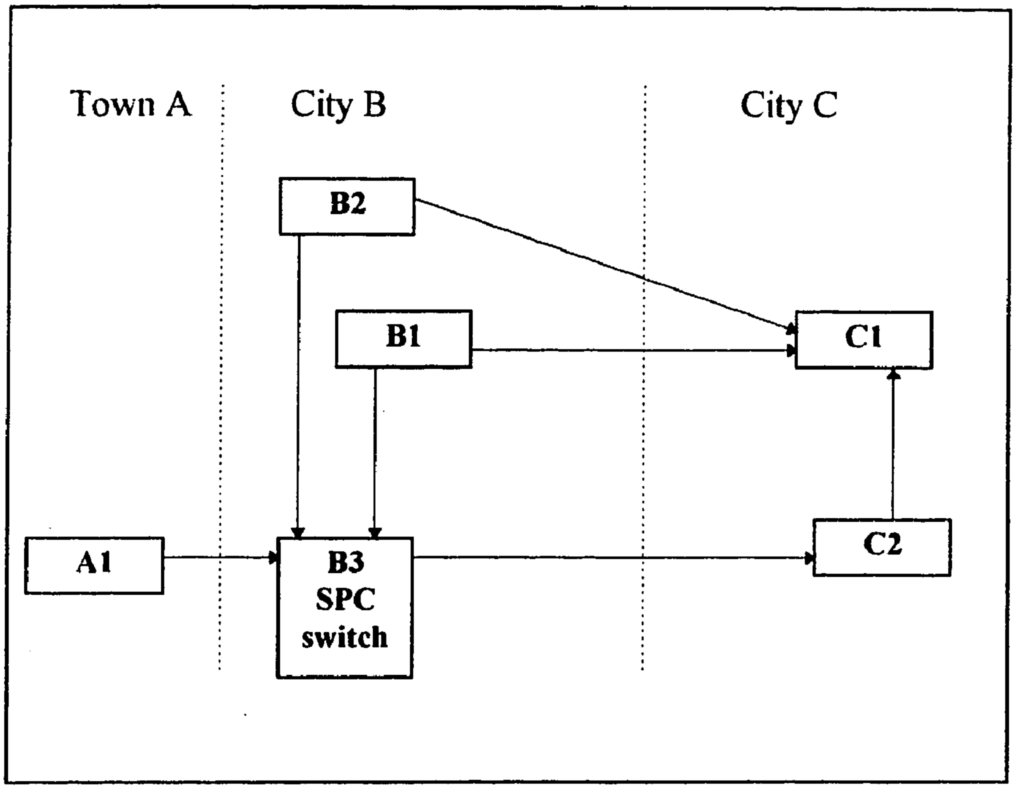



**Figure 2.7** Priority Routing

for a given route is allocated a trunk reservation value ranging from 1 to 15. The value corresponds to a number of idle circuits. If at any given moment only this number of idle circuits are available within the group, then new calls from the particular traffic stream to which the trunk reservation value applies are rejected. Each traffic stream competing for the circuit group may be allocated a different trunk reservation value. At least one stream should be given value 0 (top priority), otherwise some circuits will always be idle. In most cases, top priority is given to the original node which has a direct connection with the priority trunk. Figure 2.7 shows two large cities nodes. B1, B2 and C1 are connected to each other with a high usage (**HU**) link. B3 and C2 can be used to handle the overflow traffic as shown. Node Al in small town A has a small traffic intensity, so it is only connected to node B3. The problem here is: if Al does not have some kind of priority over B1 and B2, it may not be able to reach city C. Thus, node A1 will be given a top priority over other nodes to be able to use its trunk.

### 2.3.3 Dynamic Nonhierarchical Routing (DNR)

In dynamic routing the traffic pattern in a large network is continually changing according to the time of day, the day of the week, and so on. Adding to that the difference in time zone for international telecommunications, where the business hours in one country will be the sleeping time in another. Dynamic routing addresses all of these variables, so that it could serve the busy routes. There will be an overall saving in network resources, even though some of the individual calls might have to be routed via exchange in other time zones. Computer controlled intelligence (SPC, **CCS**) has been built into switching and trucking networks using this technique. Predetermined routing patterns can be changed many times per day based on measured and forested customer calling patterns. Three types of traffic could be handled by DNR:

1) Traffic connected to DNR switch and originated in different exchange centers.
2) Overflow traffic generated from congested nodes.
3) Through-switch traffic between exchange access networks.

The principles of switching and rerouting using DNR are:

1) Least cost routing between originator and receiver via an intermediate switch.

2) Predetermined optimal time-varying routing that benefits from idle capacity in other parts of the network.
3) Common channel signaling (SS7) being used to inform the DNR switch about rerouting information caused by any of the three traffic kinds listed above.

The network management center (NMC) frequently samples the traffic flows in the entire network, and based on the information collected, it decides which path the next call or message will follow. This method makes the network more intelligent in terms of paths employed for routing traffic. NMC has an automatic reroute algorithm capability that senses switch-to-switch overflow at certain levels. Network information is collected every five minutes to route traffic loads. The main idea behind DNH routing is that the administration and management are centralized, but the operation depends on distribution intelligence at the switches. The SPC, with signaling instructions sent to by CCS from the NMC, controls the network switching. Common channel signaling requires a separate subnetwork.

This technique is essential for large public voice networks, Intelligent networks, network management, adaptive routing, confronting, call-back queuing, and many other applications.

## 2.4 Level of congestion

Congestion in a telecommunication network appears to users who are attempting to make calls and get a busy tone or a delayed response. The problem here not only annoys the customer, but can also rapidly increase as a result of customer or equipment repeated attempts, hoping to make a quick connection by immediate re-dialing. This will increase the load on exchange equipment, which will add to the overall traffic volume.

Due to the above situations, the effective throughput of a network can actually fall under overload conditions. This makes overload worse, further reducing throughput, as shown in figure 2.8.

Figure 2.8 shows two levels of congestion in terms of impact on GOS. Point A is the point beyond which the call blocking or delay increases at a rate faster than rate at which offered load was increased. This is because the network enters a mild congestion state. This point is the final point on the curve in which the network can guarantee an acceptable grade of service. At point B, the network begins dropping frames to control the existing level of congestion and to prevent additional damage to the network provided service.

Grade of service criteria deals with the degradation in service caused by contention for critical resources when all of these resources are functioning.

The **GOS** for circuit switch **(CS),** packet switch **(PS)**, and message switch **(MS)** networks deals with the statistical distributions of the design parameters shown in figure 2.9.

The **GOS** of a **CS** is the blocked or delayed percentage of the offered traffic. The measurement of the **GOS** provided to the user, and the determination of facilities required to provide a desirable **GOS,** are based on mathematical formulas derived from statistics and laws of probability.

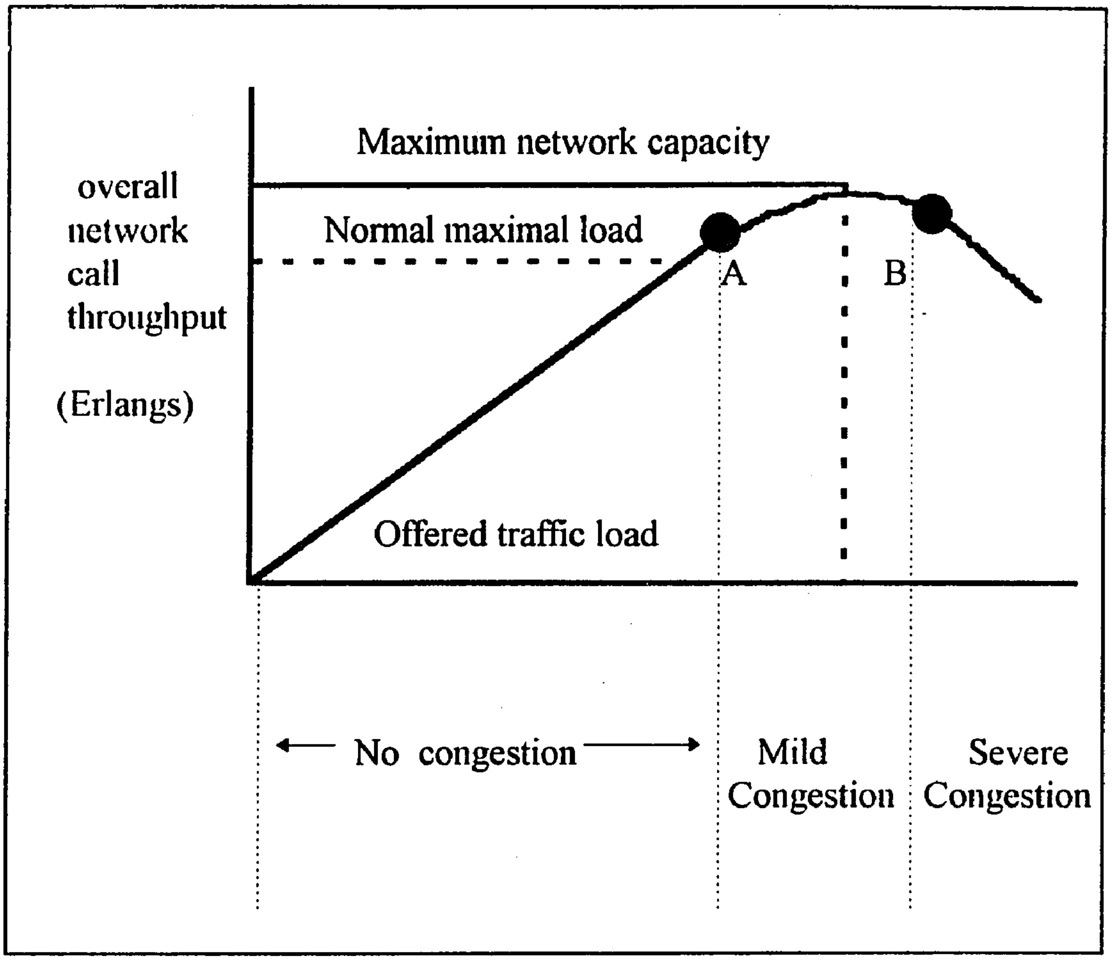



**Figure 2.8** The effect of congestion

In general, congestion creates obvious problems within the network, like reduced availability and throughput and extended response times. By balancing the amount of traffic allowed to enter a network with available network resource capacity, congestion control mechanisms will increase throughput, stability, and manageability. The importance of congestion control increases dramatically with speed and mixture of traffic in the network. A properly designed network with good congestion control delivers consistent and appropriate response times, reduces retransmission, and saves money by enabling greater utilization of resources.

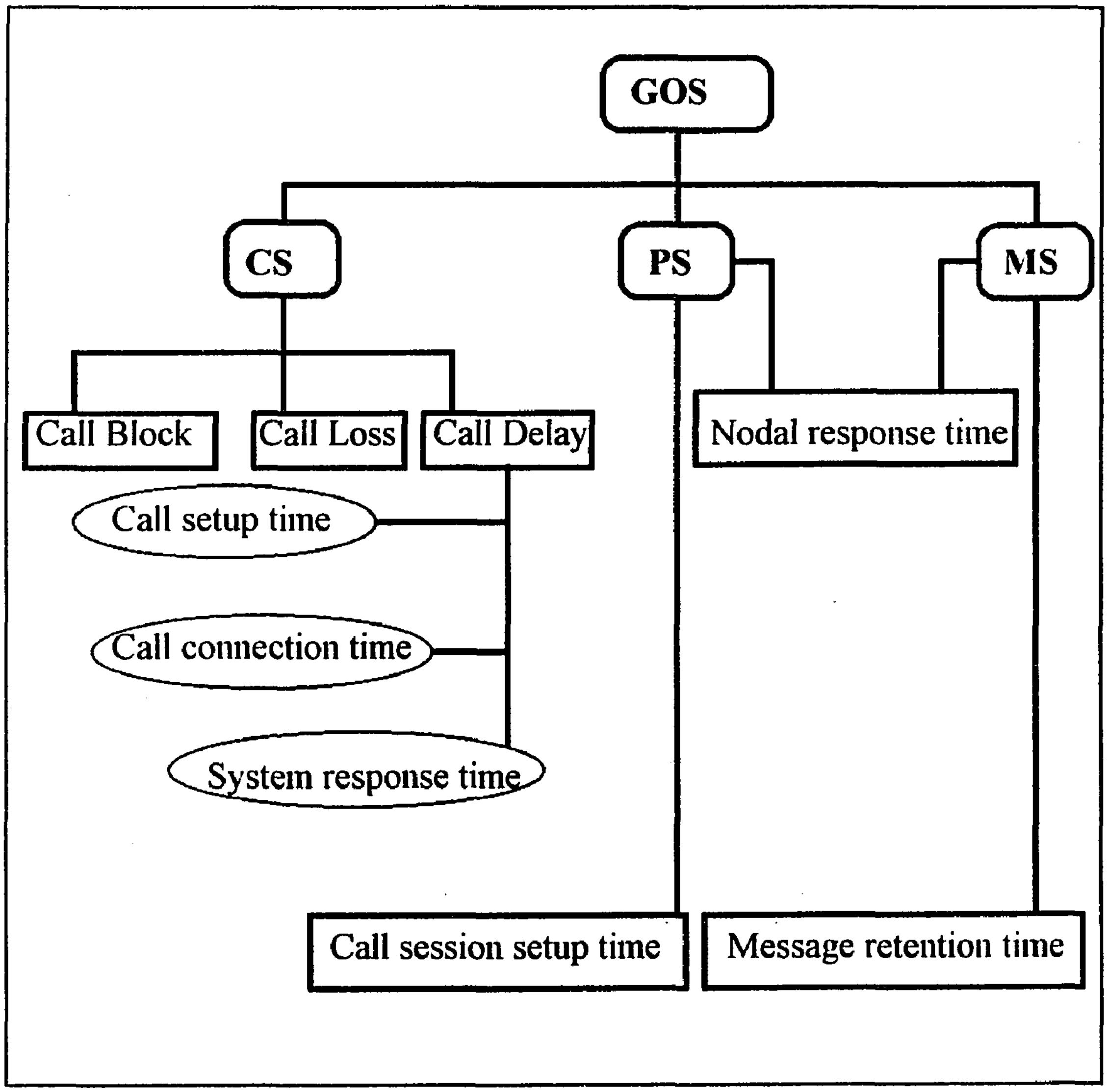



**Figure 2.9** **GOS** design parameters for **CS**, **PS**, and **MS** network systems

# CHAPTER 3

## TRANSMISSION SYSTEMS

To be able to transfer information between network nodes, a transmission medium is needed to carry the information. A medium usually carries the signal in some form which enables the receiver to translate it back to its original form.

## 3.1 Transmission Signal

In telecommunication networks, information is transferred in the form of signals. A signal is usually a time dependent value attached to an energy propagating phenomenon used to convey information. Two types of signals are used to transfer information :

### 3.1.1 Analog Signal

This is a continuous signal realized by multiplying a continuous modulating function by a high frequency carrier waveform. Bandwidth is a range of frequencies, usually specified as the number of Hertz in the band or the difference between upper and lower limiting frequencies. Since transmission cost is directly related to bandwidth, analog signals are used to provide commercially acceptable quality for telephone communications. The signals are normally limited to the range of frequencies in which most of the voice energy occurs. This range is between 200 Hz and 3.5 kHz. Analog technology is still being used even after the digital revolution reduced communication cost by providing faster transmission and extra security. This is due to the fact that most of the subscriber equipment is still analog. Data communication solves the interface problem between analog and digital signals using a modulation/demodulation (MODEM) card which can be installed in the subscriber's premises.

### 3.1.2 Digital Signal

A digital signal is an electrical signal in which information is carried in a limited number of different states. A digital line system may be designed to run with almost any bit rate, but on a single digital circuit it is usually 64 kbit/s. This is equivalent to a 4 kHz analog telephone channel.

Pulse code modulation **(PCM)** techniques are used to convert analog signals into digital format by employing the principle of sampling a continuos voice signal, quantizing the sampled values into discrete levels, and encoding these levels into a fixed sequence of binary pulses.

Adaptive differential **PCM (ADPCM)** as an enhancement technique requires only 32 kbps to digitize analog voice signals and produce voice quality. The widespread application of **ADPCM** within public networks has yet to occur because it requires special administration to handle link compatibility, signaling provision, data limitations, restrictions on the number of tandem coding/decoding points and other problems. However, the use of **ADPCM** in private networks is growing rapidly due to the great potential for cost saving and the fact that private network operators always have control over their own traffic and do not need to be responsive to random public traffic demands.

The digital transmission technology market today is growing very fast to meet the increasing demand for fully digital backbone national networks, **SONET**, **ATM**, and integrated service digital networks (ISDN). The market for this new technology is taking over LAN, MAN, and WAN networks and it is moving towards having one carrier for all data, voice, and multimedia applications. Advantages of digital transmission can be summarized as:

1. Simplicity in multiplexing and signaling.
2. Lowering of cost due to the use of Very Large Scale Integrated(VLSI) circuits and integration with digital switches and fewer repeaters.
3. Higher fidelity of information due to low distortion and additive noise.
4. Integration of many services with and without encryption.
5. Integrated management and control of the entire network.
6. Creation of a new era of Intelligent Network (IN) services and signaling systems.

As for the future of digital transmission, equipment is already being installed for rates of 280 Mbit/s and 565 Mbit/s. These rates will allow thousands of conversation to be carried in single transmission medium. Furthermore, systems with rates as high as 1.76 Gbit/s have already been tested on the laboratory bench. Meanwhile, other researchers have demonstrated that speech and other signals can be transmitted at rates as low as 8 kbit/s. This means that the 565 Mbit/s system will be able to carry more than 70,000 simultaneous telephone calls in a single cable. With the flexibility of **SONET** hierarchy, analog transmission seems to be set for an early retirement.

## 3.2 Transmission Media

A transmission medium is any material substance or free space that can be used for the propagation of suitable signals from one point to another.

The signal carried by the medium may be voice, data, network control signals, or combinations of all. cables and other media differ in the following ways:

- Bandwidth capabilities
- Susceptibility to electrical interface from other communications circuits or from unrelated electrical machinery or natural sources such as lightning.
- The ability to handle either analog or digital signals.
- Cost

Each medium has its own particular advantages and disadvantages. Although modern transmission mediums can be found in many shapes and sizes, they can be classified in two categories: guided and unguided.

### 3.2.1 Guided Medium

Twisted pair cable, coaxial cable, open wire lines and fiber optic are common guided transmission media found not only in the local loop and exchange network, but in long haul network as well. Wire is certainly the oldest and most straightforward of all mediums, yet still remains the foundation of the network.

With UTP (unshielded twisted pair, one pair is commonly used for each voice conversation. However, with multiplexing schemes it has been adapted to support 24 voice grade analog signals per pair. Coaxial cable, on the other hand exhibits useful bandwidths in the hundreds of Mhz, and certain cables are able to transmit several thousand voice channels. Because it is considerably more expensive than UTP, applications for coaxial cable predominantly require large bandwidths such as multiple channel voice, cable television, image transfer, and high-speed data networks. After

IEEE 802.3 established its 10BaseT specification, UTP cabling that complies with 10BaseT can support error free transmission at rates up to 10 Mbps over distance up to 300 feet.

Wire has several disadvantages. It is expensive, heavy, and bulky. The cost of installing and repairing long-haul wire is often prohibitive when compared with other new media. Wire is also susceptible to such environmental effects as corrosion, noise, and voltage spikes.

Optical fiber represents the newest frontier in telecommunication transmission media. These fibers are made by surrounding a high quality glass core with a glass cladding material of a different reflecting index. Plastic core and cladding materials are also commonly used. Light introduced to the core is carried down the fiber by continuously reflecting at the core -cladding interface.

Fiber optic cables are direct replacement for coaxial and twisted pair wiring. Fiber have many advantages over the metallic media. They are very thin and light, but are surprisingly strong. The optical fiber medium requires that electrical signals be converted to light signals for transmission through hair-thin strands of glass or plastic to light-sensitive receivers, where light signals are converted back to electrical signals. Optical fiber are either single mode or multimode. Single mode fibers have sufficiently small core diameters that the lightwaves are constrained to travel in only one transverse path from transmitter to receiver. Multimode fibers, with much wider cores, allow the lightwave to enter at various angles, and reflect off core-cladding boundaries as light propagates from transmitter to receiver.

Single mode fiber performance is higher than multimode fiber, single mode fiber exhibits bandwidths of up to one Ghz ore more, while multimode is in the range of 1000 to 2000 Mhz. A typical fiber can carry signals for great distances with less than one decibel per kilometer of attenuation. Repeater equipment needs to be placed only every 10 miles or more. Fibers have a wide signal bandwidth, some systems carry over 30,000 voice grade channels simultaneously. They carry no electrical current and are free from noise, ground loop effects, crosstalk, and interference. This make optical fiber the ideal choice for long haul installations. Fiber optic is expected to last for long period in telecommunication industry as a digital carrier medium.

At present fiber optics are considerably more expensive per connection than others but do find premises distribution system (PDS) application in multichannel backbone connection. where the cost can be spread over large numbers of circuits. Fiber optic has significant advantages for backbone wiring, including interbuilding connections between central and remote switch modules. This study will compare transmission cost for fiber optic versus a microwave connection for national network.

The principle advantages of lightwave transmission using fiber cable are altra wide bandwidth, small size and weight, low attenuation relative to comparable metallic media, and virtual immunity to interference. The cost of optical fiber cable competes with metallic media in WAN and MAN connections. In LAN connections, the high cost of installing transmitters and detectors out weight the benefits of optical fibers which holds them from being used in such connections.

In general, the optical fiber cable is rapidly becoming the transmission medium of choice in applications such as high capacity multichannel MAN , WAN, and backbone telecommunication networks.

### 3.2.2 Unguided Media (Wireless)

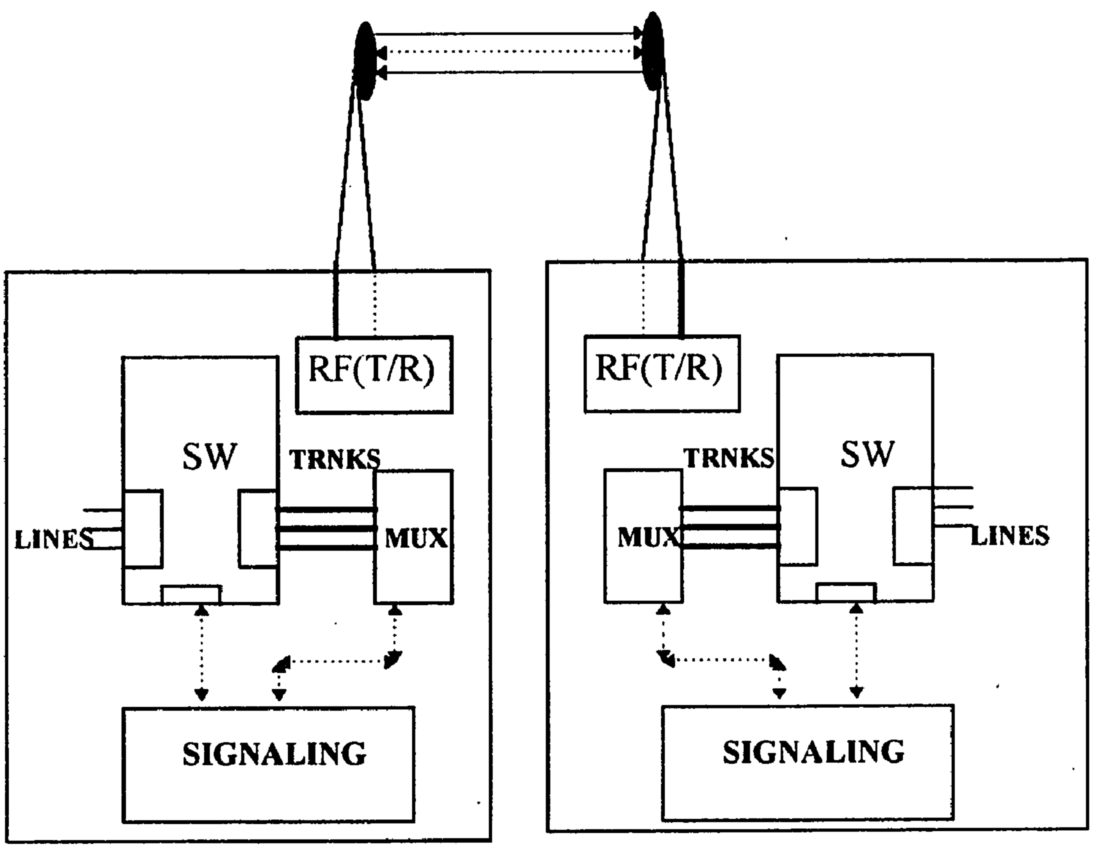
Unguided media is the atmosphere and outer space used in terrestrial microwave radio transmission systems, satellite, mobile telephone, and personal communications systems. Microwave is the name given to radio waves in the frequency above one Ghz. Terrestrial microwave radio transmission systems consist of at least two radio transmitter/receiver connected to high-gain antennas focused in pairs on each other. Microwave systems are commonly used as high capacity, point to point transmission systems in telecommunications networks, such as high-capacity trunk telephone network connections between major exchanges, or on smaller scale between buildings. The high frequency and short wavelength of microwave radio allows high capacity radio systems to be built using relatively small but highly directional antennas. The small scale yields benefits in terms of cost, installation, and maintenance.

Microwave carries are an alternative to guided metallic or optical fiber cable transmission media. There are many applications for microwave most of which are analog carriers for television broadcasting or analog and digital carriers for telecommunication. Microwave could be used locally between buildings, or as a long-haul carrier for national and international communication. Before optical fiber revolution, microwave was very effective in cost reduction. A wide variety of multiplexed signals was transmitted over microwave radio transmission systems in telecommunication networks. Microwave backbone propagation is usually used with operating frequencies 2.56-39 Ghz. This depends on the number of repeaters and the distance between them. Microwave is good to use in areas where the cost of right-of-way is very high, or in some areas where cable installation cost is prohibitive. A long distance microwave circuit has fewer amplifiers than coaxial cable link of the same length. The microwave link has amplifiers at each relay point, about thirty miles apart. The coaxial cable has amplifiers every 1.5 - 4 miles. However, as a transmission medium, the earth atmosphere creates problems not encountered with other media. Microwave transmission normally requires a line of sight path between transmitting and receiving antennas. Different atmospheric temperature, heavy ground fog, rain, and very cold air over warm terrain can cause significant attenuation or signal power loss. In addition to that, there is security problem in which all the national network could be jammed or interrupted. Figure 3.1 shows microwave connections with central office.

International telecommunication is usually carried by commercial satellites. Microwave radio is propagated from a transmitting earth terminal through free space. Commercial satellite operate in three frequency bands 4/6, 11/14, and 20/30 Ghz, which are known as C, Ku, and Ka respectively.

A communication satellite provides a form of microwave relay. It is high in the sky and therefore can relay signals over long distances that would not be possible in a single link on earth, mountains, and atmospheric conditions.

Today's satellites are more advanced than their predecessors. Compared with the Tallesat satellite ( the first international satellite launched in 1962) , which was .9 meter in diameter and weighted about 77 kg , INTELSAT's sixth generation satellite, INTELSAT VI which will serve the world's telecommunication needs in 1990s are 12 meters in height, 4 meters in diameter and two tones weight, each satellite supports up to 110,000 telephone channels.




RF(T/R): Radio Frequency ( Transmitter/ Receiver)

MUX: Multiplexer

**Figure 3.1** Microwave Transmission operation

## 3.3 Multiplexing Systems

A carrier system transmits multiple channels of information by processing and converting them to a form suitable for the transmission medium used. Many information channels can be carried by one broadband carrier system. Broadband carrier systems can be classified as either analog or digital, depending on the signal they are designed to carry. A multiplexing hierarchy is being used due to the large capacity of the carriers which can carry more than one voice grade circuit simultaneously.

In modern optical communications networks, time division multiplexing (TDM) is divided into synchronous and asynchronous time division multiplexing (STD) and (ATD).

Synchronous time division multiplexing involves defining transmission frames each of which consists of a certain number of fixed length time slots. Each transmission channel, or its corresponding time slot, always arrives at the same time during the transmission of the frame. This transmission technique is used in voice telecommunication where both parties are engaged in conversation at the same time.

In asynchronous time division multiplexing, the data stream to be transmitted is converted into information units of fixed length (cell switching) or variable length (packet switching) and transferred synchronously.

**ATM** is a transmission procedure based on asynchronous time division multiplexing using fixed length cells. These cells have a length of fifty three bytes. Five of the 53 bytes are reserved for the cell header. All the nodes in the network are connected via one or more **ATM** switches, which route the cells to their various destinations.

The fixed length cell design is the result of a compromise between the demands of analog speech transfer and digital data transmission. This means that 64 Kbps have to be carried by each speech channel every 125 micro second. Each byte in **PCM** corresponds to a 53 byte cell in **ATM**. However, the same transfer rate of 64 kbps sending only one cell every 6.6 ms. Clearly, at identical transfer rates, cell based system are limited to a significantly lower transmission sampling rate of analog signals than that of byte-oriented **PCM** systems. Therefore, to have a pure analog transfer, we need to make cell length as short as possible. A cell length of 53 bytes is still short enough for transmission of analog signals at the high **ATM** transfer rates in the megabits and gigabits per second range.

### 3.3.1 The Plesiochronous Digital Hierarchy (PDH)

Digital Hierarchy describes the various bit rates defined by the CCITT in 1972 and published in **CCITT** recommendations G.702 and G.703 for the regions of North America, Europe and Japan (table 3.1).

For the basic bit rates (E1,2.048 Mbps and T1, 1.544 Mbps), G.702 specifies a time division multiplexing structure based on 64-kbps channels to convert an analog voice signal to digital pulses.

**ATM** cell mapping techniques over the whole digital hierarchy is possible. In national networks where a high traffic density is generated, we will discuss the mapping methods for DS3. Similar mapping could be done for DS1, E1, and DS2 which have some applications in LAN and MAN.

| Hierarchy Level | MUX | North America Kbps | Europe Kbps | Japan Kbps |
|---|---|---|---|---|
| 0 | DS0 | 64 | 64 | 64 |
| 1 | DS1/E1 | 1544 | 2048 | 1544 |
| 2 | DS2/E2 | 6312 | 8448 | 6312 |
| 3 | DS3/E3 | 44736 | 34368 | 32064 |

**Table 3.1** PDH Transmission rates

A DS3 frame, with a length of 4760 bits, consists of seven transmission frames of 680 each. Each of these frames holds payload blocks of 84 bits each, separated by the frame bits F1, C1, F2, C2, F3, and C3. This provides 4704 bits per DS3 multiframe super frame for payload data, as shown in table 3.2.

A DS3 PLCP (Physical Layer Convergance Procedures) frame mapping consists of twelve rows of 57 bytes each, with the last row containing an additional trailer of 12 or 13 half-bytes to pad the payload area of the DS3 multiframe. The PLCP frame takes 125 micro-seconds to transmit, giving a transfer rate of 44.210 Mbps. It exactly fits the payload area of DS3 multiframe.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |
| **X** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |
| **P** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |
| **M0** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |
| **M1** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |
| **M0** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |
| **X** | **INFO** | **F1** | **INFO** | **C** | **INFO.** | **PO** | **...** | **C** | **...** | **PO** | **...** | **C** | **..** | **F1** | **INFO** |

7 Subframes of **680** each , (superframe of **4760** bits)
**Info.** (Information payload) each **84** bits, **4704** bits available for **PLCP**
**X, C, P, Fn, Mn** DS3 overhead bits

**Table 3.2** DS3 Frame format

The payload bandwidth for **ATM** cells transmitted using DS3 PLCP frames is 35.63 Mbps, giving a bandwidth efficiency of 79%, which means that **ATM** overhead occupies 21% of the effective payload transmission bandwidth.

### 3.3.2 Synchronous Digital Hierarchy (SDH)

The design of the SDH is mainly based on research carried out by the Bell Laboratories in America, where a transmission architecture tailored to present needs was developed under the name of **SONET** (Synchronous Optical NETwork). With the collaboration of European and Japanese standards committees, this was codified in 1988 as the **CCITT** SDH standard. The European ESTS SDH and the North American ANSI **SONET** are the two derivatives of this hierarchy. The first stage in the **CCITT** SDH is known as the Synchronous Transport Module (STM1) and consists of a frame 2430 bytes in length which is transmitted at 155.52 Mbps. The time required to transmit an STM1 frame is 125 micro second.

An STM1 frame is divided into nine rows (Subframes) of 270 bytes each. The first nine bytes of each row are occupied by section overhead (SOH), which makes the payload bandwidth of an STM1 frame 150.34 Mbps. Each byte in the SDH signal represents a transmission bandwidth of 64 kbps.

The main difference between PDH and SDH comes from their use of transparent multiplexing process. This means that a 64 kbps channel can be accessed directly from the highest multiplexed hierarchy in the SDH. In addition, the overhead structure of the SDH transmission frame was designed in such a way that it supports modern fully automated switching equipment and network management systems. One important thing about SDH is that all PDH based networks can be transmitted via the SDH network, which makes it possible to arrange a gradual transition from PDH to SDH. However, both SDH and **SONET** use the virtual container VC4 to transport **ATM** cells.

As shown in 3.3, **SONET** specifies, in addition to the three synchronous transport modules STM1, STM2, and STM3, a synchronous transport signal module

(STS1) with a bit rate of 51.84 Mbps. This is based on VC3 virtual containers which makes it very suitable for the transfer of DS3 signals.

## 3.4 Control Signaling

In order to be able to transmit information, control signals between network devices used to enable them for setup, disconnect, and control transmission. Control signals depending on the network type. Signals in circuit switches is not the same as in packet switches or message switches. Control signaling can be describes as two types: signaling between the subscriber and the local office, and signaling between switching offices.

| * STS-N LEVEL | ** OC-N LEVEL | LINE RATE (Mbps) |
|---|---|---|
| STS-1 | OC-1 | 51.84 |
| STS-3/STM1 | OC-3 | 155.52 |
| STS-9 | OC-9 | 466.52 |
| STS-12/STM4 | OC-12 | 622.52 |
| STS-18 | OC-18 | 933.12 |
| STS-24 | OC-24 | 1244.16 |
| STS-36 | OC-36 | 1866.24 |
| STS-48/STM16 | OC-48 | 2488.32 |

| |
|---|
| * STS-N Synchronous Transport Signal level |
| ** Optical Carrier Levels |

Table 3.3 **SONET** electrical and optical hierarchy.

Signaling between users and central office mostly determined by telephone unit and its human user. Each note from the Touch-tone keys consists of two frequencies, one from the group 697, 770, 852, and 941, and the other from the group 1209, 1336,1477, and 1633. Thus a self -checking code is produced with sixteen combinations. Only twelve of these combinations are used on the conventional, 12-key telephone. A 16-button dial is reserved for military communications, security purposes, and for multiple priority preemption. The ringing tone on a subscriber loops is a 20-Hz signal of 75 to 150 volts. Where the signal must travel over a carrier channel, a frequency of 1000 Hz modulated by a frequency of 20 Hz is used. The signal between switching centers, on the other hand, are entirely machine to machine signals. They are related to the multiplexing and carrier protocols that are in use. Central offices acts as a buffer between subscriber and trunks and between the trunks and their own independent, and more efficient, signaling. Between subscriber and central office, fewer signaling requirements exists. The need for cheap and reliable devices in the telephone set is the dominating factor. In national networks standardization of signaling procedures is necessary. Standardization exists within countries. However, technology is changing, and old signaling systems will have to coexist with newer ones. Many different incompatible signaling systems exist in different countries.

**CCITT** defines several signaling systems standard, the problem is that some major national systems do not confirm to **CCITT** recommendations, even the recommendations themselves give a large diversity of options in order to accommodate various existing systems.

### 3.4.1 Channel-associate Signaling

Most of national networks around the world still using this signaling techniques as shown in figure 3.2, where control signals travel with the voice channel. This signaling systems can be implemented in two ways:

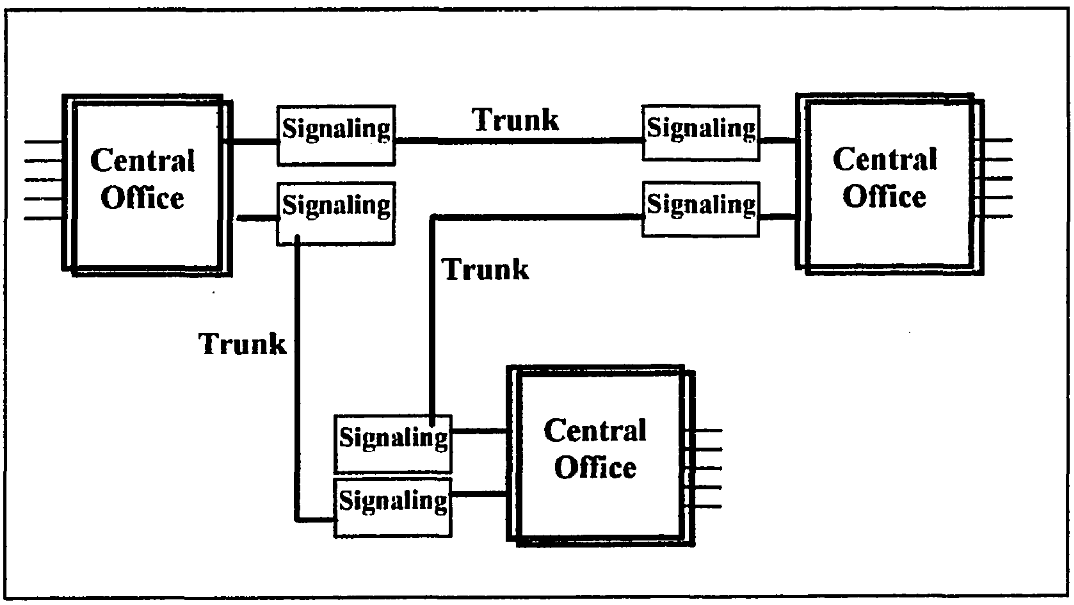



**Figure 3.2** Channel-associate Signaling

#### 3.4.1.1 In-band Signaling

Signaling between offices travel inside the voice bandwidth. This method has several advantages. The control signals can go any where the voice signals go. Therefore it can be used over any type of line plant. If **PCM** links are included in the circuit the control signals can be converted to **PCM** form along with the speech. In-band signals are not transmitted while conversation is taking place, however, the detection circuit must listen during the conversation so that it is ready to respond to signals when the call ends. The problem here detection circuit might pick up a sound as termination signal, this may happen when data sent over a voice line, the data might trigger the equipment which listens for control signals.

To transmit data we must either ensure that they avoid the signaling frequencies completely, which would limit the usable bandwidth, or that they are smeared across the band so that when there is energy at the signaling frequency there will always be sufficient energy at other frequencies to prevent the data from being mistaken for a control signal, this will make the best use of channel capacity. In **PCM** in-band signaling this problem will not occur because **PCM** links over T1 carrier employed the spare bits in voice channel which were left available for signaling.

### 3.4.1.2 Out-band signaling

An alternative , used less commonly, where channel carried both speech frequency band and a separate narrow signaling band employed a single frequency. Out-band signals has no interference with speech. They are unaffected by commanders and echo suppressers. Also signaling can take place during the conversation. However, an out-band signal needs extra bandwidth and extra electronics to handle the signaling band. Signaling rates are slower because the signal has been confined to a narrow single frequency bandwidth.

### 3.4.2 Common Channel Signaling (CCS)

In telephony there has been a gradual movement away from Channel-associate Signaling embedded in a speech channel and toward the use of a common channel dedicated to transferring signaling information for separate groups of channels. This separation is based on sound commercial and technical reasons. The use of the D channel as a common signaling channel on ISDN is an example of this approach, it was preceded by the use of **CCS** for controlling trunk circuits within the **PSTN**. The **CCS6** is the first generation of this technology. The limited capabilities of this system led to definition of much more powerful Signaling System Number 7, in the **CCITT** Q.7xx series of recommendation.

Common channel signaling is more complex than sending signals with the channel, it is a distributed computer network carrying very short messages, but as computer circuits dropped in cost it increasingly become attractive and affordable. It gives much faster signaling speeds and a greatly enhanced signaling capacity.

The **CCITT SS7** signaling systems as described in the Q.7xx series of **CCITT** recommendations. A common channel systems, optimized for digital networks, it allows direct transfer of call information between exchanges processors. This system can be installed between two exchanges at least provided necessary signaling functions between them, comprising a number of layered and modular parts, each with different function, it is a powerful general purpose signaling system capable of supporting a range of applications and administrative functions, including:

- ISDN.
- Intelligent networks.
- Mobile services.
- Network administration, operation and management.
- Its availability to be used in any new services that can be conceived.

The SS7 can be seen as a four-level system consisting of the datalink, link, network, and user levels.

### 3.4.2.1 The Message Transfer Part (MTP)

The intra network specification of **SS7** is the message transfer part **(MTP)**. It defines a connectionless but sequenced mechanism for secure transfer of packetized data between nodes, and its general are used by range if different functions as shown in figure 3.3. The message transfer part **(MTP)** is the foundation level of the **SS7**, takes care of the conveyance of messages, fulfilling signaling level functions 1,2 and 3. The level 1 function allows for unstructured but stream to be passed between signaling points (SPs) over an isolated signaling data link this level corresponds to the physical layer of the **OSI** model. Level 2 is similar to the data link layer of the **OSI** model. Flags, bit stuffing, and a CRC check sequence are used. It defines the functions and procedures relating to the structure and transfer of a signal. Message flow, and error detection and correction are included. The third level of **MTP** correspond to a connectionless network sublayer of the **OSI** model. It defines transfer of labeled packets (messages) between SPs, and also defines network management functions to control the routing and to adapt to changes in status of signaling network and there links. Route sharing may additionally provide protection against failure of **STPs** (signal transfer points) which may used to link two or more SPs.

### 3.4.2.2 The User Parts of SS7

The user parts may be used in isolation, or sometimes together. Thus the telephone user part (**TUP**) and the **MTP** together are sufficient to provide telephone signaling between exchanges. **TUP** comprises all the signaling messages needed in a telephone network for setting up telephone calls. Thus an exchange using **SS7** carries out the normal process of digit analysis and rout selection, seizes the outgoing circuit and sends the dialed

digit train on the next exchange in the connection by using the SS7 signaling link, conveying **TUP** encoded messages using the **MTP**.

The data user part (DUP), ISDN user part (ISUP), and other user parts need not be built into a pure telephone exchange. DUP is similar to **TUP**, but it is optimized for use on CS data networks. Meanwhile, ISUP used in conjunction with **MTP**, designed for use in ISDNs. It is a combination of capabilities similar to **TUP** and DUP, which allow voice and data switched series to be integrated within a single network.

The SCCP was introduced to enhance the capabilities of **MTP** in two general ways:

1) To transfer messages between any two Signaling System 7 exchanges in the world.
2) To support connection-oriented network service between any two Signaling System 7 exchanges in the world.

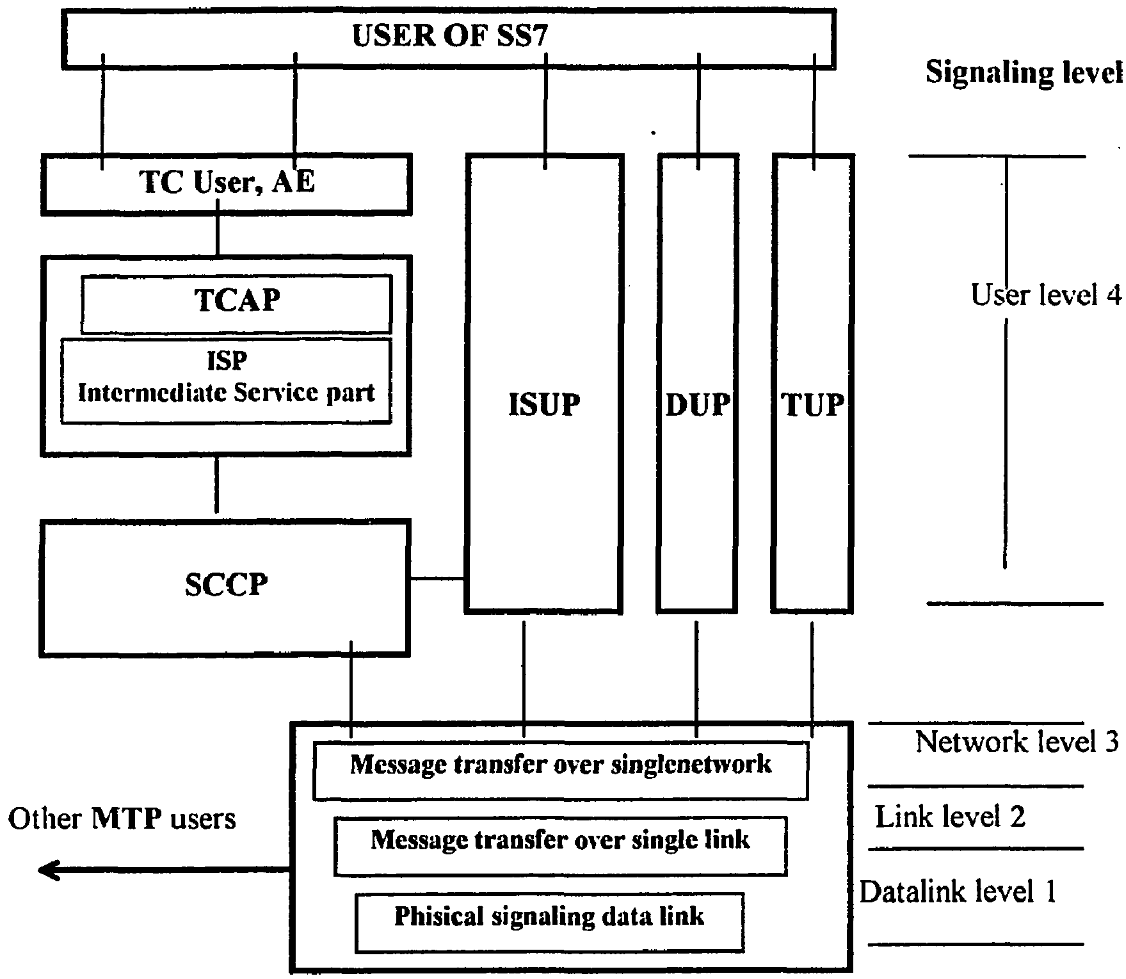



**Figure 3.3** Architecture of SS7

In intelligent networks, it is an ideal data transfer mechanism for interrogation of central database, updating cellular radio location registers, remote activation and control of services or exchanges, and data transfer between network management or network administration and control centers.

Transaction capabilities (TC) undertaking the functions of **OSI** layers 4-7. Its development has been intertwined with the development of intelligent networks. It is ideally suited for supervising short 'Ping-Pong' style dialog between signaling points, typically between an exchange and intelligent network database. Transaction capabilities exists to serve a 'TC user', called an application entity (AE), which contains the necessary functions to serve a particular application. An example of an AE of **SS7** is the mobile application part (MAP), developed to serve a particular application. It is used between a mobile telephone network exchange and an intelligent network database. Thus the mobile telephone customer's incoming and out going calls can be handled at any time. Figure 3.4 shows an international and national signaling networks taken from **CCITT** Recommendation Q.705. Same node may functioning as national and international, or may be purely national or international.

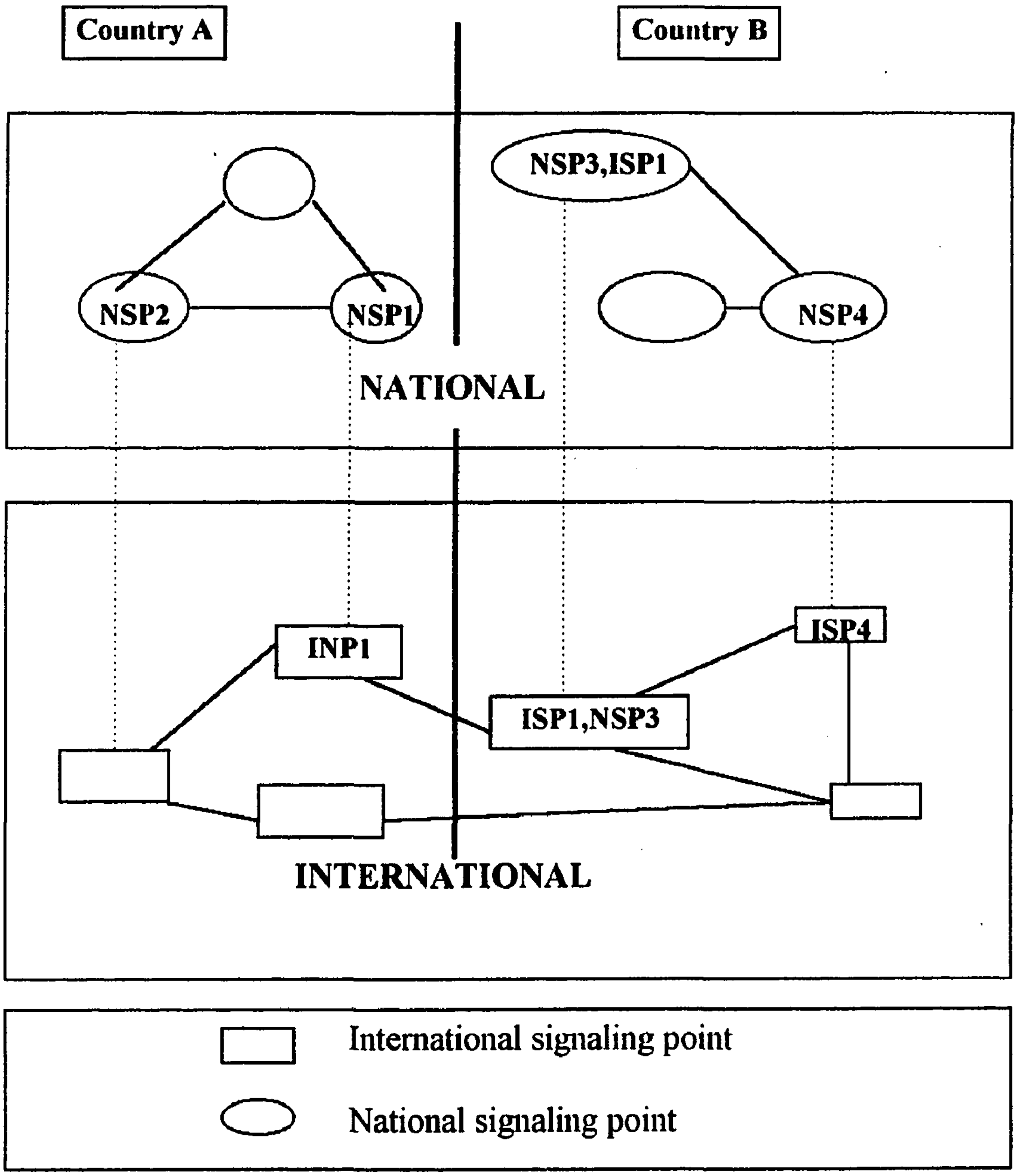



**Figure 3.4** International and national signaling networks

# CHAPTER 4

## SWITCHING SYSTEMS

A switching system is an assembly of equipment arranged to establish connections between lines, between lines and trunks, and between trunks. The system includes all kinds of related functions, such as monitoring the status of circuits, translating addresses to routing instructions, testing circuits for busy connections, detecting and recording troubles, sensing and recording calling information, and other functions. Circuit switching establishes connections on demand and permits the exclusive use of these connections until they are released. Packet and message switching is primarily used in data communications networks.

The earlier family of space switching techniques connect and disconnect physical contacts using a switch points matrix. When a connection has been established through a space switch, a permanent electrical path exists throughout the duration of the call. This technique was used for a long time before digital technology was developed.

Digital technology has some advantages in cost saving and reduced delay and congestion, adding to that signal purity which made most of the telecommunication companies replace their switches by either totally digital switches or mixed technology switches where both space and time techniques are used together. In this study, I will show a comparison between using a digital high speed switch interfaced with an optical fiber carrier and a microwave carrier.

Digital switches are designed as nonblocking devices. Therefore, only the availability of access lines or trunks will determine the grade of service.

This section gives a quick look at the architecture of digital circuit switches and the **ATM** switch. Both types of switches will be used as a part of the national telecommunication design. They will be interfaced together in a mixed technology for the backbone network.

## 4.1 Circuit Switching Systems (CS)

Circuit switching techniques used to connect a large number of telephones which have transmission paths between them. The main components of CS are:

### 4.1.1 Switch Matrix

This is the mechanism that provides electrical paths between input and output signal termination points. For small line/trunk sizes, switches can use time division multiplexing alone, while for large central offices, combinations of time division and space division multiplexing are required due to the speed limitation of TDM buses.

A digital matrix, considered as a black box, interfaces the external environment by internal **PCM** lines, either primary rate (2.048 or 1.544 Mbps) or others, operating at rates that are multiples of the primary rates. Analog lines for both subscribers and trunks, are first digitized, then either concentrated or multiplexed on **PCM** lines. All of this occurs within the exchange termination units. Switching matrix interacts with the common control, which gives it all the necessary commands, there is a flow of responses from matrix to common control. As a fundamental part of the exchange, the matrix needs to be tested and diagnosed exhaustively, efficiently, and quickly. These maintenance functions are implemented by using hardware and firmware devices which are part of the actual matrix. Typically, these devices make extensive use of processors, so the functions that they implement, can be considered as a part of the common control. The implementation approaches of switching matrices in digital exchanges make extensive use of special VLSI components, which, together with microprocessors and related memories, constitute most of the matrix.

### 4.1.2 Central Control Computer

Digital computer technologies permit the operation of a switching system to be altered by software program changes. An SPC (Stored Program Control) processor arrangement typically uses full centralized control, with independent multiple processors that can load share, and functional multiprocessing in which different functions are allocated to different processors. Over eighty percent of an SPC switch's functionality is implemented in software.

The basic components of the SPC systems are:

1) One or more high speed processors that sense input and output circuit conditions and execute stored program instructions.
2) Program store memory which contains an operating system and application software processing.
3) Temporary memory to record accumulate data during call processing.
4) Scanners through which central office control acquires input signal information such as on-hook, off-hook.

### 4.1.3 Switching Interfaces

They depend on the application the switches will be used for. Central office switches usually have lines and trunks interfaces, while tandem switches have trunks on both sides. Most existing CS are designed to handle both digital and analog signals. Some switches provide line side interfaces for multiplexed signals carried in digital loop carrier (DLC) systems. Some designs are capable of supporting direct digital connections for computers and local area network (LAN). Finally, other interfaces support administration and maintenance terminals and processing systems. The largest switches include built-in test and diagnostic capability to automatically perform basic switching equipment and loop transmission impairment tests. Digital interfaces permit data communications directly between the switch central control computer and other processors used for support functions.

Figure 4.1 shows a typical digital circuit switching system. This can be applies to all types of circuit switches (central office, tandem, or BPX switches), keeping in mind that not all the components illustrated in figure 4.1 would necessarily be implemented in all switches.

Connections in a CS data network are established in the same way as telephone connections. Once the connection is established, the data protocols in the two end terminals control flow of data across as a point-to-point connections. In order for data terminals to be able to use public CS network a hardware cards must be installed at customer premises (Modems) to convert data from digital signal to analog signal and vice versa. figure 4.2 shows transmitting data over a public switching telephone network.

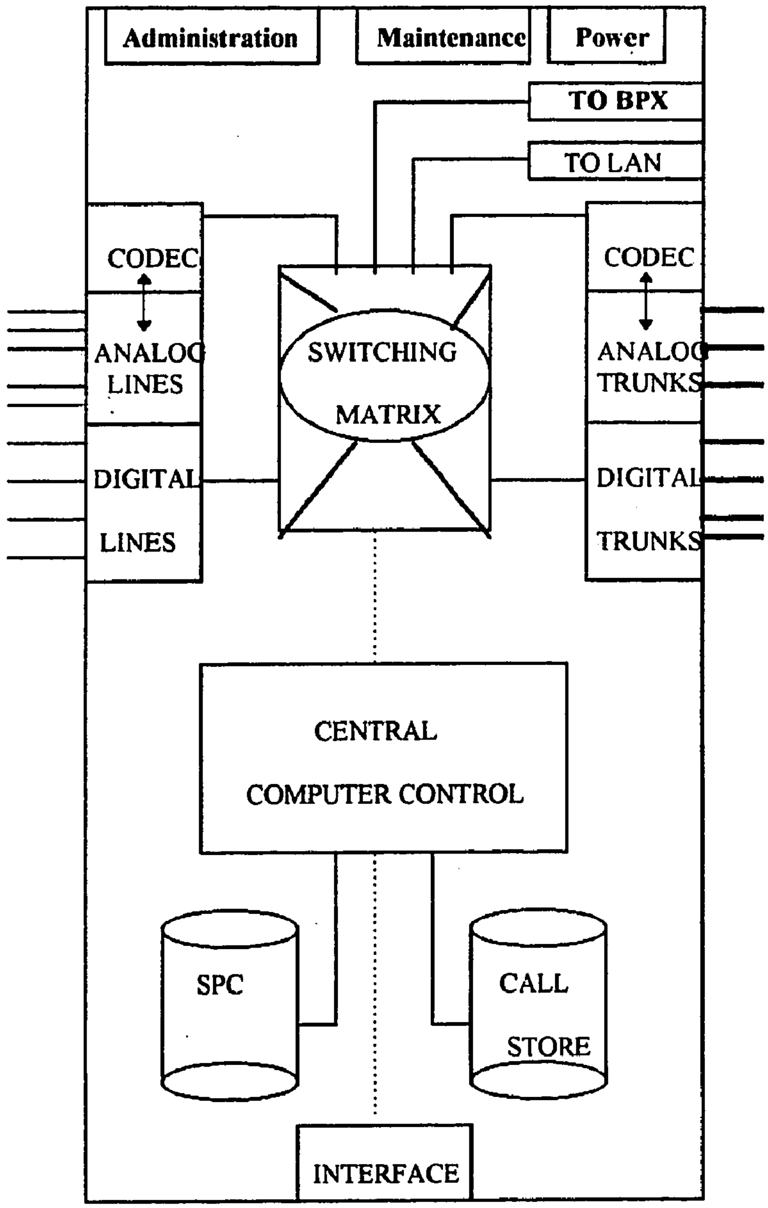
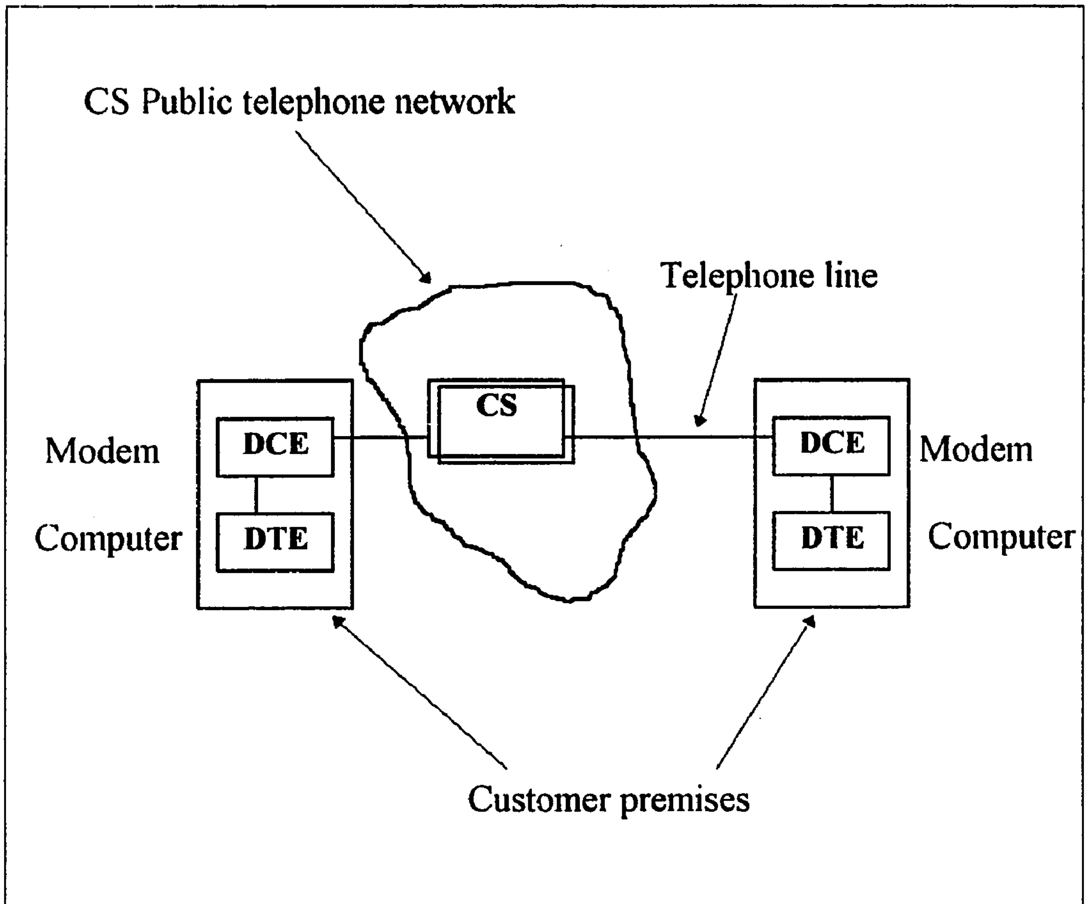



**Figure 4.1** Digital Circuit Switch

## 4.2 Packet Switching Systems

A limitation of circuit switched networks when used for data is their inability to provide variable bandwidth connections. This leads to inefficient use of resources when only a narrow bandwidth or low bit rate is required. Conversely, When short bursts of high transmission rate is required, we may have data transmission delays.




DCE: Data circuit terminating equipment

DTE: Data terminal equipment

CS: Circuit Switch

**Figure 4.2** Transmitting data over the telephone network

These reasons lead to packet switching technology which emerged in the 1970s.

The distinguishing property of CS connection is the existence of unbroken physical and electrical path between origin and destination points. The path is established at 'call' setup and 'cleared' when call 'terminates'. Conversely in **PS** networks, an entire physical path origin to destination will not generally be established at any time during communication. Instead, the total information to be transmitted is broken down into a number of smaller packets, each of which is sent separately. Each of the individual packets, even those with the same overall message, may take different paths through the network. With this flexible routing, variable bandwidth can be accommodated, and transmission link utilization is optimized. Packets are routed across the individual paths within the network according to the traffic conditions, the link error reliability, and the shortest path to the destination. The route chosen are controlled by the layer 3 software of the packet switch, together with 'routing information' presented by the network operator. **PS** gives end-to-end reliability. It is also efficient in its use of network links and resources by sharing them between a number of calls which increased their utilization.

Most of **PS** networks today adopted **CCITT** protocol standards X.25, which sets out how DTE should interact with DCE, forming the interface **PS** network. The X.75 developed for international interconnection in **PS** networks used for interconnected different **PS** networks for different countries.

A typical packet switch have the following functions:

1) Input and output buffering for temporary packet storage.

2) Processing for decoding header address, routing control, error detection, and flow control.

3) Internal switching to connect input and output buffers.

As the packet are transmitted, switches read the address and route it to the intended destination. Users receive only those packets meant for them, even though the pathway contains packets for many users. The term virtual circuit (VC) is used in conjunction with this technique, because the user sees the pathway as being dedicated, when in fact it is shared. Packet switching works well for LAN, MAN, and WAN inter networks, which often have burst traffic patterns. There are many different packet-oriented networks in the market today.

**CCITT** recommendation X.25 specifies synchronous interfaces between data terminal equipment (DTE) and data circuit terminating equipment (DCE) for terminals operating in the packet mode on public networks as shown in figure 4.3. The X.25 interface based on three levels of protocols: physical level, frame level, and packet level. Each level is designed to function independently. Frame relay, is a high speed **PS** technique providing ten times the throughput of existing X.25 networks. It is eliminating most of the state tables of X.25 and adding out-band signaling (CCS).

Applying a bar minimum of routing functions reduces the state tables required. The destination station generates acknowledgments, providing better indications of end-to-end connections and allowing timer values to be reduced due to fewer network transmission delays.

The low error rates inherent in fiber optic digital transmission media and the advances in microprocessing have made frame relay possible.

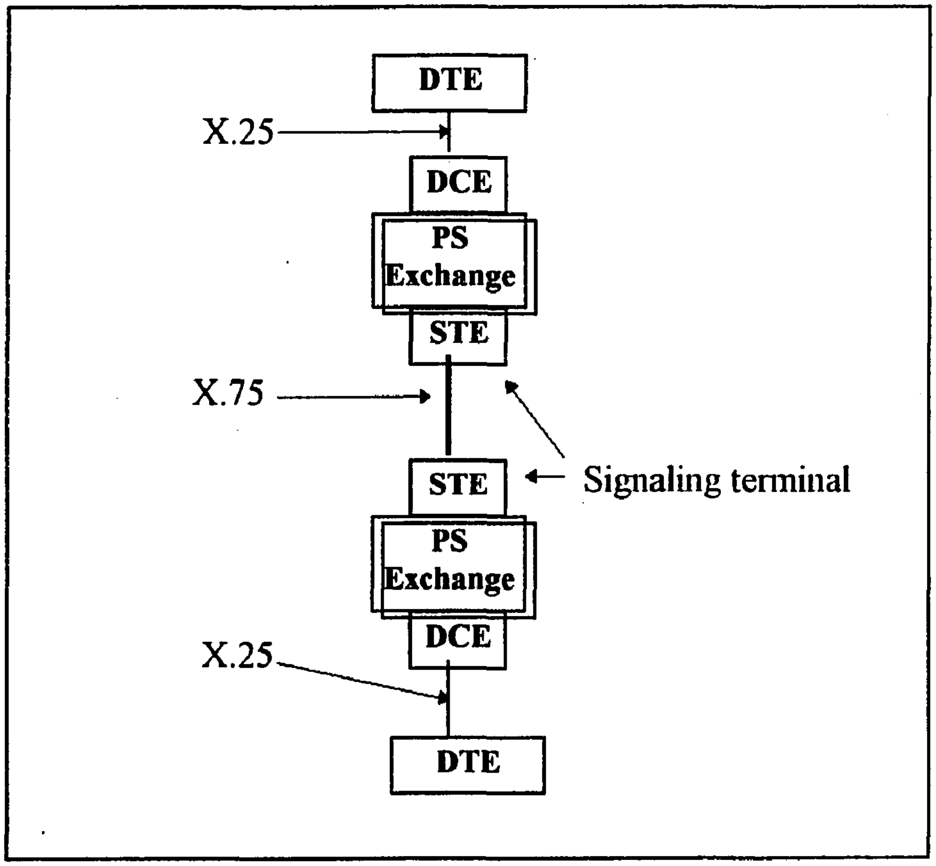



**Figure 4.3** X.25 Packet Switch connection

Frame relay and cell relay both operate in asynchronous transfer mode **(ATM)**, they offer an alternative to the traditional X.25. Statistical multiplexing of different user data stream is also a feature of frame relay, as well as not having flow control and error control. The end-user devices implement their flow control and error detection as needed.

## 4.3 ATM Switches

In the beginning of 1992, a new telecommunication technology exploded in the media. B-ISDN (Broadband Integrated Services Digital Network) and **ATM** (Asynchronous Transfer Mode) became the center of attention of communication researchers and developers.

An **ATM** switching unit has two basic jobs:

1) Identify and analyze the channel and path identifiers (VPI/VCI) in the **ATM** cell.
2) Transport the **ATM** cell from one of the unit's input ports to the output ports that take the **ATM** cell to its destination. The two main types of **ATM** switching units are:

A) Cross-connect Virtual Path switches (VP): which terminates incoming paths and transfer them along with all channels in the path to another outgoing path; and
B) Virtual Channel switches (VC) : which eliminate both incoming paths (VPs) and incoming channels (VCs) and reroute them to other outgoing paths and channels. VC switches can also can be used as cross connects, in which case the channels will pass through the switching unit unaffected.

Dynamic transmission paths between the input ports and the output ports are carried via a switching fabric, the heart of **ATM** switching unit. Switching fabrics are made of small cell-routing units known as switching elements. There are two basic types of interconnection network for switching elements: matrix structure networks and time division multiplexing networks.

### 4.3.1 ATM Switching Elements

In switching elements with matrix structure, the **ATM** cells are transported in parallel via a network lattice connecting together the inputs and outputs of the switching element. cells arrived to the input transferred simultaneously. Buffer memory is needed in both input and output ports to avoid the loss of blocked cell when output port is busy. The cycle time between two switching instants is known as a slot. Calculating the number of cells that can be received by the output buffer within a single slot time is an important factor . This factor known as speed-up factor. This factor controlled by the capacity in both output and input buffers. figure 4.4 shows the matrix switching elements.

Switching elements based on time division multiplexing the cells are either serially transferred and switched using a common high speed bus (16-32 bit) or ring structure, or the cells are written to a common central memory unit which they are read by output controllers.

Two types of cells routing inside **ATM** switches: self routing where an additional header is added to the front of the cells, containing coding for the transmission path along which the cell is to be sent, or table controlled routing, in which the length of **ATM** cell is unchanged. Before each switching element, the channel of the cell is translated into a switching-specific value indicating the destination output port for the cell at this switching element. The values allocated to the cells are defined in the connection setup and stored in tables. Self routing algorithm is better suited to large multistage architecture than the table routing method. Table 4.1 illustrates **ATM** fabric comparison between major **ATM** manufacturers.

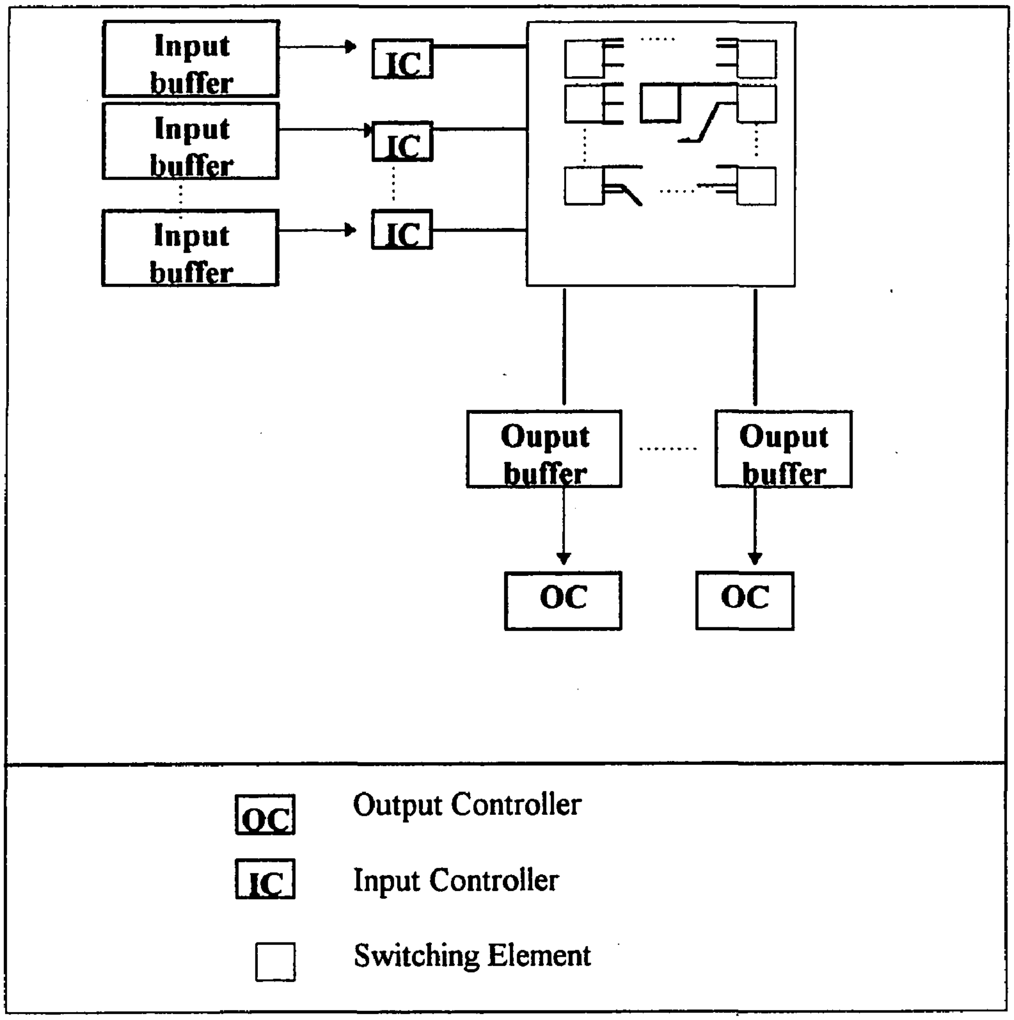



**Figure 4.4** Switching Elements with Matrix Structure

### 4.3.2 Traffic Control in ATM switches

Traffic control in **ATM** switches based on the following:

1) Management of network capacity: It is implemented by means of path management. This allow the switching requirements for the setting up of path connections to be reduced by reserving transmission capacity in paths. Channels with similar quality parameters, such as cell lose rate and cell transfer delay, should be routed over the same **ATM** path by the traffic control. If the overall transmission rate of all the channels exceeded the capacity of the path, the cell loss can be distributed over all the channels by statistical channel multiplexing.
2) Access controls: Which carried out by the network during the connection setup phase. This involves checking the user contract to see if they can access requested service.
3) Usage parameter control: The task of this function is to check that the traffic profile negotiated for the particular case and the correctness of the path or channel identifier are being maintained.
4) Traffic shaping : Allows the cell stream to be profiled so that it conforms to a specific traffic characteristics. Traffic shaping can be implemented by either the network or the user.
5) Sending congestion message to remote station asking for reduction in the transmission rate increase of congestion.

Most of the existing **ATM** switches are designed with an expandable capacity of 80 Gbps or more. An **ATM** switch equipped with a local multiplexer to support **ATM** interfaces at DS3, OC3, and OC12 with traffic policing functions. The low cost of **ATM** switches today gives a very strong potential impact to replace backbone network switches by **ATM** switches for both data and voice networks.

Note that **SONET** provides standards for fiber optic transmission and multiplexing signal structure, while permitting interconnection of different fiber and multiplexer equipment designs. Figure 4.5 is a conceptual diagram of a BISDN network arranged to support voice, data, and video customer premises services. It shows how **ATM** and **SONET** portions physically relate to each other.

The user **ATM** interface is an **ATM** adapter layer whose function is cell assembly and disassembly. Meanwhile the router function is frame assembly and disassembly.

### 4.3.3 ATM network Advantages

One of the main advantages of migration networks backbone to **ATM** is cost saving in both switching equipment and transmission, which will be shown later in this study. Other advantages of migration to **ATM** include the following:

1) **ATM** enables the creation of productive new applications and business processes, such as those involving real-time video and audio. It provides integrated transport for voice, video and data, this eliminated the need for building and maintaining multiple overlay networks for different types of data. ATM will allow these diverse communications to be consolidated in a single, centrally managed network.

2) The 45-Mbps DS3 links currently installed at most areas of the of national network can be upgraded to OC-3.

3) Increased bandwidth supports the growth in network traffic and emerging business applications.

4) **ATM** technology assures a network that can provide high performance and stability and meet global standards.

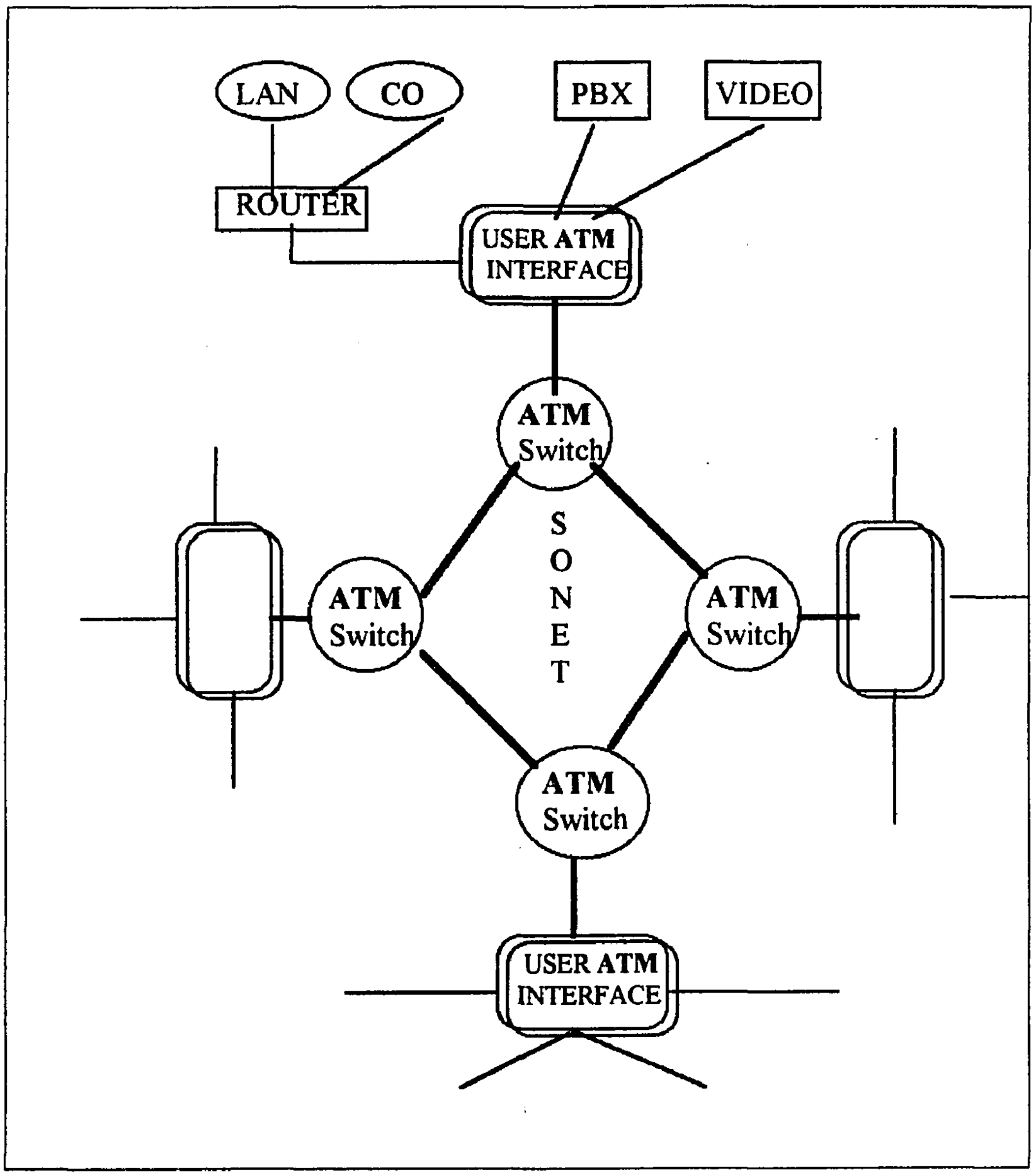



**Figure 4.5** Public or Private **ATM** Network

| Characteristic | Alcatel | NEC | Fujitsu | AT&T |
|---|---|---|---|---|
| Element type | Shared mem | Distr. mem. | Crosspoint | Shared mem. |
| Buffer type | Output | Output | Crosspoint | Output |
| Element size | 16x16,32x 32? | 32x32 | 8x8 | 8x8 |
| Architecture (growth beyond small module) | Multiplane with resequencer, 3,5-stage Beneslike | Multiplane with resequencer, 3 -stage Benes, Clos | Single plane, 3- stage Benes, Clos | Single plane 2-stage with memoryless distribution front-end |
| Max. capacity in equivalent STM1s | 128->512, 16k ? | 1024 | 1024 | 128 -> 512 1024 ? |
| Burstiness allowed | Low | Low | Low | High |
| Priority | No | No | No | Yes |
| Multicast | Yes, fabric | Yeas, fabric | No | Yes, port or service CM |
| Fabric speed (Mbps) | 150 | 150-> ? | 2400 | 2400 |
| Ports(Mbps) | 150,600, 2400? | 150,600,2400 | 150,600,2400 | 150,600,2400 |

**Table 4.1 ATM** Fabric Comparison [2]

5) **ATM** can accommodate any medium of electronic communications: voice, video, data, graphic and image to provide enough bandwidth and throughput to handle both intra and inter connections.

6) An ATM-based infrastructure will permit a mixed technology coming from multiple vendors because **ATM** standards will let the various **ATM** switches work together even if the switches are from different vendors.

7) The competitive **ATM** switch market promises attractive prices.

8) ATM can be implemented gradually, and at all levels in LAN, MAN, WAN, and national switched networks.

### 4.3.4 ATM Network Management [1]

Since ATM will be deployed throughout a network, the problem of managing ATM needs to be attacked on multiple levels. A good strategy is to begin with ATM switch management, then move on to ATM fabric management and, finally, to end-to-end management across the enterprise network.

#### 4.3.4.1 ATM Switch Management

The task of configuration new ATM switches and ATM hosts or edge devices is a prime candidate for automation. The ATM Forum has taken an important first step in this direction by defining the Interim Local Management Interface (ILMI). ILMI automates the discovery of inter-switch connections, discovers ATM-attached hosts and edge devices and completes the registration of their ATM addresses. Administrations can use ILMI to assign structured address prefixes, which will allow large, scaleable ATM networks to be deployed.

Once switches are initialized, they should be engineered to automatically load their configuration information from initialization servers. Administrators can then enforce configuration policy by controlling the information kept in a profile for a group of switches. Changing a profile in the initialization server would automatically update

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[1] McConnell J., Business Communication Review, a supplement to volume 26, february 1996, ATM-The next generation, pp. 10-11

each switch and allow large ATM networks to me deployed without the need for a comparable large staff.

Monitoring is essential for both switch and fabric management, In the near term, administrators should look for switches with port or "connection-snooping" capabilities. The ATM Forum is currently hearing proposals for an ATM Monitoring (AMON) standard, which could define how an ATM switch should copy or "steer" traffic from individual virtual connections to another location where an external analyzer awaits. The ATM analyzer would collect virtual connection statistics at very high speeds and presents the network administrator an overall view of backbone operation.

#### 4.3.4.2 ATM Fabric Management

Basic statistics are easily collected for each port or for an entire switch. These statistics must then be refined and correlated, because many virtual connections will be using each port and traversing many switches. Statistics for each virtual connection across the fabric also are needed to troubleshoot specific problems or to track service levels for reliable Quality of Service (QOS) support. Cooperation between embedded management agents and sophisticated management applications is needed for end-to-end delay or jitter and throughput measurements so these can be compared with expected service levels.

Administrators will need connection-tracing tools that find the exact physical path each virtual connection follows through the fabric. Connection-tracing must be integrated with basic statistics collection and reporting so administrators can tell at a glance if a particular virtual connection is going through congested part of the ATM fabric or find the user whose virtual connection is consuming too much bandwidth.

Routing management is another important ATM management issue at the fabric level. Connection routing functions will be distributed throughout the fabric, and the information must be integrated to provide an overall view of routing performance and to help identify problems.

#### 4.3.4.3 End-to-End and Enterprise ATM Management

Enterprise management tools need to incorporate ATM management information. The data collected by switches during configuration should be integrated with all other inventory data as well.

## 4.4 Cellular Mobile Systems

Cellular radio networks make efficient use of the radio spectrum where the same frequency channels can be systematically reused. Oriented in a honeycomb fashion shown in figure 4.6, each cell is kept small, so that the radio transmitting power required at the transmitting base station can be kept low. This limits the area over which the radio signal is effective, and therefore reduces the area over which radio signal interference can occur. Outside the interfering zone of the transmitter, the same radio channel frequency may be re-used. Furthermore when an active mobile subscriber moves through an area, the cell has to be handed-off between cell site transmissions.

One feature of cellular radio networks is their ability to cope with an increasing level of demand first by using more radio channels and more antennas in the cell, and then reducing the size of cells, splitting the old cells to form a multiplicity of new ones.

The number of channels needed in a given cell is determined by the normal Erlang formula for traffic intensity.

The total call demand during the busy hour of the day depends upon the number of callers within the cell at the time. Reducing the size of the cell has the effect of reducing the number of mobile stations that are likely to be in it at any time, which, in effect, relieves congestion.

Mobile telephone switching office (MTSO) provides connectivity to nationwide cellular telephone networks. L.M. Ericsson, AT&T, and the formed alliance between Motorola and Northern Telecom are the leading cellular switch vendors.

There are still number of problems in (MTSO) technology, like expensive cost, limited hand-off capability(when an active mobile subscriber moves throng an are, his call has to be hand-off between cell site transmissions), analog design of the system has implications for the encoding and error correcting schemes that can be exploited to improve data transmission throughput.

Digital Microcellular was able to overcome some of the analog cellular systems problems by introducing with more distributed intelligent and lower cost. This is implemented by interconnecting the base stations via optical fibers or high bandwidth microwave radio networks. The network switch connects mixed services of LAN, MAN, WAN, and public central offices using **ATM** switches.

Overall, digital Microcellular technology leads to an inexpensive switches, small antennas, and extensive hand-off capability.

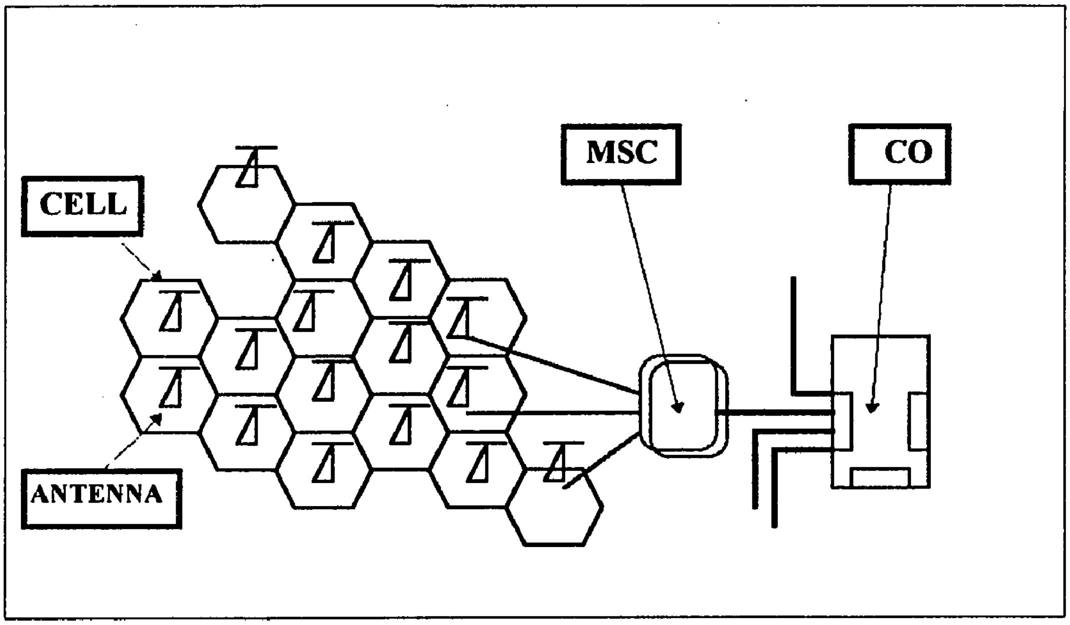


**Figure 4.6** Cellular Network

# CHAPTER 5

## NATIONAL TELECOMMUNICATION NETWORKS

### 5.1 Telecommunication Structure in the United States

An important factor influencing network performance in the US is the increasing deregulated, competitive, and market oriented nature of the telecommunication industry.

The AT&T divestiture in 1983 resulted in two main types of networks; LECs and IECs which serve two different functions. The LECs support intra-Local Access and Transport Area (LATA) traffic, and provide access to IECs and international networks via IECs. Meanwhile LECs support intra-LATA, inter-LATA, and international traffic, as shown in figure 5.1 .

Inter-LATA switched services, provided through IXC POPs, enable sharing of IXC (Inter eXchange Carrier) facilities and generate rate structures based on usage.

For both types of networks, tariffed rates are mileage sensitive and discounted during evening and nighttime, adding to that a special discount increase for the high traffic customers due to the market competition, specially between the IEC carriers. There is also an optional plan for replacing PBX networks by a private line services or IXC special contract offers under a special discounted rates.

AT&T is now a major inter-exchange carrier (IXC) sharing the market with some rapidly emerging competitors like MCI, US Sprint, ITT and others. The RBOCs constitute the local exchange carrier (LEC) part of the industry.

The amount of traffic in the United State demands higher speed and lower rates which pushed the telecommunication era forward into to meeting these demands.

Nowadays, the trend is towards LECs, IXCs, and competitive access providers offering virtual private networks and other integrated switched and private line special contract alternatives to user-owned and user-operated satellite and hub switch enterprise networks. In large networks, trade-off factors are complex and interrelated, spanning technical, management, maintenance, and financial realms. Normally, the user's focus should be first on making quality requirements, then on obtaining analysis from service providers and/or third party network design professionals with modern computer aided tools, to select the best mix of services.

By analyzing several network rates, during busy hours, lesser-cost routing among combinations of private and public network services permits large users to achieve savings and maintain good GOS in situations where the use of private services alone would have resulted in unacceptable GOS.

Figure 5.2 shows a general layout of the US Sprint Network, while figure 5.3 illustrated the hierarchical structure for the United states network with IXC and LEC carriers.

## 5.2.1 Evolutionary Aspect of American Networks [2]

Public domain communication networks can only evolve. The size and expense of these networks make even incremental changes in their functioning and administration

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[2] Syed V. Ahamed and Victor B. Lawrance, Intelligent Communication System, Chapter 6, pp. 152-159

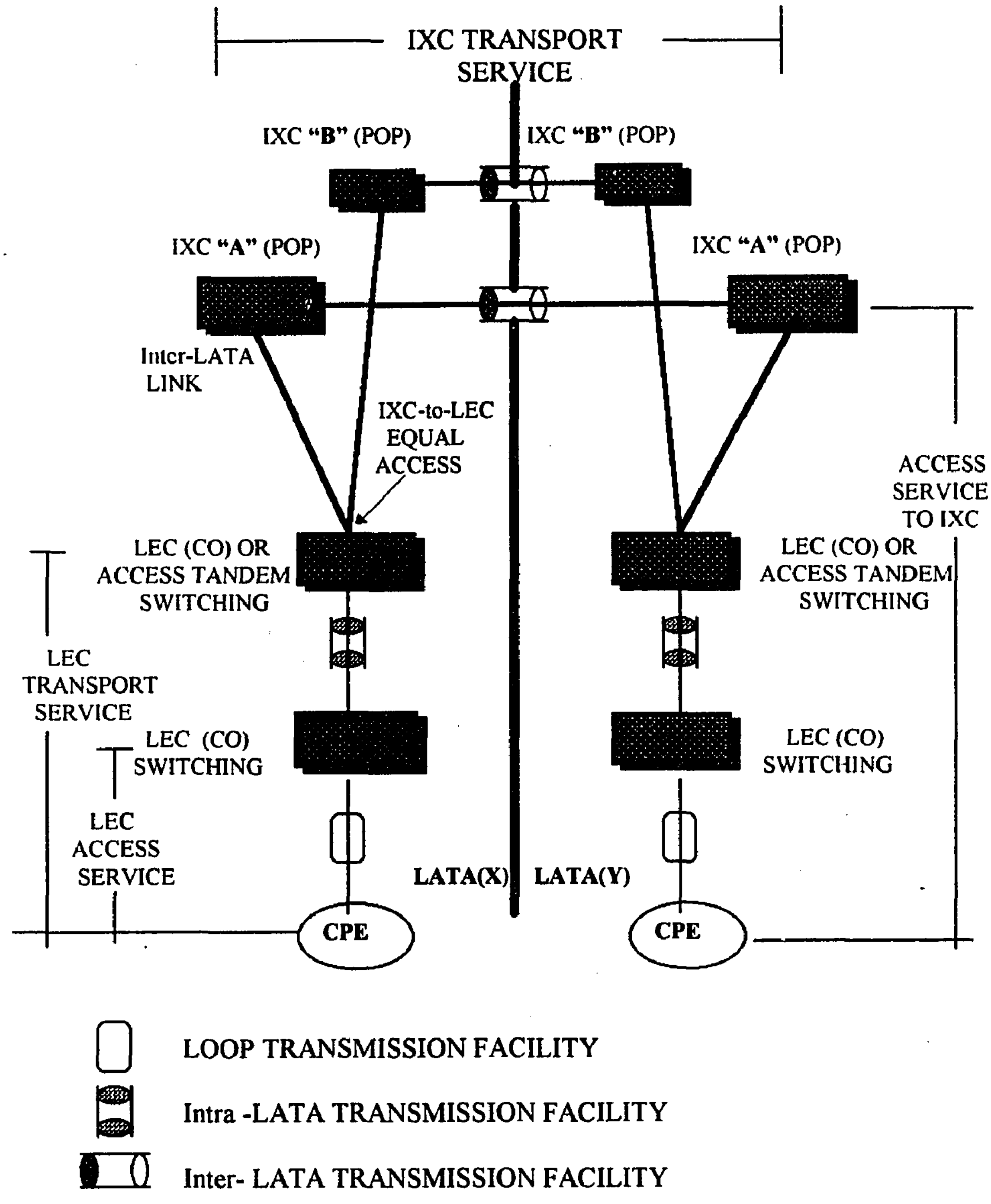
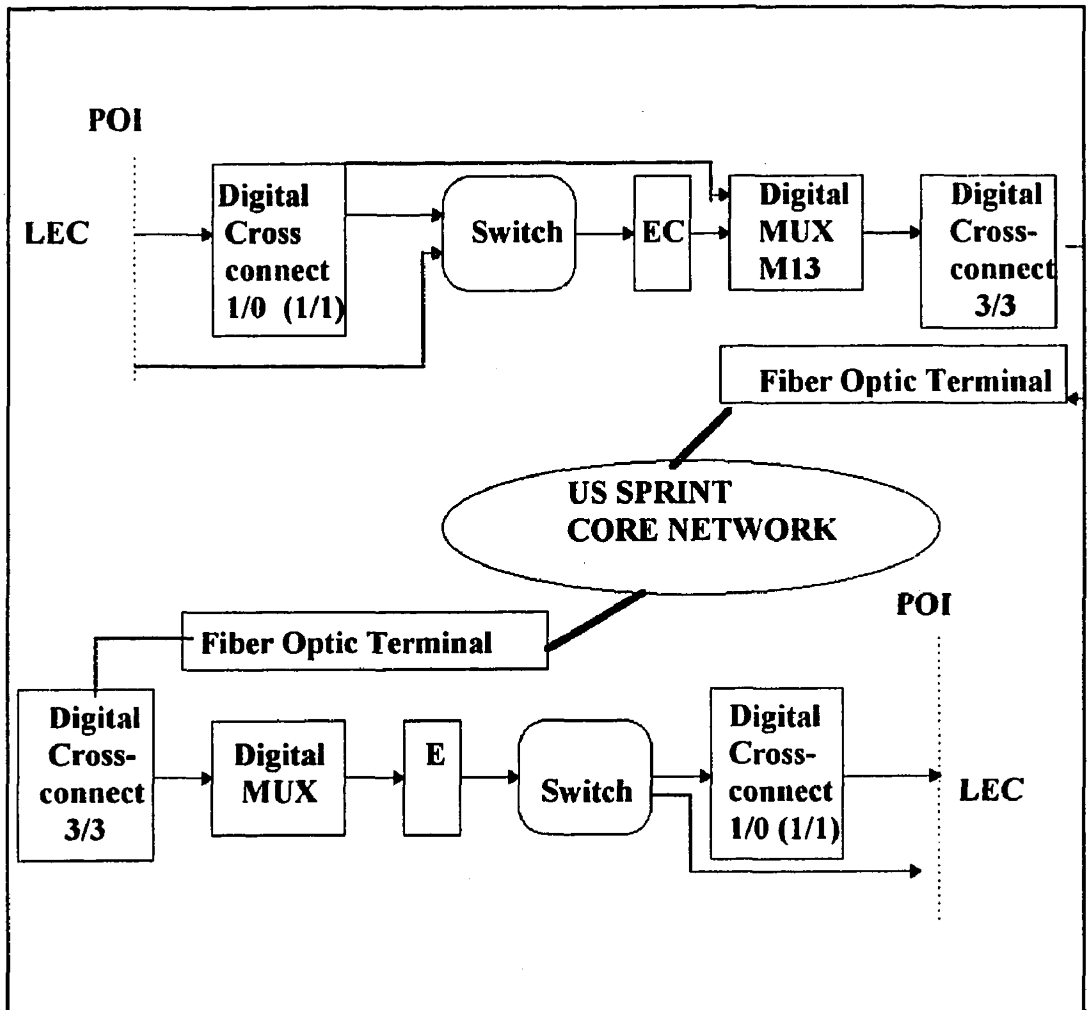



**Figure 5.1** LEC/IXC facilities and services used to complete Inter-LATA calls




EC  Echo Chancellor
LEC  Local Exchange Carrier
x= Dsx= Interfaced Digital Signal
POI  Point Of Interface
x/y  Digital Cross-connect
y=DSy=  Switched and/or Interfaced Digital Signal

**Figure 5.2** General layout of the US Sprint network [US sprint]

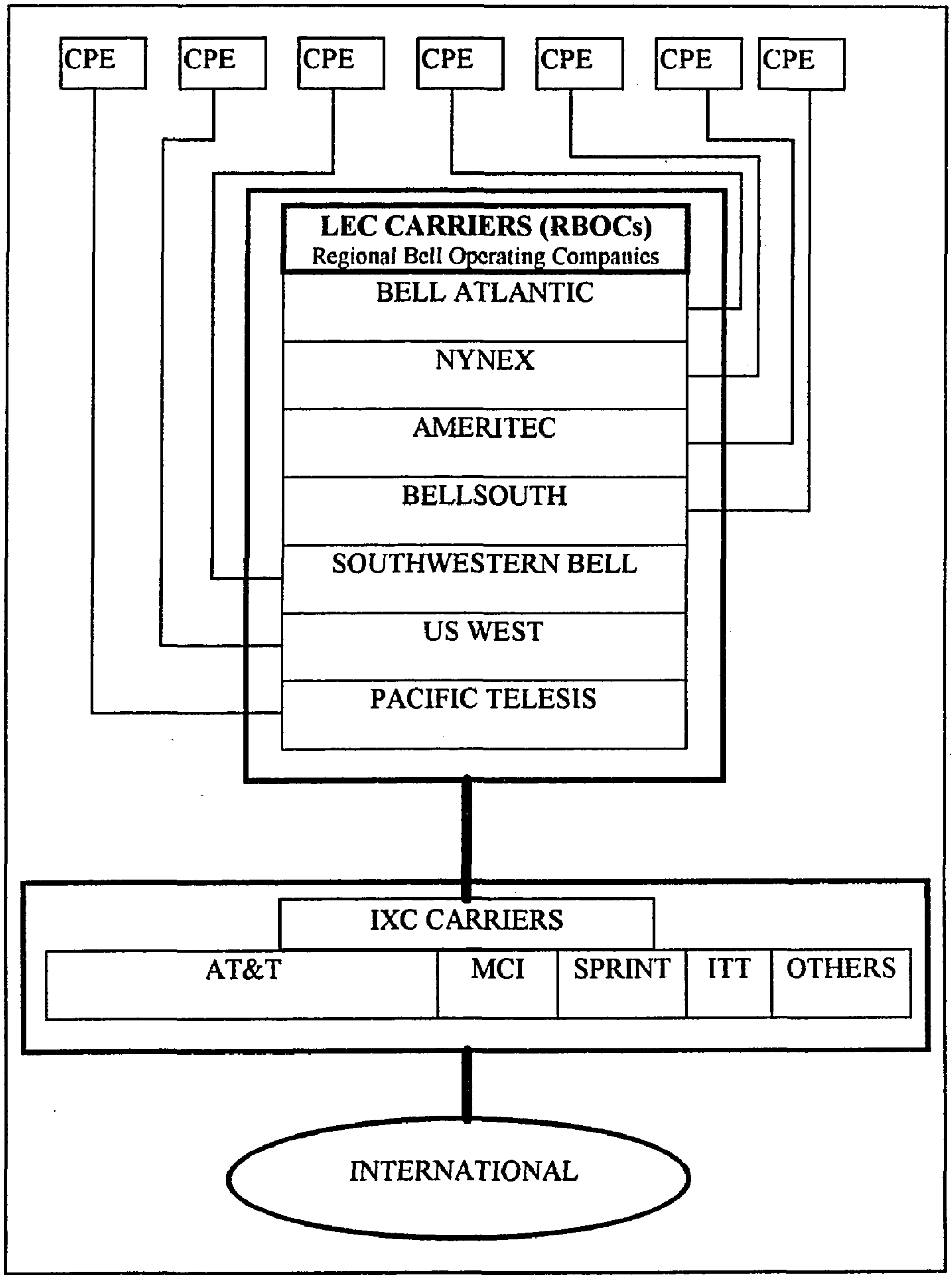



**Figure 5.3** Structure of the United states Telecommunication network

expensive and time-consuming. The American telephone network is an example of this situation. A majority of this vast national network was owned by a single organizational entity (AT&T) until the divestiture of the Bell System in 1984. This majority-ownership status prevails in most public networks.

The recent public domain Ins, which are built around standard interfaces and standard signaling systems, are able to control, monitor, and administer new services in the evolving networks. The introduction of ISDN services and capabilities is based upon the development of the existing telephone networks [and the common Channel Interoffice Signaling (CCIS) network] in the United States and around the world to provide new digital services to a large and diversified customer base. Similarly, the introduction of the most rudimentary IN (IN/1) is also based upon the development of the existing telephone network [and the Common Channel Signaling (CCS) network] in the United States and around the world to provide a layer of sophisticated, network-based, and value-added services, as well as novel information services. Sophisticated signaling capability is a prerequisite for all novel IN services.

In the context of enhancement to existing communication networks, the service-oriented networks are derived as a new architectures of information processing nodes (for example, stored program control switching system, SSPs; real-time data base facilities, SCPs) through advanced signaling systems ( for example, SS7) to provide value added service. At the most fundamental level, selected nodes are chosen and enhanced to perform more than the typical communication functions they perform in telephone systems. Those nodes are interfaced with customers providing them with more convenient, economical, and quicker services [ such as, 800 number, alternate billing service (ABS), and Green Number Service (GNS)]. At a more advanced level, the functions within the Ins are varied and dispersed, an can be tailored to the need of individual communities. The data bases can also be dispersed and tailored to provide look-up or look-forward services using quick and economical computer-based methodologies.

### 5.2.1.1 Local Switching Environments

In 1965, the first software-driven (stored program control, SPC) Central office was commercially introduced as the No. 1 ESS™ Succasunna, New Jersey. The hardware in this Central Office was not all software controlled. Numerous subsystems (such as, line-scanner, signal distributor, and central pulse distributor) are combined into a basic hardware unit to interface with the line and trunk circuits and perform local functions. They are monitored by their own program control. The switching network interconnects different segments of the communication path depending on the need and availability. This switch primarily electromechanical in nature. Because of software consideration, the No. 1 ESS switch-based Central Office (see figure 5.4) was still designed specially to handle the communication functions in real time with the dependability in (about two hours downtime) and life span at (40 years) typical Central Office. The usual switching element was the ferreed switch to make or break a signal connection at a time under high-speed centralized control. The centralized control for the first No. 1 ESS is driven by one group of programs (about 90 different ones) with about 100,000 words. With the growth and number of specific services demanded from the No. 1 ESS, the program size increased rapidly to 250,000 words of code. The program word for the No. 1ESS is 44

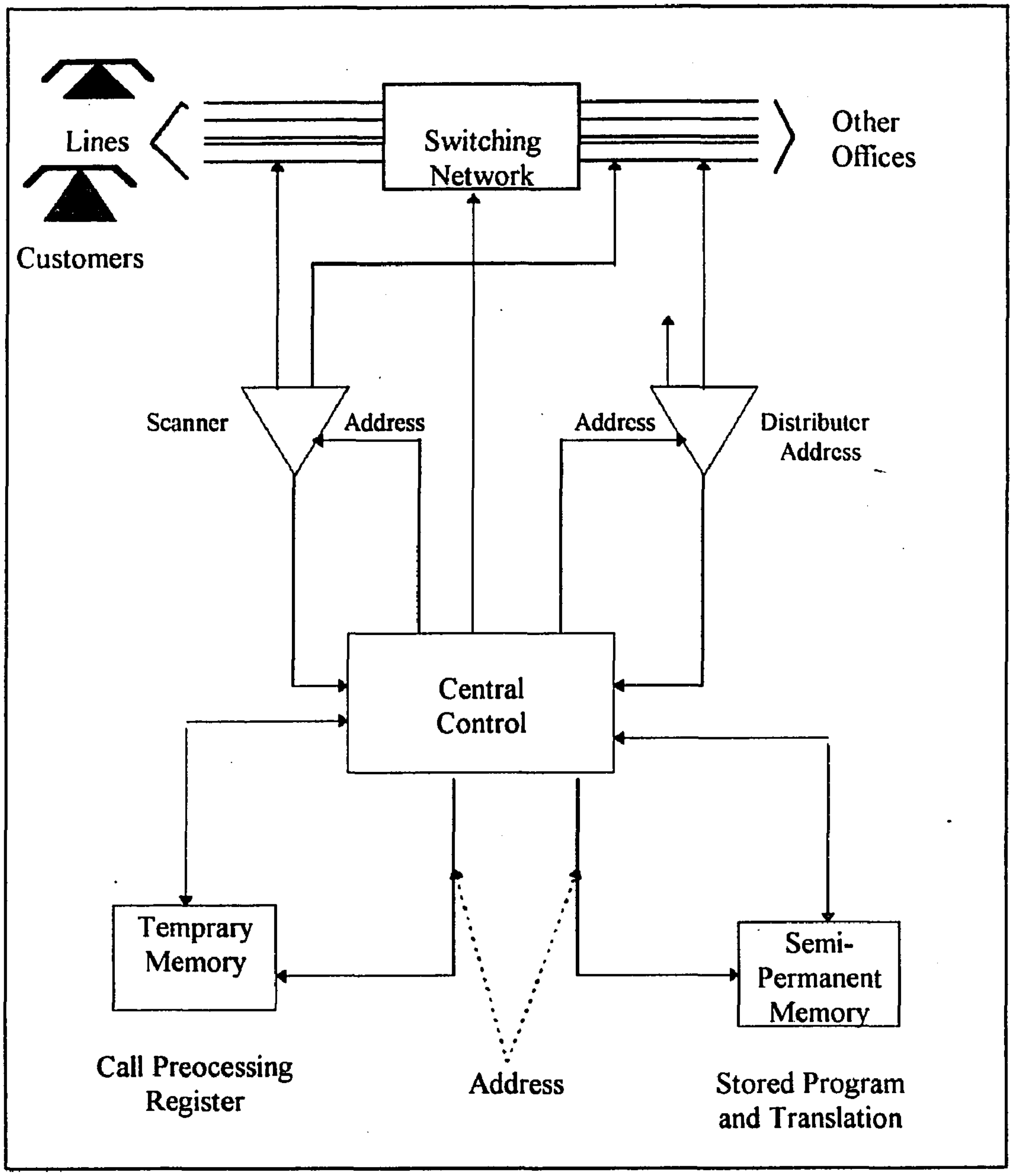



**Figure 5.4** Schematic of a No. 1 ESS Switch. Source: AT&T Bell Laboratories Record vol. 43. 1965. (June)[3]

[3] Syed V. Ahamed and Victor B. Lawrance, Intelligent Communication System. Chapter 6. pp. 155

bits (37 data bits and 7 bits for single error correcting Hamming code and parity). The program store size is 131,000 words and each generic Central Office could have as many as 12 program stores for handling as many as 65,000 lines in parallel. The cycle time is 5.5 microseconds.

Other major developments that rapidly followed the introduction of the No. 1ESS architecture to the switching systems was the No. 1A ESS switch. Integrated circuits and faster clock rates offered greater call handling capacity. This development is similar to what happened when the second generation computer systems were introduced in the late 1950s and early 1960s. Translation of operational code and software code with No. 1ESS permits growth and expansion in the telecommunications industry that is typical of the late 1960s and 1970s. The No. 1A ESS is capable of serving up to 128,000 lines and 32,000 trunks with a total capacity of 10,000 erlangs. This number translates to 36 million call seconds per hour.

Numerous other Central Offices (No. 2 ESS, No. 2B ESS and No. 3 ESS switches) where also introduced during the late 1960s and early 1970s, but the impact of the switches was not as dramatic since the systems addressed the growth and speed aspects of switching systems.

#### 5.2.1.2 Switching in Toll Environments

The electronic translator, consisting of the SPC processor No. 1, was introduced within the 4A Crossbar Toll System in Grand Rapids, Michigan in 1969. This toll system was the first system to include some of the same functions and features of computerized systems. For example, the system could have the centralized message accounting system (CAM) for local and toll billing. This system also included the peripheral bus computer (PBC) to interface to the 4A/Electronic Translator System (ETS) that monitored the system performance in service. However, the major enhancement to the system included the ability to accommodate the CCIS between processor-equipped switching systems. With the introduction of the full-fledged 4A/ETS, the telephone system was transforming itself into a computerized network for telephone systems with limited network capabilities but with a great potential to grow.

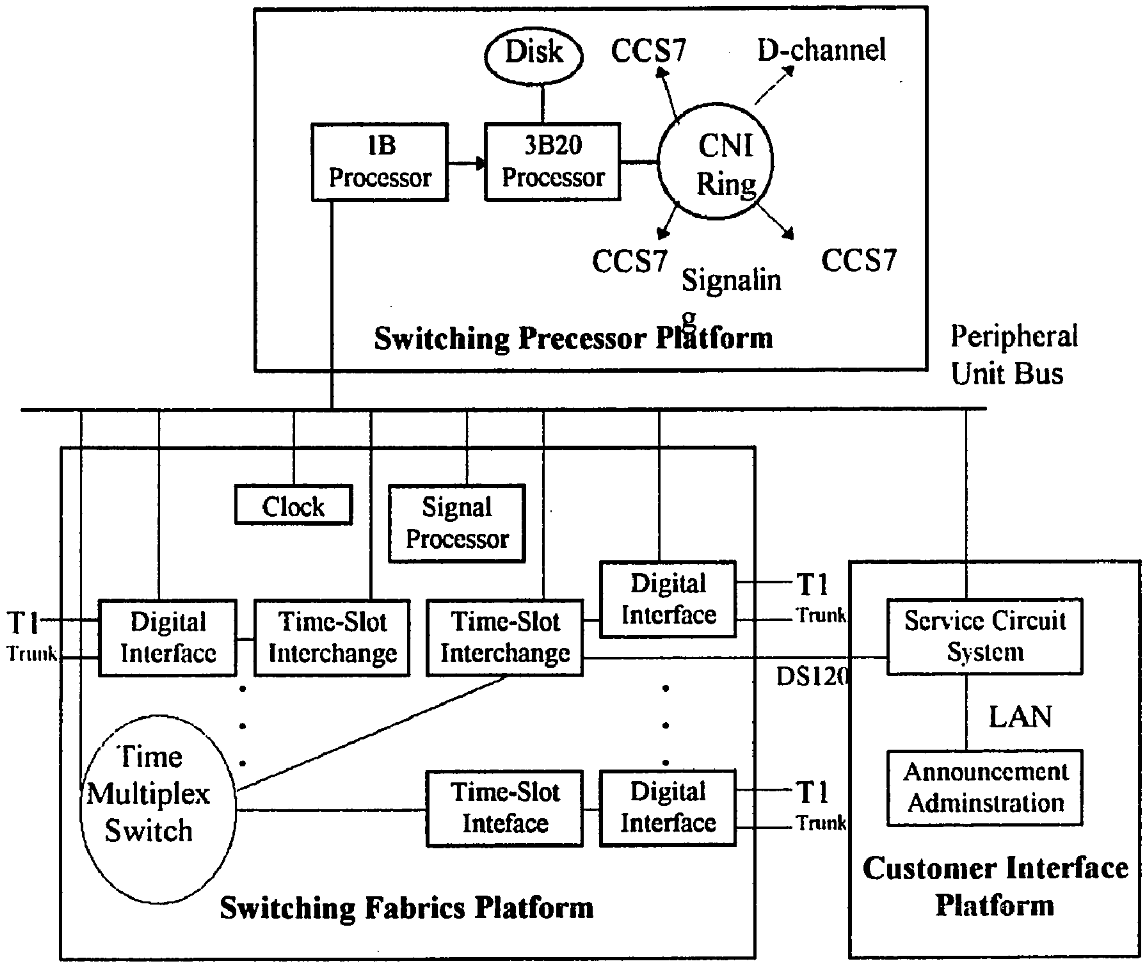
### 5.2.1.3 4ESS

The next major step in toll switching is the 4ESS toll switching system (see figure 5.5). This machine is a logical (and managerial) extension of the No. 1 ESS switching system to reduce the fixed costs and running expense, and to provide flexibility with the changing socioeconomic climate of the early 1970s. The processing capabilities for toll, the more sophisticated toll network resource and channel allocation, and the pulse code modulation (PCM) transmission and switching capabilities were also included in the 4ESS switch. The first 4ESS switch was capable of handling about half a million calls per hour with a trunk capacity of over 100,000 calls per hour. This switch provided a benchmark for the capacity and reliability of trunk switching systems.

To a degree, the 4ESS switch initialize the impact of computerized control into toll switching. This trend in the communication industry funneled in all the rewards to the digital processing and handling of telephonic information in the early stages. More recently, this same trend has evolved into networks that make any relevant information accessible to anyone authorized to receive it, at any time, and at any place with any degree of accuracy and resolution within the framework of security and the legality of exchange of information.

As a telecommunications switching facilities, the recent 4ESS switch completes as many as 800,000 calls per hour as the call attempts reach about 1,200,000 during peak calling periods. More recently, similar strides have been made in retaining the compatibility between the 4ESS switch and the more modern communication systems and networks. Typically, the existing 4ESS switch is capable of interfacing with the SS7 via its common network interface and the ISDN implementation with **CCITT** Q.931 standards. The switching platform functions with a spatial separated time-multiplex switch capable of interconnecting numerous time slot interchange units. The "B" (that is, the DS0 at 64 kbps) channel integrity is retained in this switch. Total synchronization between the switching clock and the network clock is retained throughout the 4ESS switch. In its current design, the 4ESS switch can also interface with DS3 carrier systems initially and then with the **SONET**- based transmission facilities.

The introduction of the new processor (1B) to replace the original processor (1A) in the 4ESS switch has contributed to the increased call-handling capacity of the switch. The expand volume that the switches handle is expected to increase at an approximate rate of 5 percent every year. The demand for the 800 number, cellular, fax, and video messaging is likely to remain high. Rather than replacing the switch with the newer 5ESS switch, a more economical and feasible alternative is to replace the processor. For this reason, the new processor is designed to function at a call-handling




LAN: Local area network

1B Processor: 1994 version of call processor for 4ESS

3B20 Processor: complimentary process for overall call control

CNI: common network Interface

CCS7: common channel signaling 7

**Figure 5.5** Architecture of the 1994, 4ESS Switch [4]

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[4] Syed V. Ahamed and Victor B. Lawrance, Intelligent Communication System, Chapter 6, pp. 156

capacity 2.4 times greater than that of the original processor. The speed and memory access is more than doubled. The reliability is enhanced, and operations and maintenance are streamlined. The overall switch (the 4ESS) capacity with the new processor is expected to be over one million calls an hour.

### 5.2.1.4 5ESS

The introduction of the first single-module 5ESS switching 1982 (in Seneca, Illinois), and then the introduction of the multimodule 5ESS switch in 1983 (in Sugar Grove, Illinois), started another major trend in Central Office capabilities. In essence, the integrated architecture and time division digital switching that is inherent in this machine provides for most of the distributed processing and multifunction capabilities for expanding telecommunication market. This machine offers seven distinct features:

1) It is a single system that can serve all the applications: operator, local, toll, and international.
2) It provides for digital switching between numerous subscriber loop carrier systems and interexchange carrier circuits, making the transition to ISDN easy and elegant. It also interfaces with the analog interexchange systems.
3) It has a modular approach in the hardware and software design, which permits adding newer devices as technology evolves and which allows itself to interface with the older generation switching systems.
4) Its hardware modularity permits gradual growth as the network and service demands increase. This permits a cost effective deployment of Central Office resources.

5) Being mostly digital in devices and its control, it has a reliability comparable to, if not better than, most computer systems. Extra error correction stages and parallel functionality of the CPUs permit quick and dependable retractability of any call processing step(s).

6) The computer orientation of the switch design permits local and centralized maintenance by running diagnostics in any module, combined modules, extended subsystems, or global systems. The operations, engineering, and maintenance (OE&M) functions become much simpler.

7) The 5ESS operating system, being modular and encoded in a higher language (the C language), permits Central Office capabilities to added easily. The system is portable and modular to be customizes to the particular Central Office need. New digital services (such as, ISDN) and new IN services within the SSPs can be accommodated by altering the flow control within the call-processing environment; such network services can include the detection of the trigger condition, data-base lookup in a network information data base (NID) or invoking an intelligent peripheral (IP), or exercising service logic program (SLP).

Numerous other digital switches also exists. In Europe, for example, Siemens' EWSD and Ericsson's AXE systems perform comparable functions. Equivalent systems in Japan have also been built and function with similar precision and dependability.

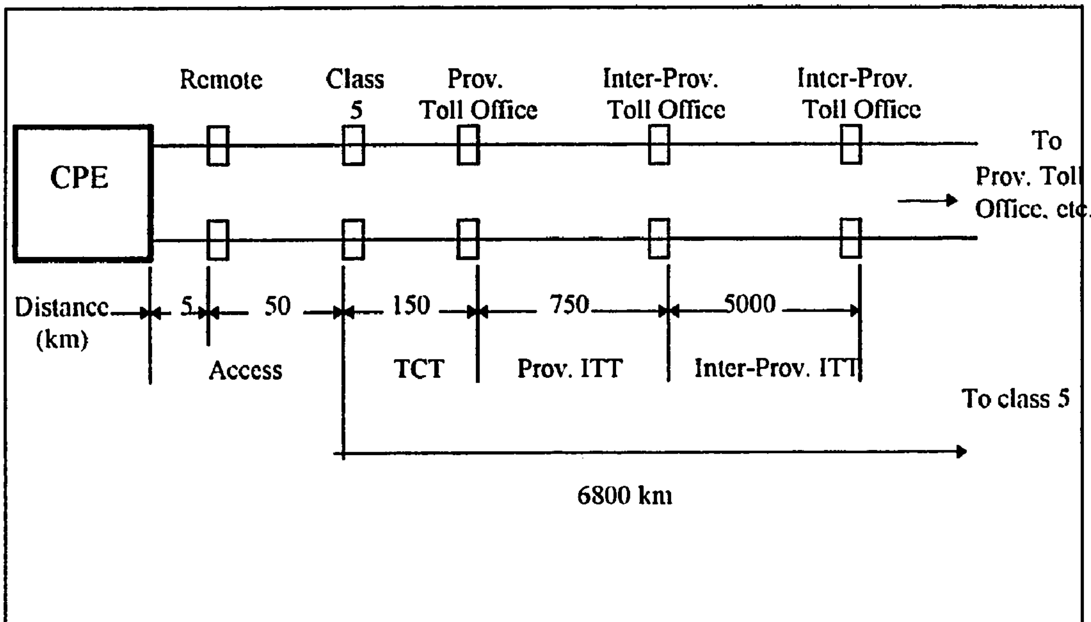
The 5ESS-2000 switch in the American environment, contends with both the ISDN and IN functionality. In addition, this newer 5ESS platform permits enhanced processing capabilities, as they exist in the IN environments, and servicing capabilities with simpler operations, administrations, maintenance and provisioning (OAM&P). Servicing capabilities include handling as many as 200,000 lines, newer remote-switching modules with line capacities of 20,000 lines, wireless services, etc. The provisioning aspects unique to most of the recently designed ESS platforms for the United States and Europe. The reliability of the 5ESS platform is better than that of most computer facilities and recorded (as of December 1994) to be at zero failure in the first seven months of its installation in eight countries.

The newer wireless networks, **SONET**, independent packet networks (such as, INTERNET, KNOWLEDGENET, or MEDINET) are going to be tied into the public domain networks. The interfacing with the 5ESS-200 permits it to perform as a totally software-driven versatile switch. The switching module (SM-2000) of this machine permits its interfacing with the fiber optic nets using the synchronous digital hierarchy (SDH), with OC-1 and OC-12 (future) carrier capabilities. At the other extreme, the (mB+nD) servicing features of ISDN make provisioning of digital services quite easy and manageable with this 5ESS-2000 platform.

## 5.2 Canadian Networks

Canadian and American networks have many technological similarities. In some cases there are significant architectural and topological differences. The Canadian national network is essentially long and thin, as in certain networks in the USA like those of MCI and US sprint, unlike the AT&T long-haul network which is more like mesh with higher connectivity. This makes the Canadian networks fall under the **CCITT** large country category.

Telcom Canada has developed HRX for voice and voiceband data services covering interprovincial and provincial intertoll trunks, toll connecting trunks, and an access network which includes remote units and CPE. figure 5.6 shows an example of a Canadian Hypothetical Reference exchange (HRX).




CPE - Customer Premise Equipment
TCT - Toll connecting Trunk
ITT - Intertoll Trunk
Prov.- Provincial

**Figure 5.6** Example of a Canadian Hypothetical Reference eXchange (HRX)

## 5.3 Intelligent Networks (IN)

The concept and the development of IN originated in North America. The major vendors behind this technology are AT&T and BROC (American Regional Bell Operating Companies). The concept is based on the premise that all services can be broken down into functional components. In the centralized intelligent network architecture, data and service logic supporting advanced network services are kept in a small number of one or more central network computers called Service Control Points (SCPs). These unites are connected with intelligent switching (SSP) points which are just telephone exchanges that have been developed to include new intelligent interfaces. The interface allows the exchange to refer call control of advanced service calls to the SCP allowing it to manipulate subsequent actions of the exchange. Common channel signaling system (CCS7) links all units where the transaction capabilities application protocol (TCAP) level of the CCS7 is used. The number of SCPs deployed in any given IN depends on a number of factors which include the complexity of the service logic required to support the advanced services, and the traffic demand for them. SCPs are connected with a Service.

Management System (SMS) which provides management and updates for the database in SCPs and statistics and maintenance for the querying node.

A concern in this topic is with IN lies in its major effect on the CO functions. IN moved telephony functions from CO switches onto multiple computing platforms. Prices for these platforms will fall from $20 million to less than $2 million in the next three to five years. This technology eliminates the need of costly, time consuming CO switch

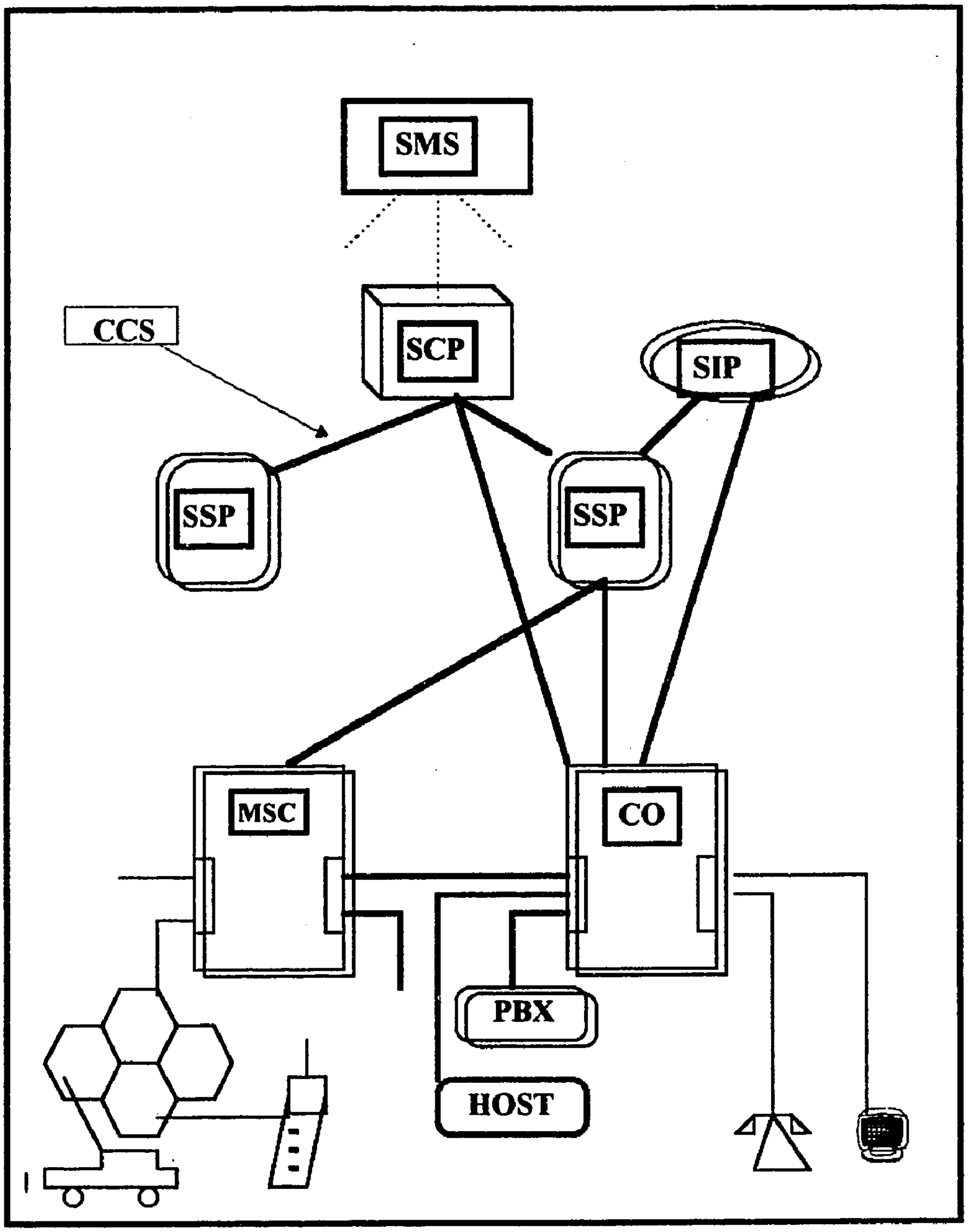



**Figure 5.7** IN Architecture

upgrades that used to be only way to provide advanced features and services. As an alternative, centralized services will store data and run the programs that will deliver IN services to widely scattered service areas. Figure 5.7 shows how the features of a national IN are connected.

### 5.3.1 American Intelligent Networks[5]

In the United Stares, major network standards, definitions, and functional devices with certain generic and interface requirements have been introduced in the past few years. Three such networks IN/1, IN/1+ and IN/2 are commonly accepted for phase introduction over through the 1990s.

There are four basic components of IN/1 as it exists in the United States. This network meets the three requirements (SPC, CCISS, and some service independence) to be classified as intelligent. The building blocks of IN/1 are service switching points (SSPs), service control point (SCP), service management system (SMS), and signal transfer points (STPs). One SMS may serve numerous SCPs, and one SDP may serve numerous SSPs.

The architecture of this network was aimed toward introducing newer service capabilities. The software building blocks of this network's SSP, SCP, and SMS were designed and assembled to permit the customers to use new specific services (800, weather, time of day, etc.) on a widespread basis in real time. The introduction of newer services is still a problem because the software modules are specific to each service and

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[5] Syed V. Ahamed and Victor B. Lawrance, Intelligent Networks: Architecture and implications, Encyclpedia of Phisical Science and Technology, vil. 8, Academic Press. 1992, pp. 230-262

have to be developed for each new service introduced. The service capabilities are also limited. Suggested architectures of more sophisticated networks (Such as IN/1+, and IN/2) to be deployed during the nineties, the SMS design philosophy will need considerable reorientation because of the enhanced service independence concept waved into the working of such newer networks.

Some of IN services were introduced by the individual RBOCs, and the concepts leading to refined intelligent networks to serve the BROCs were evolved at Bellcore (Bell Communications Research). It is here that the concepts leading to IN/1, IN/1+, and IN/2 were developed.

One of the key functions of the intelligent network also took place in 1984. The custom local area signaling services (CLASS) actually perform the intelligent functions in SPC based #1ESS central office by being able to selectively reject calls, auto recall, or callback service. Once again, the CCIS capability to relay the called party and caller information was used by programs stored in the central offices to force intelligent network response. Call-related information could be exchanged between central offices via the CCIS 6 extended message capabilities, thus providing an automatic number identification (ANI) feature between switches.

The business and/or residence customer services also introduced in 1985 permit user to use the generic programs embedded in the central offices. With access and option to exercise these powerful central office routines (such as computer system utility routines with appropriate input data) provide the customer with Centrex-custom calling, and electronic tandem switching capabilities.

Numerous developments in other directions such as billing and authorization also facilitated the commercial viability of the newly enhanced intelligent functions. While the network may functionally respond to signals and codes forward by the central offices and users, the collection of tolls and revenues for the service provided is also crucial. To facilitate this aspect, the validation of billing information was provided by authorization in the data-base administration systems distributed within the network. This facility, initially introduced for the 800 calls in 1981, also paved the way for other services such as calling card services. The human (operator) intelligence in handling the queries and call processing was gradually replaced by the programs. These programs queried the distributed data bases for authorization to connect and process calls by algorithmically decoding the long strings of digits to the called numbers through the networks.

The concept of call routing was also introduced as far back as 1981. The CCIS 6 provided the 800 service facility to respond to these calls by matching the location of the user with the nearest or most logical service provider. Intermediate data bases to provide the routing information were distributed throughout the network. Thus, the functions of obtaining the appropriate authorization, call routing, switching, and finally billing where all streamlined into one programmed and streamlined network operation.

The introduction of common channel signaling system 7 (CSS 7) by CCITT permitted the eventual integration of the numerous facilities under one common conceptual and architectural umbrella. By and large, this CSS 7 becomes central in streamlining the flow of information between three basic modules, SCP, SSP, and the TAO (tandem access office) of most intelligent networks.

In addition to the usual communication functions that the networks need to accomplish, these services also performed the specific task of translating user requests for services and connections to network command by accessing a network control point embedded within the network itself. Thus more and more of the functions were being automated and programmed to bring the conventional intelligence or adaptability within the network.

AT&T recognizes the need for International standards coexisting with national implementations. In IN/1+, the use of intelligent peripherals to interface the intelligent networks of the BROCs and/or other intelligent nodes in provisioned.

More recently, an extension of the widely used switched capability prevalent in the United states, a feature-rich service environment, universal information service (UIS) has been proposed. Most of the features of the intelligent networks, such as virtual private network, 911 public emergency service, automatic calling card, and televoting 900 services, can be included in the UIS. The user's need for critical, accurate, and quick access information to enhance productivity are addressed in the design of the network. The blending of voice, data, video, and image services will become available in this environment.

### 5.3.2 European Intelligent Networks

The European IN closely follow the Bellcore IN/1, IN/1+, and IN/2 models. Vendors whose products follow an evolution strategy consistent with the modernization plans of the various countries in Europe are most likely to be chosen as a supplier of telecommunication products to that country.

British Telecom established two business divisions: The national networks (NN) which plan and provide both the traditional POTS and specialized services, while the Local communication services (LCS) is responsible for the local exchange network.

The intelligent network deployed by the British Telecom DDSN ( derived digital service network) is quite similar to the American IN archetecture. DDSN supplied and installed by AT&T to provide full intelligent network capabilities to the United Kingdom. Initially DDSN supported the freephone (0800), premium service (0898, and other service that ASDN (analog derived services network) supported with enhanced network management and customer features. Advanced service features been added as: routing services, call prompter which the caller to enter more information that the network requires to complete call processing, call queuing, and other features similar to the US INs.

British IN has four NCPs (network control points), two NETSTARS(network subscriber transaction, administration, and recording), two NSCXs (network services complex), and one MFOS (multi-function operating system) connected to the DDSSCs (DDSS centers) to provide a wide range of intelligent network services.

The NCPs are connected by CCITT X.25 data links to NETSTAR. Administration access to NETSTAR is through CCITT V.24.

Most of other European countries have similar INs network with a slightly differences in some service and number of INs elements depending on the geographical and demographically factors.

## 5.4 JORDANIAN TELECOMMUNICATION NETWORK

The communication network in Jordan is one of the moderate systems in the area, but its services account for a limited population and do not accommodate the population growth. The latest large improvement was during the five-year plan (1981-1985). The total population of Jordan is 3.7 million, where the national telecommunication network capacity is 321,978 covering 318 thousand subscribers. There are more than 150,000 applications waiting for new line services, which is around 50% of the existing capacity.

In the network, 68% of telephone exchange capacity consists of digital SPÇ equipment with 203,000 direct exchange lines (DELs) in service.

The Greater Amman metropolitan area has 41% of Jordan's population and about 65% of the exchange line services .

The national and regional backbone routes, which are part of the Jordanian long distance network to Saudi Arabia, Iraq, Syria, and Egypt, implemented using digital Microwave links.

International services are provided through two standard "A" satellite earth stations working with the Atlantic and Indian ocean Intelsat systems, and one earth station working with the Arabsat system.

The national network is a three level hierarchy (RLUs, Primary, and Transit) corresponding to level zero to two, as shown in figure 5.8. The two transit centers NSC and ISC are located in the capital Amman. Both centers are French made E10-B and MT20. They have been in service since 1985. These two centers are connected to all exchange centers via direct high usage routes. The topology of the national network is mesh shaped in Amman, and a star in the rest of the country as shown in figures 5.9 and 5.10.

The Jordanian national network is owned and operated by the governmental telecommunication corporation (TCC). A new project will be implemented this year to sell 49% of TCC to public share holders. Another significant step taken this year is the cellular phone network, which is owned by a private Jordanian company. The cellular network is functioning now, but the subscription charges still high compared to those of other countries.

### 5.4.1 Amman Metropolitan Area

Due to the percentage of population in the Amman area, and because most of the national and international trades are centered in its area, we can see that more demand for service enhancement is required here.

Amman exchange centers are connected by an 8 GHz microwave in a mesh network as stated before. Coaxial cable connect the ground satellite station with the international switching centers.

Subscribers growth in the Amman area over the period 1980-1984 is shown in figure 5.10. Traffic growth for that period, as computed from the data in the figure is only 6%. This factor is controlled by the availability of service. Therefore, if the service becomes available per demand, traffic growth will reach more than 10%. This growth

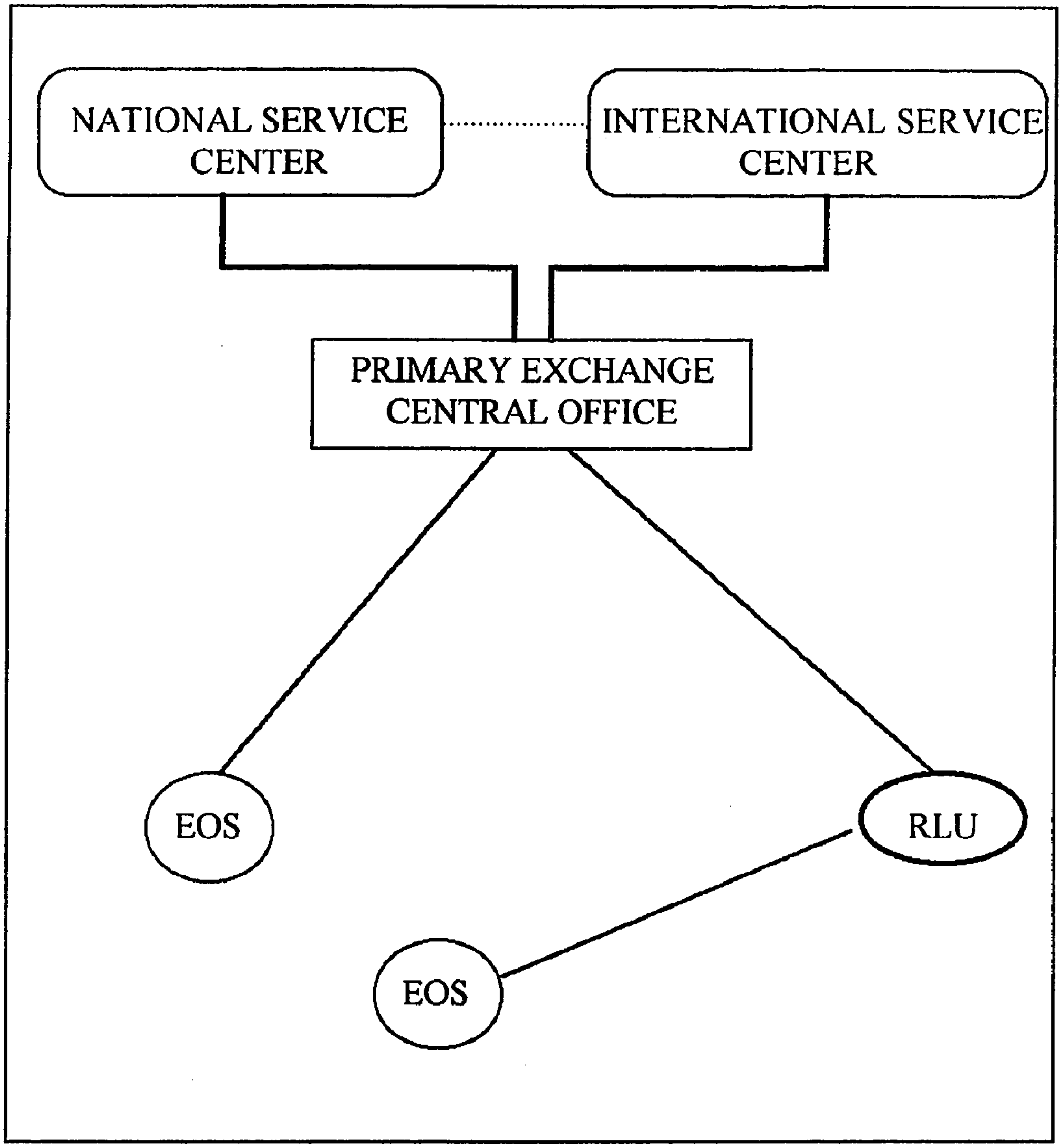


**Figure 5.8** Switching and routing hierarchy for the Jordanian public network

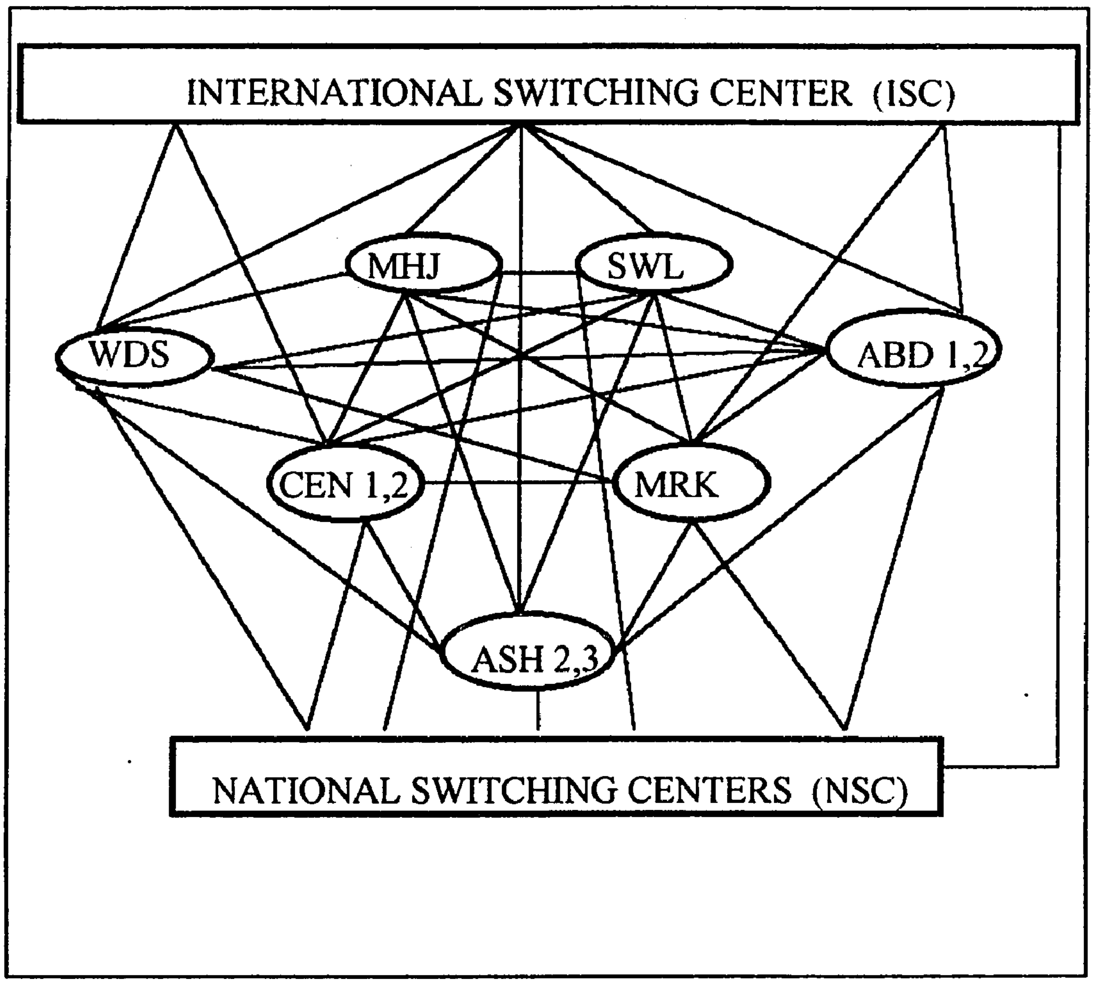


**Figure 5.9** Mesh Shaped Network for Amman Area

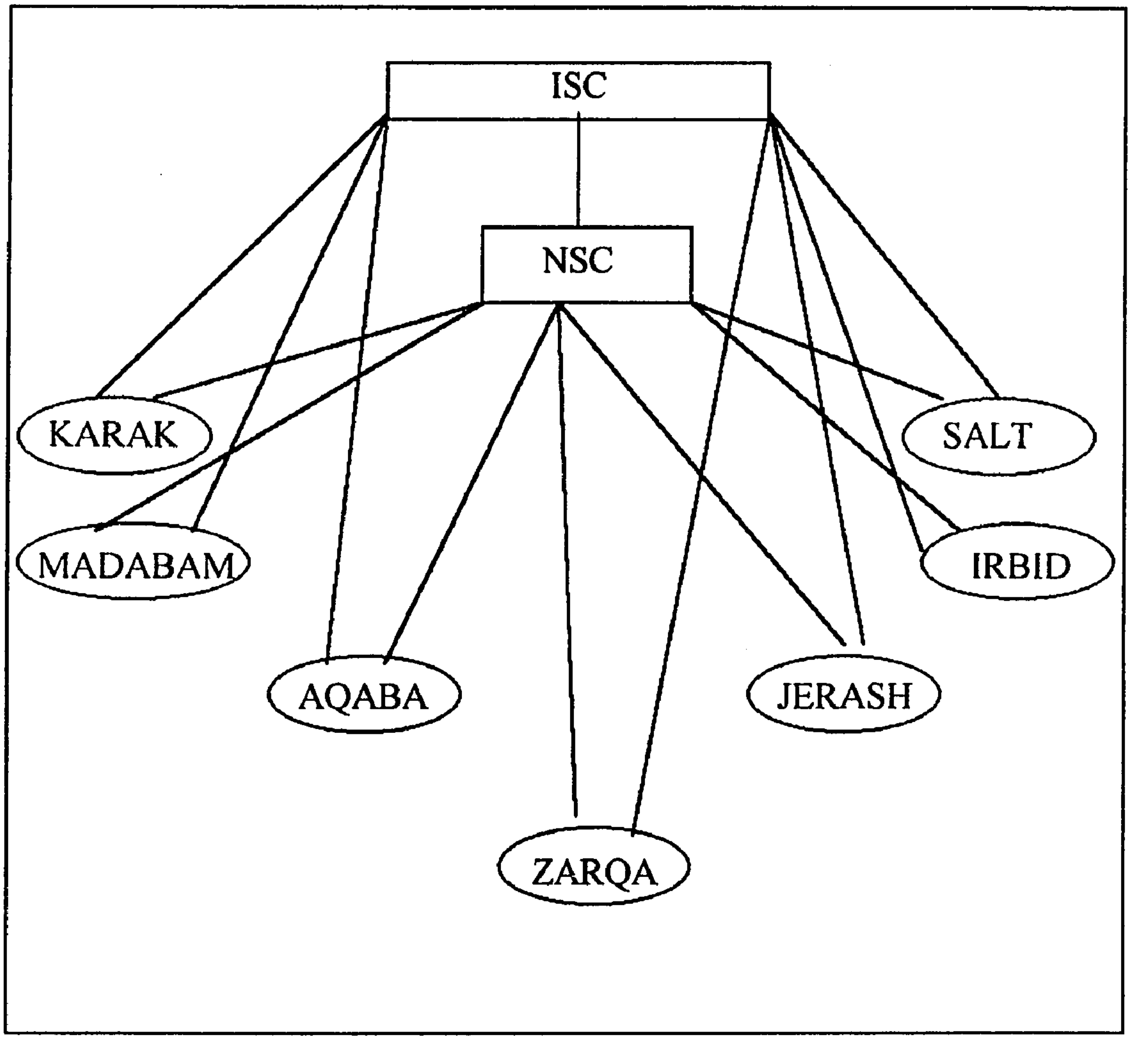


**Figure 5.10** Star Shaped Network for rest of Jordan

Figure 5.12 shows the relationship between the capacity of exchanges and the number of subscribers in 1994. It could be seen from the figure that all centers are fully loaded. Nodes 4, 5, and 6 have no extra lines to be used even in case of an emergency.

The relationship between traffic through the and the number of circuits in them is shown in figure 5.13. From the parallel relationship seen in the figure, we conclude that increasing the number of available circuits will increase the traffic. The actual 1994 data for traffic and trunks used in this study are shown in tables 5.1 and 5.2.

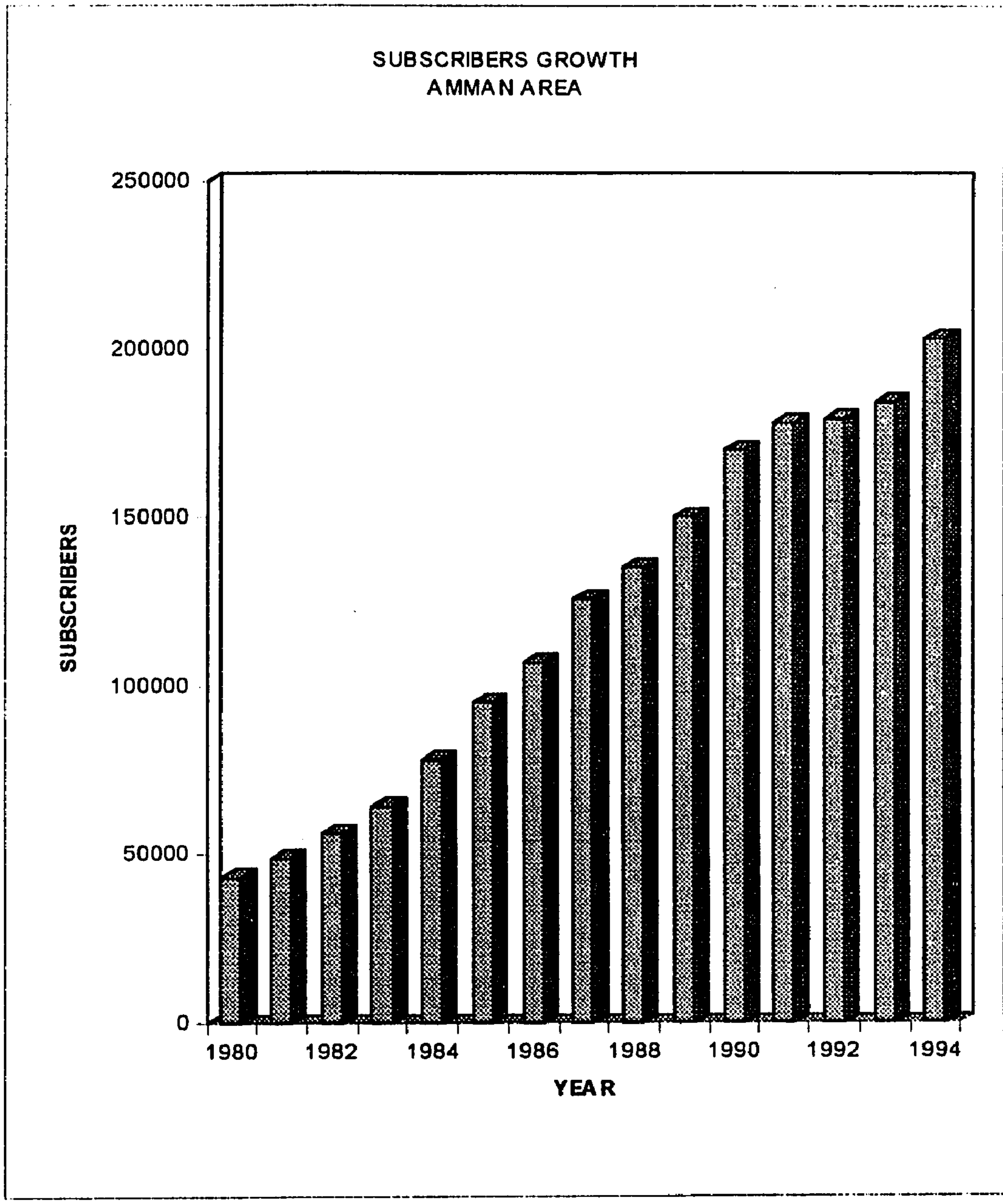


**Figure 5.11** Subscribers Growth in Amman Metropolitan Area

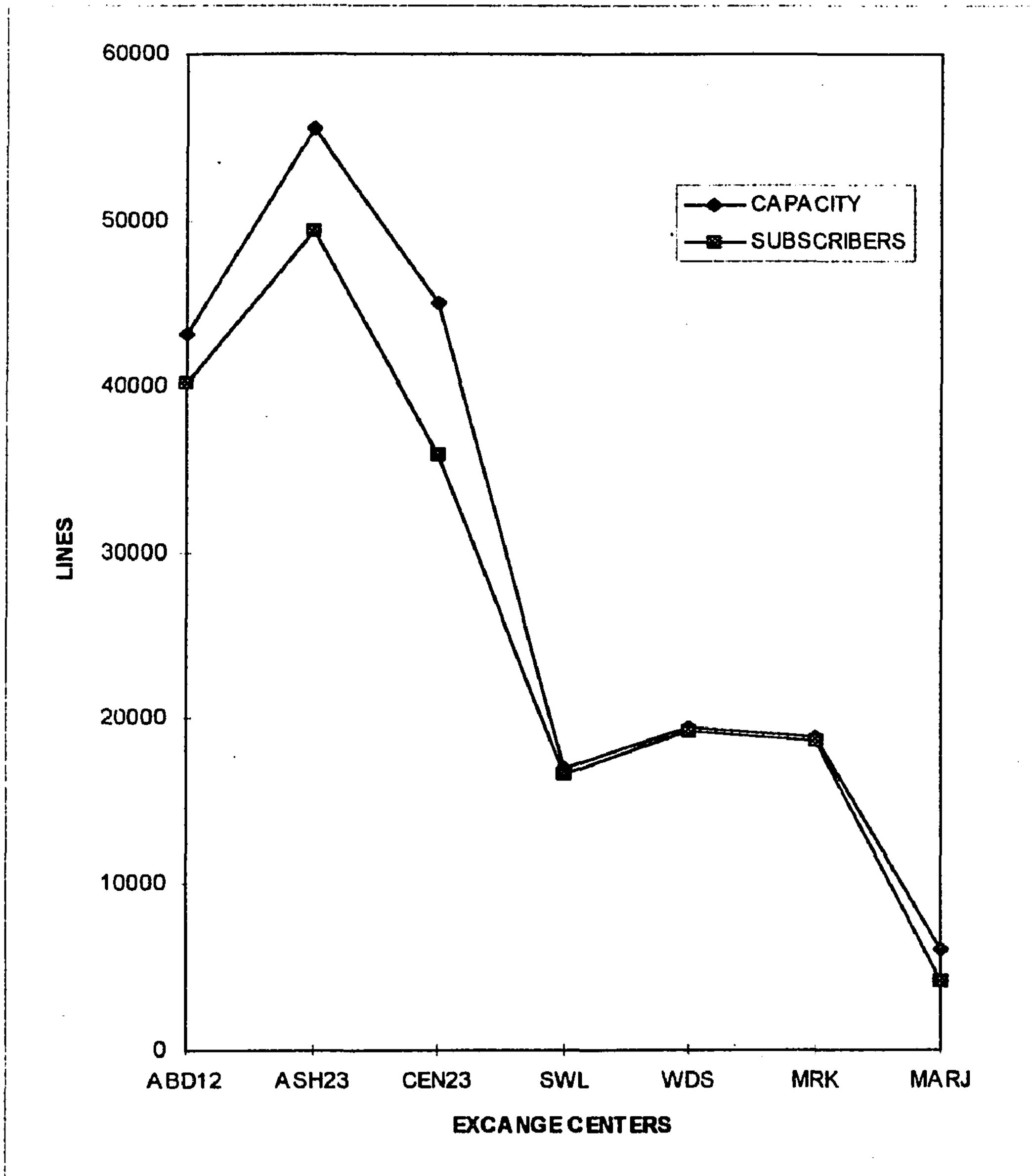


**Figure 5.12** Capacity versus Subscribers, Amman area (1994)

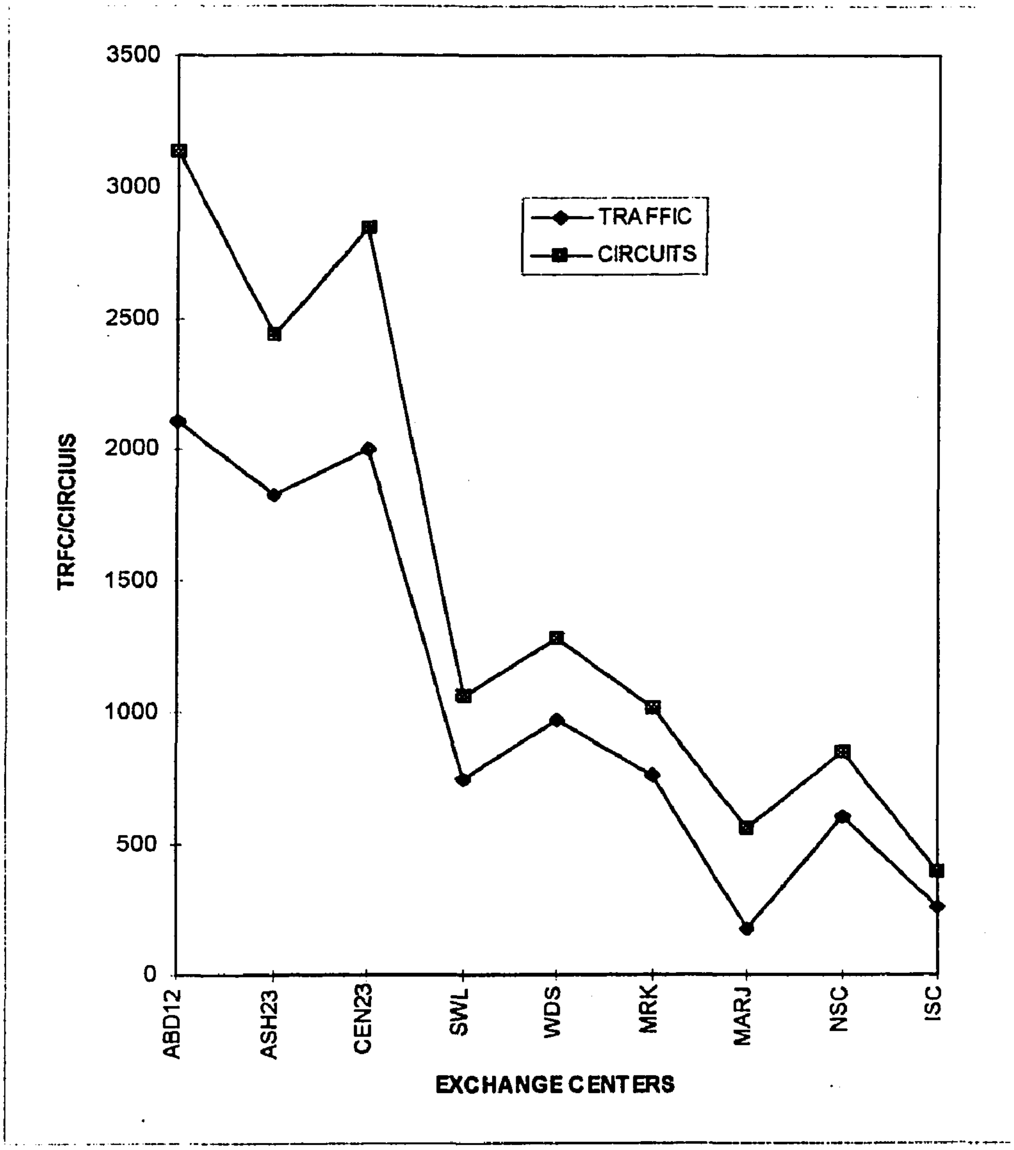


**Figure 5.13** Traffic versus Circuits, Amman area (1994)

| | ABD | ASH | CEN | SWL | WDS | MRK | MRJ | NSC | ISC | IN |
|---|---|---|---|---|---|---|---|---|---|---|
| ABD | 584.9 | 262.6 | 535.3 | 113.9 | 199.8 | 107.4 | 63.2 | 170. | 85.1 | 2122 |
| ASH | 231.2 | 831.6 | 269.3 | 79.3 | 110.0 | 125.9 | 25.2 | 113 | 27.4 | 1813 |
| CEN | 498.0 | 267.2 | 601 | 132.6 | 152.6 | 114.4 | 23.9 | 128 | 55.4 | 1973 |
| SWL | 121.9 | 82.56 | 143.6 | 229 | 62.55 | 40.16 | 10.4 | 57 | 11.1 | 758. |
| WDS | 211 | 89.5 | 159.4 | 61.1 | 307.2 | 33.3 | 49.8 | 47.6 | 24.1 | 983. |
| MRK | 105.9 | 118.7 | 106.9 | 33.6 | 31.68 | 255.7 | 7.6 | 75.3 | 8.36 | 743. |
| MAJ | 46.12 | 27.77 | 24.09 | 10.1 | 24.77 | 8.09 | 4.8 | 2.1 | 2.1 | 150 |
| NSC | 175.3 | 117.1 | 137.5 | 53.5 | 46.76 | 67.32 | 10.8 | 0 | 0 | 608. |
| ISC | 123.7 | 46.86 | 55.08 | 17.1 | 30.33 | 19.08 | 4.4 | 0 | 0 | 297 |
| OT | 1974 | 1844 | 2032 | 730. | 966 | 771. | 200 | 593 | 214 | |

**Table 5.1** Amman Traffic Matrix (1994)

| | ABD | ASH | CEN | SWL | WDS | MRK | MRJ | NSC | ISC | IN |
|---|---|---|---|---|---|---|---|---|---|---|
| ABD | 802 | 399 | 810 | 169 | 277 | 163 | 173 | 238 | 129 | 3160 |
| ASH | 360 | 967 | 394 | 113 | 146 | 166 | 87 | 145 | 46 | 2424 |
| CEN | 775 | 381 | 760 | 185 | 211 | 164 | 82 | 174 | 85 | 2817 |
| SWL | 176 | 117 | 189 | 330 | 80 | 55 | 37 | 71 | 19 | 1074 |
| WDS | 283 | 123 | 218 | 78 | 340 | 47 | 103 | 61 | 35 | 1288 |
| MRK | 183 | 161 | 153 | 47 | 44 | 286 | 30 | 91 | 16 | 1011 |
| MRJ | 167 | 90 | 72 | 37 | 75 | 29 | 12 | 38 | 11 | 531 |
| NSC | 144 | 150 | 184 | 68 | 60 | 83 | 36 | 0 | 45 | 770 |
| ISC | 121 | 69 | 86 | 27 | 42 | 29 | 14 | 16 | 0 | 404 |
| OUT | 3011 | 2457 | 2866 | 1054 | 1275 | 1022 | 574 | 834 | 386 | |

**Table 5.2** Amman Trunk Matrix (1994)

## 5.4.2 National Network

The national subscribers growth in Jordan, seen in figure 5.14, is similar to that of Amman. But the national call per subscriber rate in Amman is the lowest rate in Jordan (see figure 5.15) which indicates that callers in Amman receive more calls than they make.

On the other hand, the international call per subscriber rate in Amman is more than twenty times higher than the rate of any other city in Jordan. (see figure 5.16). This is due to the fact that most businesses in Jordan are centered in Amman, which has about 41% of the entire national network service. Consequently, most of this study will be dedicated to the improvement of the Amman network area. The national and international traffic matrix is shown in table 5.3.

The national tariffs, in US dollars, are shown in table 5.4. These tariffs are very high, considering the fact that an average minute cost $.207 in a network service covered an area smaller than the State of New Jersey

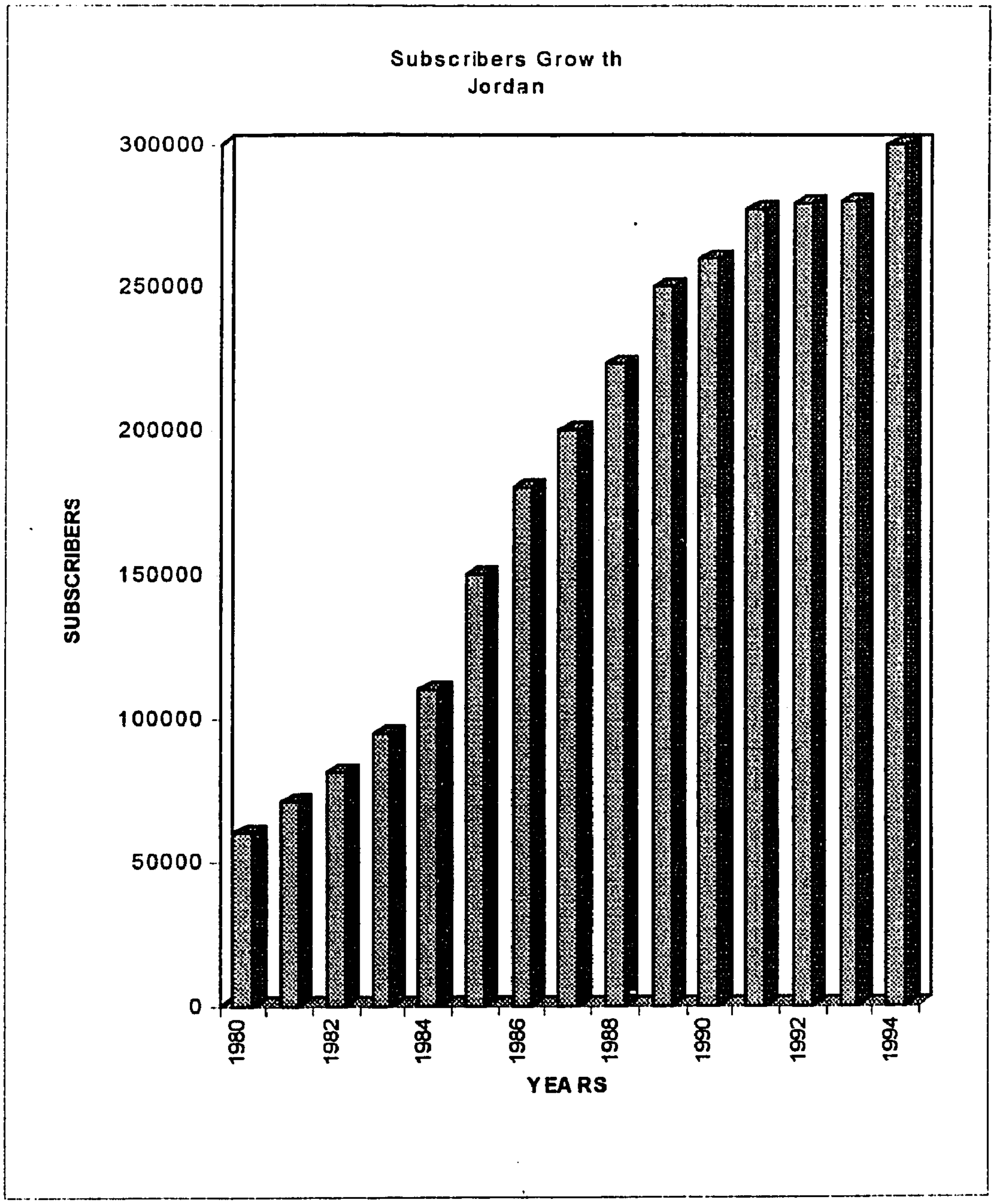


**Figure 5.14** Subscribers Growth in Jordan

| Area code | AMM 06 | KRK 03 | MDB 08 | SALT 05 | ZARQ 09 | IRBD 02 | JERS 04 | NSC | ISC |
|---|---|---|---|---|---|---|---|---|---|
| AMM | 7736. | 0 | 0 | 0 | 0 | 0 | 0 | 592.9 | 128.4 |
| KRK | 0 | 277 | 0 | 0 | 0 | 0 | 0 | 11.84 | 2.21 |
| MDB | 0 | 0 | 135. | 0 | 0 | 0 | 0 | 33.07 | 0.79 |
| SALT | 0 | 0 | 0 | 171.1 | 0 | 0 | 0 | 53.15 | 0.92 |
| ZAR | 0 | 0 | 0 | 0 | 351.7 | 0 | 0 | 250 | 28.19 |
| IRBD | 0 | 0 | 0 | 0 | 0 | 705.1 | 0 | 151.3 | 22.63 |
| JERS | 0 | 0 | 0 | 0 | 0 | 0 | 140.6 | 66.71 | 6.18 |
| NSC | 608.5 | 11.84 | 33.1 | 53.13 | 249.9 | 151.3 | 66.71 | 0 | 0 |
| ISC | 296.5 | 2.21 | 0.76 | 0.92 | 28.19 | 22.63 | 6.18 | 0 | 0 |

**Table 5.3** National and International Traffic (1994)

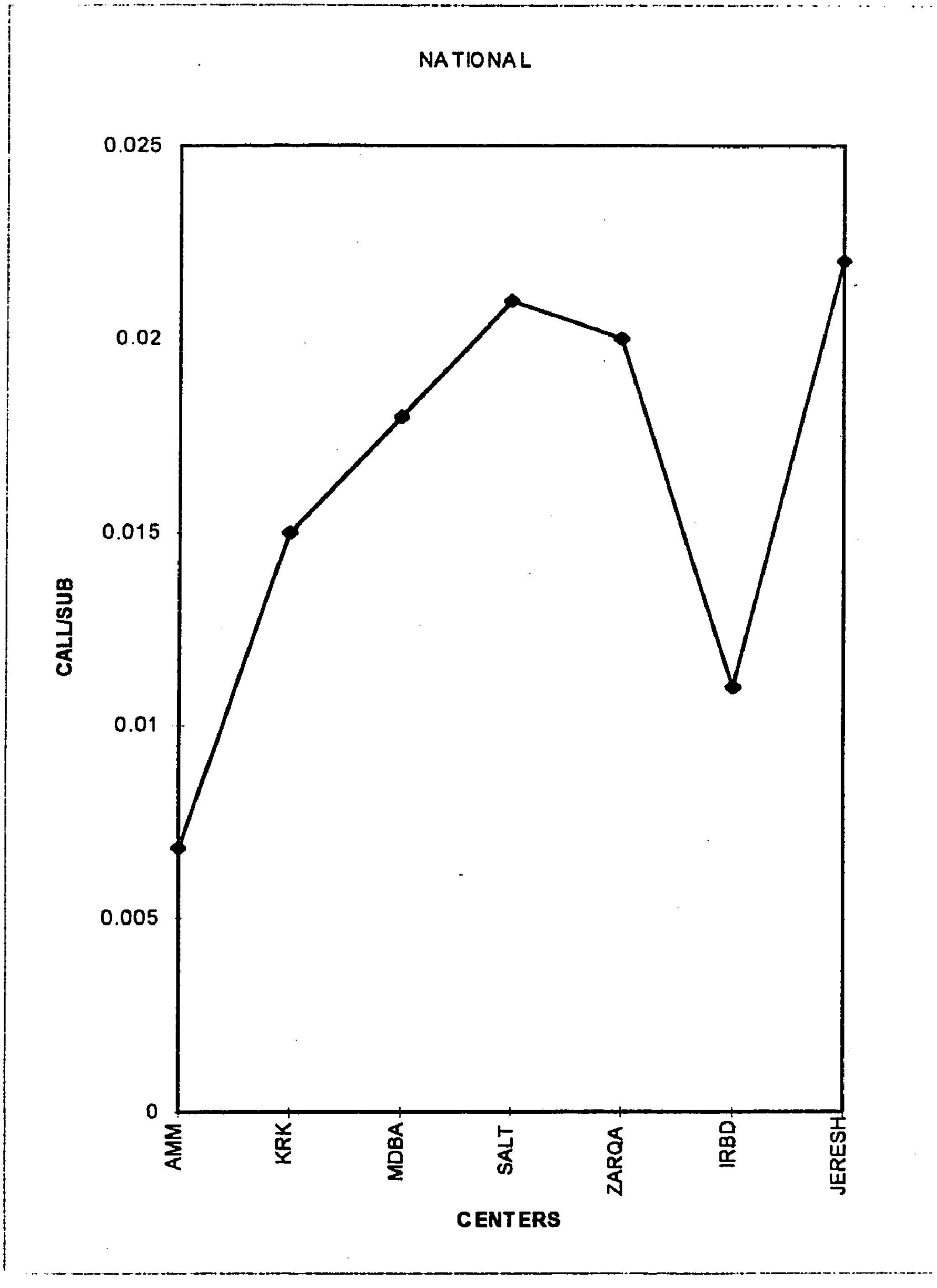


**Figure 5.15** National Call per Subscriber (1994)

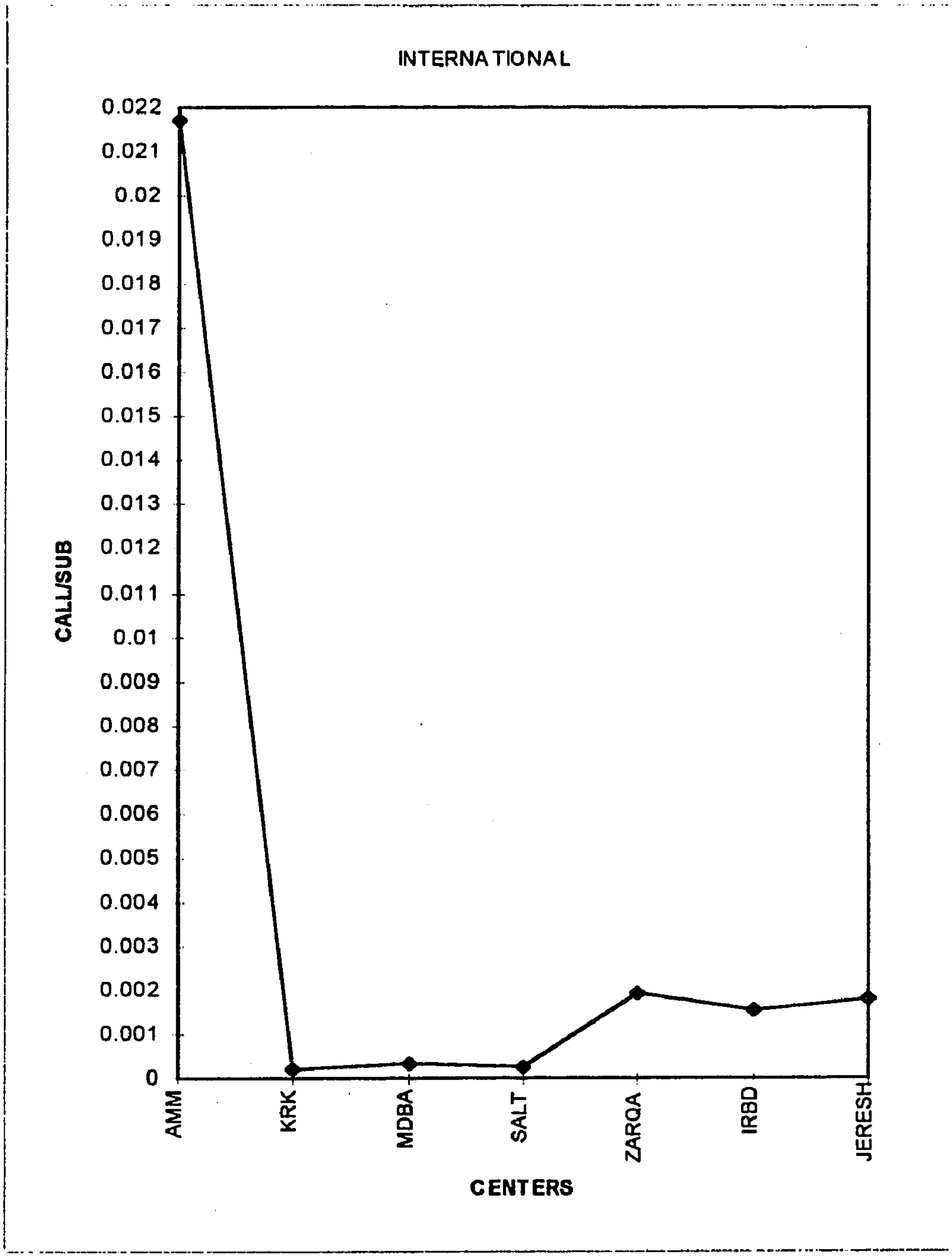


**Figure 5.16** International Call per Subscriber (1994)

| | AMM | KRK | MDB | SALT | ZARQ | IRBD | JERS | AVE. |
|---|---|---|---|---|---|---|---|---|
| AMM | 0 | 0.28 | 0.09 | 0.12 | 0.09 | 0.2 | 0.2 | |
| KRK | 0.28 | 0 | 0.2 | 0.28 | 0.28 | 0.28 | 0.28 | |
| MDB | 0.09 | 0.2 | 0 | 0.2 | 0.2 | 0.32 | 0.2 | |
| SALT | 0.12 | 0.28 | 0.2 | 0 | 0.2 | 0.2 | 0.2 | |
| ZARQ | 0.09 | 0.28 | 0.2 | 0.2 | 0 | 0.2 | 0.2 | |
| IRBD | 0.2 | 0.28 | 0.32 | 0.2 | 0.1 | 0 | 0.12 | |
| JERS | 0.2 | 0.28 | 0.2 | 0.2 | 0.2 | 0.12 | 0 | 0.207 |

**Table 5.4** National Tariff ($) (1994)

# CHAPTER 6

## NETWORK SYSTEM ANALYSIS

The purpose of network system analysis is to develop an explicit description of existing needs This leads to forming an objectives for the communications system and defining a problem statement of the performance criteria desired by the communications network. Probably the primary objective for national network analysis is to minimize networking cost which could be done by:

1) Replace or consolidate low speed access lines.
2) Obtain the best transmission services.
3) Eliminate the Unnecessary facilities.
4) Optimize communication equipment configuration.
5) Insure proper performance, reliability, and response time.
6) Increase network capacity to meet traffic demand, by defining growth strategies.
7) Knowing whether hardware components, servers, node processing, or applications are the bottlenecks in network performance.
8) Monitor customers satisfaction to increase their confidence level.

To achieve improvement of cost and performance, network design tools needed for creating and checking various alternative network designs to produce an optimal network configuration.

## 6.1 System performance

In general network system performance deals with costs, throughput, quality of service, and grade of service.

### 6.1.1 Network Cost

System cost is the most critical performance parameter. All network design include inventory of lines, equipment, and software needed to make them run. Including all the cost elements (installation costs, shipping charges, purchasing price, maintenance cost, and service cost) into the optimization process prevents unpleasant surprises. There are three major cost components in a national network design: line cost, equipment cost, software cost.

1) Line costs: include both recurring monthly service charges and non-occurring one time installation cost. Many networks design optimize based on network cost parameter only.
2) equipment costs: Which include the cost of switching equipment, multiplexors, concentrators, and any other devices used in central offices. These charges have a high dependency on the market prices and the quality of required equipment. For this reason most network designer try to avoid including this factor in their optimization. This situation was in the past due to the limited number of vendors. Today with the technology and too many vendors its is very important for this factor to be included.
3) Software costs: It is generally correspondingly to the complexity of the national network design generated and type of service required, CS, PS, ISDN, or IN. This

software usually supplied by the equipment vendor and included in the equipment cost.

Total network cost per month = TR + RN + HRD

where

TR = Transmission cost per month

RN = Runnung cost per month (maintenance, overhead, and other related expenses)

HRD = Total hardware cost divided by network life cycle, including interest rate

### 6.1.2 System Throughput

System throughput measures the overall capability of the system in terms of maximum number of transactions that can be handled per busy hour.

The throughput of CS system is represented by the maximum number of call attempt and calls completed per average second of a busy hour by each network node and by the entire network system. A very large of unsatisfied call attempts is an almost certain of congestion. If actual busy hour traffic not available, and call attempt need to be included, busy hour traffic and busy hour paid time can be estimated by the following formulae.

Busy hour traffic(in *Erlangs*) = No. of call attempt in the busy hour X (average call holding time)/60

Busy hour paid time = No. of call attempts in the busy hour X average paid time per call.

The throughput of **PS** system is represented by the number of input packets or messages that can be handled per average second of a busy hour, or by the maximum bit rate handled by the system per second. Successful message throughput (TP) is

$$TP = [M (1-P)]/[(M/R)+T]$$

where

M = average message length in bits.

P = The probability of errors in the received message.

R = Line speed in bits per second.

T = The average line time wasted between messages and M/R( the time required to transmit average message).

In national network backbone connections, total system throughput is the sum of all network nodes throughputs.

### 6.1.3 Quality of service (QOS)

Quality of service deals with performance issues such as the transmission quality, voice quality at the receiver, length of error free periods, average bit error rate, system reliability, delays, noises, and other user- oriented performance factors.

### 6.1.4 Grade of service (GOS)

Grade of service for CS deals with statistical distributions of the system response time, call connection time, and call setup time, while GOS for **PS** deals with nodal response time and call session setup time.

Measuring QOS and GOS can be measured by opinion models, which addresses users perception or expectation of a particular service, or by behavioral models, which address how users react if they are not satisfied with a particular service. These models are based on subjective testing of speech quality and on the derivation of transmission rating models. Grade of service can be calculated by the following formula:

GOS = ( No. of busy hour call attempt - No. of busy hour call completion) /

( No. of busy hour call attempt).

## 6.2 Network Analysis models

Several techniques are used for network system analysis, all of which could be categorized in two models: analytical models, and simulation techniques .

### 6.2.1 Analytic Models

Analytic models have been the most commonly used technique for along time. They are mathematical models of a network in which queuing theory plays a major role . A queuing process can be illustrated as shown in figure 6.1. Information units requiring service are generated over time by an input source which has two characteristics: population size and distribution function. These two characteristics define the way the information units arrive at the queuing system. The most common assumption is that the number of units generated until any specific time follows a Poisson distribution. This is the case where arrivals to the queuing system occur at random and at a certain average rate. These information units enter the queuing system and join a queue. At certain points in time, a member of the queue is selected for service by the service mechanism according to some rules known as service discipline. The required service is then performed by the service mechanism, after which the information unit leaves the queuing system. There are two types of queuing systems employed in switched communication systems: (1) Loss system, where the unit is ignored if no free server is available then taken out of the queue for service. (2) Delay system in which the unit remains in the queue until it is served. The performance of a loss system is generally measured in terms of blocking probability, where the performance of a delay system is determined by the probability distribution for the time spent in the system.

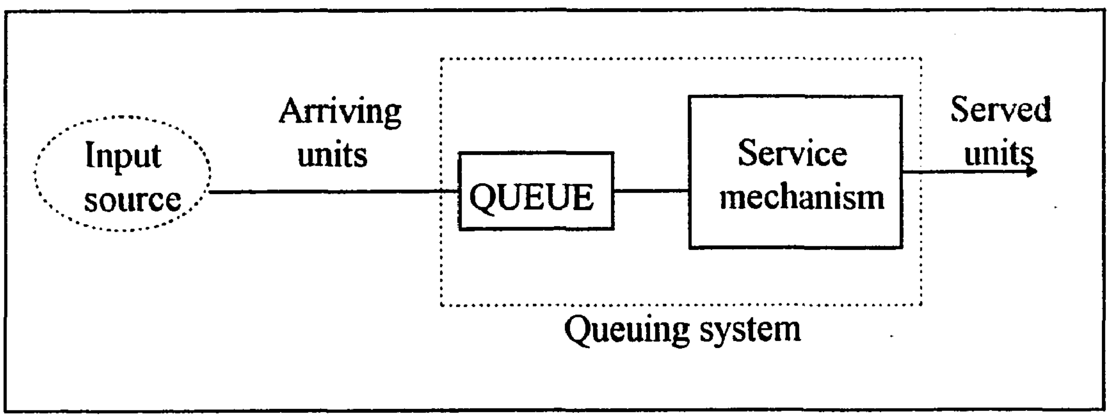


**Figure 6.1** The Basic Queuing Process

These models have some limitations because of their assumptions in predicting performance of a design. Analytic heuristic equations use statistics and queuing theory under the discipline of traffic engineering. Heuristics are employed to reduce the number of possible network designs down to a manageable amount. Because not all possible configurations are exhaustively evaluated, this is a potential source of difference between a truly optimal network and an optimized network design.

Analytical modeling proves inadequate when a large or complex system can not be divided into statistically independent subdivisions. As the complexity of a model increases, solvability of mathematical equations decreases, sometimes drastically. Complex models are often solved using numerical techniques (computational methods), but these methods are also potentially expensive.

### 6.2.2 Simulation Models

Simulation uses interactive software programs to build a fairly realistic model of the network in operation. Less abstraction is required and the process of model formation is a more straightforward task. These models also offer more means for evaluating and comparing new systems before they are actually built.

A simulation model describes events, their effects on system components and on other events, and their occurrence, based on the underlying statistical behavior. When driven by a proper statistical input stream, a simulation model initiates the system being simulated and generates data equivalent to measurements in a real system experiment. Because the event generation process depends on the pseudorandom number stream, performance measures output by the model (message delay, device utilization, buffer occupancies, throughput, and so on) which is random in nature. Simulation of a system undergoes three phases :

- Building of a simulation model.
- Design of simulation experiments.

- Analysis of data generated in simulation experiments.

All three phases are equally important in successful usage of the simulation technique. These techniques are normally time-consuming. They are more accurate because they are not based on as many assumptions as Analytic techniques. Simulation is now recognized as a preferable alternative to analytic approaches in computer and communication system performance analysis. Telecommunication line traffic routed through a discrete event simulator captures the parameters of a proposed network design. Simulation can be incredibly accurate in timing an individual event, however, it generally requires considerable processing time to execute. The development of the simulation software may take a sizable amount of time..

Furthermore, the use of a mainframe for predicting the performance of every interesting configuration may cost a great deal of money.

## 6.3 Analysis Tools

From the earliest days of telephone, mathematicians have concerned themselves with the problem of predicting service under various loading conditions. A number of traffic formulas and tables have been derived that adequately fit, or can adapted for fit.

### 6.3.1 Voice Network Analysis Tools

A traffic system consists of set of time-varying demands, a group of facilities to serve those demands, and service criteria to be met by the system. A mathematical model consists of a set of assumptions about the first two factors, with the objective of predicting the third. Traffic theory is based upon probability theory and assumptions.

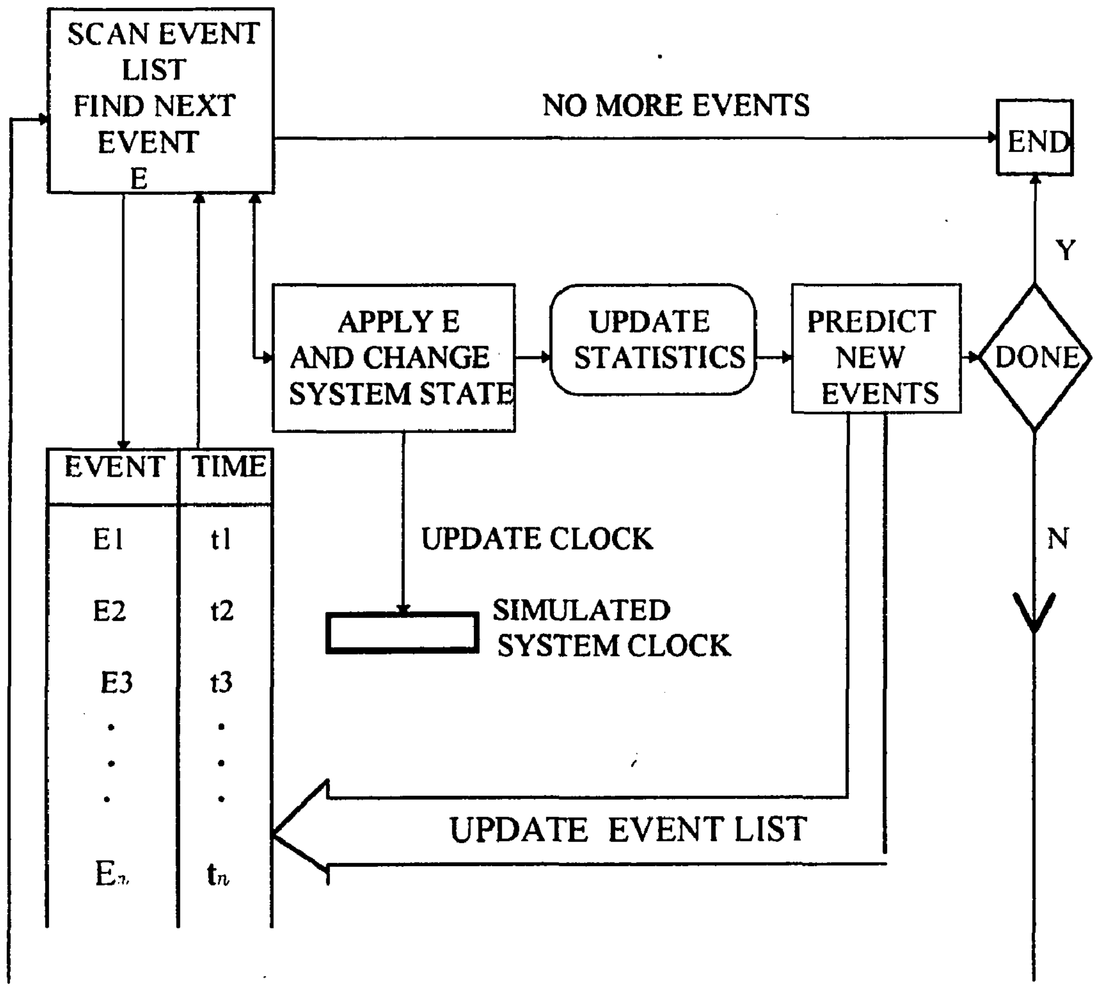


**Figure 6.2** Action of Simulator

Assumptions should be minimized, valid statistical data, and careful analysis can yield satisfactory results. Traffic analysis used to compute the performance of CS voice network in term of inter-nodal blocking and the number of inter-nodal circuits as a function of the allowed blocking probability. Three factors used to choose the required formula:

1) Number of circuits ( Finite or Infinite).
2) Blocked call disposition ( Held, Cleared, or Delayed)
3) Holding time distribution (Constant or Exponential)

In addition, all traffic formulas assumed that subscribers originate call at random, and independently of other subscribers.

### 6.3.1.1 Poisson Formula

The assumed assumption in Poisson formula is that the number of trunks in the trunk group is infinity, calls are held for a duration of time equal to call holding times, and holding time is either constant or exponential. If A represents offered traffic intensity, the blocking probability (B) on a system with (N) outlet circuits is:

$$B = 1 - \sum_{n=0}^{N-1} (A^n \cdot e^{-A}) / n!$$

### 6.3.1.2 Erlang-B Formula

Erlang-B formula is based on the assumption that sources are infinite, blocked calls are cleared, and holding time is either constant or exponential. It is used to dimension server pools that are not provided with a waiting queue, such as interswitch trunk groups. It is used mainly for dimensioning high-usage trunk group in alternate-routing arrangements, where block calls can be re-routing to another HU group or final group.

$$\mathbf{B = (A^N / N!) / \sum_{n=0}^{N} ( A^n / n!)}$$

This formula being used in the simulation routines written for this research to calculate generate trunks matrix from national network traffic matrix. In order to ease calculation for this formula, it can be re-written in a recursive form as :

$$\mathbf{B(N+1) = A * B(N) / [N + 1 + A * B(N)]}$$

If the cleared calls are allowed to return at random, the value of the new offered traffic(A') can be expressed as follows:

**$A' = A / (1-B')$ , where $B'$ = Blocking probability for $A'$.**

### 6.3.1.3 Erlang-C Formula

The Erlang-C formula assumes sources are infinite, blocked calls are delayed for a given time, and holding times are approximated by negative exponential distribution. This formula used in automatic call distribution (ACD) systems where a blocked call sent to the next available agent (FIFO). If all agents are busy when the call arrives, it must wait for the first agent that becomes available. After a given period of time the call will be cleared if no agent still available.

$$\textbf{Prob. ( delay > t ) = P0 * } e^{(-(N-A)t/Ts)}$$

where

A = Offered traffic

N = No. of agents that serving incoming calls

P0 = Prob. ( delay > 0) = (B * N ) / ( N - A(1 - B))

B= blocking probability for given A and N

Ts = Expected call duration.

### 6.3.1.4 Engest Formula

The Engest formula is based on the assumptions that sources are finite, blocked calls are cleared, and holding time either constant or exponential. It is used for dimensioning equipment that has a number of sources, such as line concentrators.

$$B = \binom{S-1}{N} \{ ( A / (S - A (1 - P)))^N \} / H$$

where

$$B = \sum_{i=0}^{N} \binom{S-1}{i} \{ ( A / (S - A (1 - P)))^i \}$$

N = Number of servers in group

A = Offered traffic

S = Number of sources

## 6.3.2 Data Network Analysis Tools

Traffic analysis tools for data traffic are required to compute the system response time. One of the most important performance measures of a data network is the average delay required to deliver a packet from origin to destination. Furthermore, delay considerations strongly influence the choice and performance of network algorithms, such as routing and flow control. Queuing theory is the primary framework used to analyze network delay. There is many types of queuing models, each model assumes a unique traffic model. Models assumptions such as date arrivals, customer service time distribution, number of servers, and number of sources.

### 6.3.2.1 The M/M/1 Queuing System

This system consists of a single queuing station with a single trunk. Customers arrive according to Poisson process with rate ( $\lambda$ ), and the probability distribution of the service time is exponential with mean ( $1/\mu$ ) seconds. The number of customers in the system in steady state can be calculated as:

$$N = \lambda / (\mu - \lambda)$$

The average delay per customer (T) = waiting time in queue + service time.

$$T = N / \lambda$$

The average waiting time in queue(W) = T - average service time ( $1/\mu$ )

$$W = \lambda / (\mu (\mu - \lambda))$$

Relation between utilization factor ( $\rho = \lambda / \mu$ ) and N shown in figure 6.3. We can see in the figure that as $\rho \rightarrow 1$ , $N \rightarrow \infty$.

### 6.3.2.2 The M/M/m Queuing System

The M/M/m system is identical to the M/M/1 system except that there are m trunks. A customer at the head of the queue is routed to any server that is available.

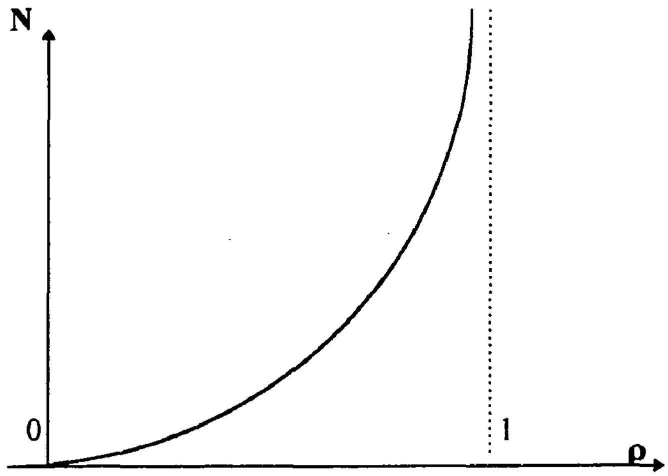


**Figure 6.3** Number of trunks versus utilization factor

The average time waiting in queue (W) is:

$$W = \rho P / (\lambda(1 - \rho))$$

where P = the probability that an arrival will find all trunks busy and will be forced to wait in queue

The average delay per customer $T = (1 / \mu) + W$, and using $\rho = \lambda / m\mu$, T can be written as:

$$T = (1 / \mu) + P / (m\mu - \lambda)$$

The average number of customers in the system is

$$N = (\lambda / \mu) + (\lambda P / (m\mu - \lambda)) = m\rho + (\rho P / (1 - \rho))$$

### 6.3.2.3 The M/M/m/m Queuing System

This system is same as the M/M/m system except that if an arrival finds all m trunks busy, it entered the system and is cleared. This model wide use in telephone networks. In data networks, it can be used as a model where arrivals corresponds to requests for virtual circuit connections between two nodes and the number of virtual circuits allowed is m. the average service time ($1 / \mu$) is then the average duration of virtual circuit conversation.

The probability that an arrival will find all m trunks busy and will therefore be lost is the same as Erlang-B formula.

## 6.4 NATIONAL NETWORK ANALYSIS APPROACH

Network design tools should be capable of taking into consideration many factors such as line topology, traffic load, facility cost, equipment types, communication protocols, hubbing arrangement, routing arrangement, different performance parameters of both voice and data, and other factors depending on the nature of analyzed network. These factors must be considered simultaneously with variables as switch performance, which includes queuing, blocking, and reliability. The type of traffic that the network must support is an important factor today. Types as voice, data, image, full motion video are the goal for all future networks.

National network analysis and optimization planing starts with the following four steps:

1. Selecting an appropriate design technique for network optimization.
2. Obtaining a network design tool that will apply the desired design technique.
3. Developing a model of the network using one of design tools.

4. Analyzing the model by applying the design tool in various cases.

Once these steps are completed, design results will be available as input into the cost-performance break-even analysis, which involves generating and evaluating an alternative network designs. Different cases of transmission components and traffic profiles will be generated and evaluated by interactive process of network refinement.

Each of the various alternate configurations will have associated costs and performance levels which will be plotted on a graph of costs vs. other factors. All network configurations that satisfy the operational evaluation criteria produce a family of cost-performance curves. This set of trade-off relationships between cost and performance will form a solution set of alternate network designs. Most of network analysis tools end at this stage leaving an important factor which has a direct effect on network performance and cost: obtaining the necessary communications hardware. This hardware is now offered now by a large number of vendors in a highly diverse industry with competitive prices and good performance.

Putting all the above together will take the following steps:

1. Choose an analysis network tool which will output different network topologies with their costs.
2. Write a program to take the above output and find the central office switching equipment for this configuration, and to choose the minimal cost for the whole network.
3. While there are more cases, repeat steps 1 and 2.

4. Chart the relations between different factors, and find the minimum solution configuration.

Many software packages are available in the market for step 1. Most of them are designed for LAN or WAN data communications.

This study will use the actual data from the traffic intensity of an existing national telecommunications network in Jordan. It will measure the existing traffic performance for that network and will come up with an optimal network with performance acceptable by the international standards. This analysis will be performed using a software package developed specially for this research. The Jordanian national network and the capital Amman metropolitan area network will be both analyzed.

Actual data generated by the Jordanian Traffic Management Group in 1993-1994 will be used to analyze the existing national telephone network in Jordan, these actual data include the following:

1. Traffic intensity for the national network ( from - to traffic).
2. . Network topology .
3. Network capacity for each node.
4. Number of subscribers for each node.

The rest of information is based on international availability data:

1. Tariff information for two carriers (Microwave, and Fiber optic). Different tariffs will be used for cost and capacity analysis.
2. Central office and PBX switching data base information (capacity, adaptability, and cost).

The simulation program will output a list of optimal overall networks. Jordanian network which can be described as full Trunk Microwave network, is costly and noisy, because of its dependability on weather and other nature changes. Furthermore, the overall national telecommunication could be jammed or corrupted by an outside source, which is a big security problem.

The expected optimal network will suggests some major changes. This is due to the availability of fiber optic technology which will increase trunk backbone and central office capacity, to meet the increased public demand which is more than 50% of the existing capacity. The analysis in this study will also provide five and ten-year plans for the network.

# CHAPTER 7

## SIMULATION ROUTINES

The simulation model is shown in figure 7.1. It is designed for national network analysis using an existing network and study all improvement factors which can be implemented in the network optimization.

## 7.1 Input and Output Files

Read Input files:

Traffic Matrix, Distance matrix, Network Topology, Subscribers

Initialize :

Congestion = .05

Microwave multiplexing =480 Voice Grade Circuit (VGC)

OC3 Multiplexing = 2376 VGC

Traffic Growth array (1, 1.5, 3, 4.5)

Create the following Directories

CPM = Cost per minute (Transmission only)

TCPM = Total cost per minute ( Transmission + Hardware)

RN = Running cost per month

YEARS = Return on investment years

TPLGY = Network modified topologies

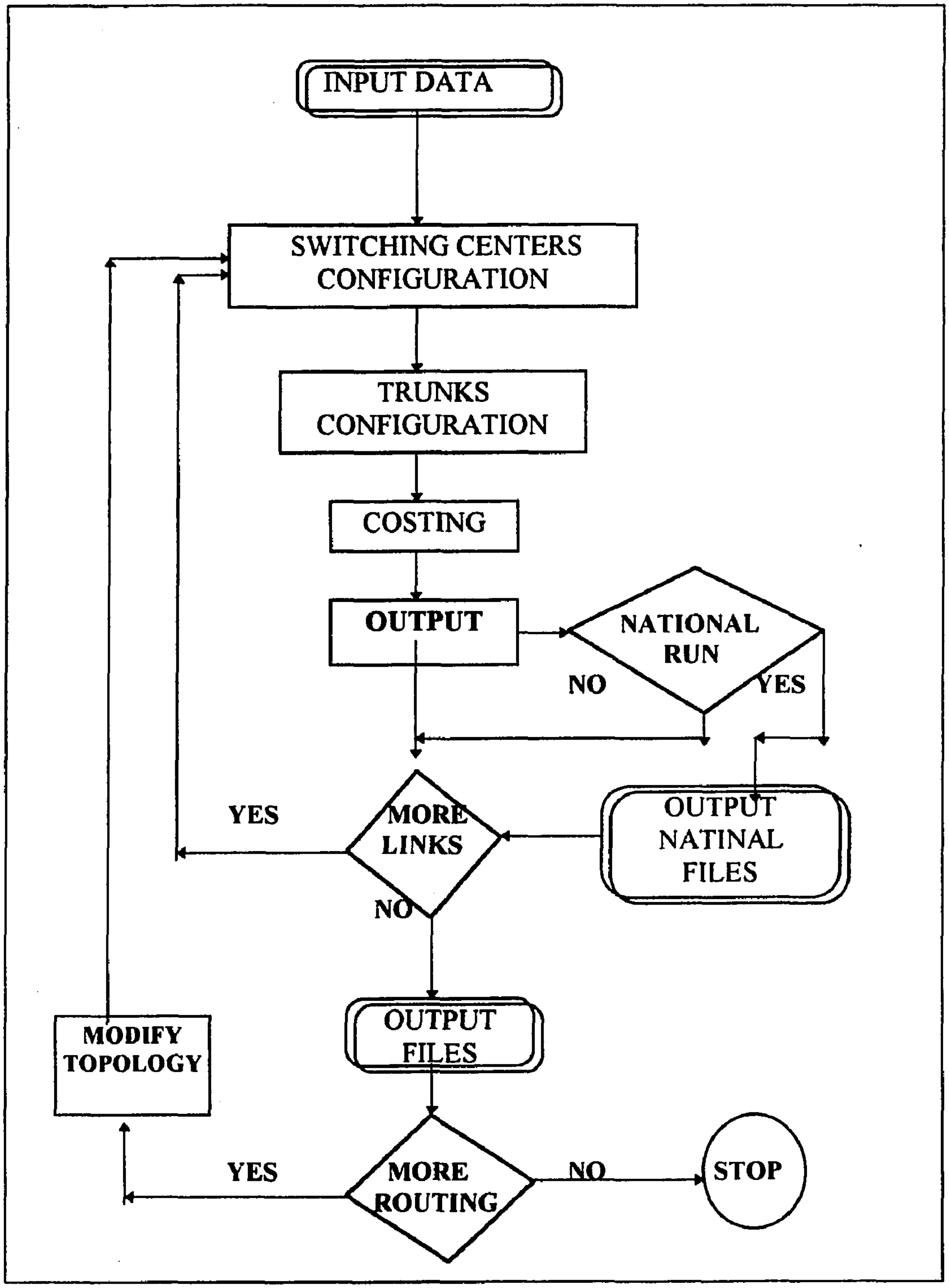


**Figure 7.1** Simulation Model Flowchart

Each of the above directories contains files for all traffic growth factor cases and congestion.

## 7. 2 Main Procedure

(1) Initialize

(2) Read input files

(3) Create directories

(4) Call Calcircuits

(5) Initialize costs

(6) Call Exchange

(5) Call trunktraffic

(6) Call costing

(7) Call Output

(8) If there are more available links, goto 5 (initial links =35 direct connections)

(9) Call Modify Topology

(10) If there are more topology modification, goto 4

(11) Change traffic growth factor and goto 4

(12) Change congestion and goto 4

## 7.3 Subroutines

*CALCIRCUITS*

This routine calculates the number of trunk circuits using the Erlang-B loss formula. It assumes an infinite number of sources for random call arrivals. The lost calls are cleared as soon as they are blocked.

Blocking probability is computed using the following recursive formula:

**Blk (n+1) =Traffic * Blk(n) / (n + 1 + Traffic * Blk(n))**

where **Blk** = Blocking probability

**n** = number of trunks

*EXCHANGES*

In this routine, total traffic and the total number of trunks are calculated for each exchange. The routine also Calculates cost of switching equipment for the following cases:

1) Microwave network for all 9 nodes .

2) **SONET** network with **ATM** switches for all 9 nodes.

3) Nodes 1, and 3 as **ATM** switches, other nodes as microwave

4) Nodes 1, 2, and 3 as **ATM**, others as microwave

5) Nodes 1, 2, 3, and 5 as **ATM**, others as microwave.

6) Nodes 1, 2, 3, and National tandem as **ATM**, others as microwave.

7) Nodes 1, 2, 3, 5, and National tandem as **ATM**, others as microwave.

8) Nodes 1, 2 , 3, and both National and International tandems as **ATM**.

For all the above cases the existing network cost is counted, Even though most of the existing exchanges are already outdated, I assumed that it will be functioning in the next five years. The cost of DS3 can be excluded if that center already has this capability and most of the exchanges already using a digital **PCM** units and a microwave multiplexing. If re-routing increases the number of VGC regard, the cost of required trunks will be added.

***TRUNKTRAFFIC***

For all the above links, cost of transmission, maintenance and overhead are calculated in this routine. The formula used in calculating the cost of transmission is illustrated in [42].

Monthly cost($) = A + B * (circuit/path length in miles)

+ C * (#VGCs Carried).

where A, B, and C are:

A = 1448, B = 135, C = .58 For optical fiber.

A= 1486, B = 155, C = .77 For microwave.

The multiplexing factor played a major role here because Jordanian microwave carriers had a multiplexing for each trunk = 480 VGCs. This number is the actual value taken from the Jordanian national network. The optical fiber for **SONET** uses an OC3 carrier with 2376 VGCs.

The total cost for installing a 24-fiber cable is $70 per linear foot, including labor cost.

If more microwave units are needed for the existing network as the traffic growth factor is increased, their cost will be added. The cost will vary between $50,000 - $150,000 per unit depending on its capacity. The cost of towers is not included when more microwave transmitter/receiver is needed because of the assumption that they are already in place.

***COSTPERMONTH***

Cost per month for hardware connection and switching is calculated for a seven-year period with an insert rate of 7%. These values are added to the cost per month from the COSTING subroutine to get total cost per month for the entire network.

Life cycle cost are influenced by the following:

1) System management

2) Switching equipment maintenance and repair.

3) Moves adds and changes.

4) Cables installation or towers constructions.

***MODIFYTRAFFIC***

After running all the subroutines above for all of the eight links, start with existing mesh network with 35 directly connected nodes for the Amman area (exclude one connection between national and international because traffic intensity = 0). The ***MODIFYTRAFFIC*** subroutine searches for the minimum traffic node and reroute this traffic using the shortest path algorithm. This will be done each time this routine is called until there are only 15 directly connected routes left.

***CALCULATIONS***

This subroutine call from PRINTRESULT, it calculates the following

1) Cost per minute (CPM) = T/(TRFK * C/2)

where

T = Total monthly cost of (Transmission, maintenance, overhead)

TRFK = Total traffic intensity in Erlangs

C = (day/month) * ( busy hours/day) * ( calls /hour)

For 20 business day per month Five busy hours per day, and three minute per call.

C = (20) * ( 5* 60 ) * (60 /3) = 1200

2) Total cost per minute:

Same as above except that T includes hardware cost.

3) Investment years: Calculated by the following formula:

Years = [( H - EM) / (MT - T)] * 12

where

H = Each of the other link types hardware payment per month (seven years).

EM = Microwave hardware payment per month.

MT = Microwave transmission per month.

T = Each of the other link types transmission per month.

***PRINTRESULT***

For each of the traffic growth factors (1, 1.5, 3, and 4.5) an output file is generated and placed in the appropriate directory. The file names include the traffic growth factor and congestion. This approach is used to ensure that a new files will be open for every configuration and no any file will replace the other. Tables 7.1-7.17 are samples of output files.

**DIRECT CONNECTIONS = 35**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 7) ( 4, 8) ( 4, 9)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 7) ( 6, 8) ( 6, 9)
( 7, 8) ( 7, 9)

**DIRECT CONNECTIONS = 34**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 7) ( 4, 8) ( 4, 9)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 7) ( 6, 8) ( 6, 9)
( 7, 9)

**DIRECT CONNECTIONS = 33**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 7) ( 4, 8) ( 4, 9)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 7) ( 6, 8) ( 6, 9)

**Table 7.1** Amman area network topology (DC = 35- 33)

**DIRECT CONNECTIONS = 32**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 7) ( 4, 8) ( 4, 9)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 8) ( 6, 9)

**DIRECT CONNECTIONS = 31**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 7) ( 4, 8) ( 4, 9)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 8)

**DIRECT CONNECTIONS = 30**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8) ( 4, 9)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 8)

**DIRECT CONNECTIONS = 29**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 7) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 8)

**Table 7.2** Amman area network topology (DC = 32- 29)

**DIRECT CONNECTIONS = 28**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8)
( 5, 6) ( 5, 7) ( 5, 8) ( 5, 9)
( 6, 8)

**DIRECT CONNECTIONS = 27**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 7) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8)
( 5, 6) ( 5, 7) ( 5, 8) ( 6, 8)

**DIRECT CONNECTIONS = 26**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 8) ( 2, 9)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8)
( 5, 6) ( 5, 7) ( 5, 8)
( 6, 8)

**DIRECT CONNECTIONS = 25**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8)
( 5, 6) ( 5, 7) ( 5, 8)
( 6, 8)

**Table 7.3** Amman area network topology (DC = 28- 25)

**DIRECT CONNECTIONS = 24**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 6) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 6) ( 4, 8)
( 5, 7) ( 5, 8)
( 6, 8)

**DIRECT CONNECTIONS = 23**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 8)
( 5, 7) ( 5, 8)
( 6, 8)

**DIRECT CONNECTIONS = 22**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 8)
( 5, 8) ( 6, 8)

**DIRECT CONNECTIONS = 21**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5) ( 4, 8)
( 6, 8)

**DIRECT CONNECTIONS = 20**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8) ( 3, 9)
( 4, 5)
( 6, 8)

**Table 7.4** Amman area network topology (DC = 24- 20)

**DIRECT CONNECTIONS = 19**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8)
( 4, 5)
( 6, 8)

**DIRECT CONNECTIONS = 18**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8)
( 4, 5)

**DIRECT CONNECTIONS = 17**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 4) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8)

**DIRECT CONNECTIONS = 16**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 5) ( 2, 7) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8)

**DIRECT CONNECTIONS = 15**

( 1, 2) ( 1, 3) ( 1, 4) ( 1, 5) ( 1, 6) ( 1, 7) ( 1, 8) ( 1, 9)
( 2, 3) ( 2, 6) ( 2, 8)
( 3, 4) ( 3, 5) ( 3, 6) ( 3, 8)

**Table 7.5** Amman area network topology (DC = 19-15)

LINK # ( 1)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 23

| SW # | TRAFFIC | TRUNKS | EXIST DS3 | REQUIRED | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 5952.51 | 5883 | 9.8 | 2.4 | MW | 1458750$ |
| 2 | 2990.145 | 3005 | 6 | .2 | MW | 113750$ |
| 3 | 4205.07 | 4188 | 8.6 | .15 | MW | 92500$ |
| 4 | 1545.54 | 1601 | 3.1 | .2 | MW | 141249$ |
| 5 | 2063.04 | 2112 | 4 | .45 | MW | 267000$ |
| 6 | 1504.845 | 1548 | 3 | .2 | MW | 122500$ |
| 7 | 510.6 | 555 | 2. | 0 | MW | 0 |
| 8 | 1801.8 | 1862 | 3 | .7 | MW | 402501$ |
| 9 | 765.09 | 800 | 1.7 | 0 | MW | 0 |

**Table 7.6** Microwave Network Switches Traffic Growth Factor (TGF = 1.5)

LINK # ( 2)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 23

| SW # | TRAFFI C | TRUNKS | EXIST DS3 | REQUIR ED | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 5952.51 | 5883 | 9.8 | 0 | ATM | 600000 |
| 2 | 2990.145 | 3005 | 6.1 | 0 | ATM | 600000 |
| 3 | 4205.07 | 4188 | 8.1 | 0 | ATM | 600000 |
| 4 | 1545.54 | 1601 | 3.1 | 0 | ATM | 600000 |
| 5 | 2063.04 | 2112 | 4 | 0 | ATM | 600000 |
| 6 | 1504.845 | 1548 | 3. | 0 | ATM | 600000 |
| 7 | 510.6 | 555 | 2.2 | 0 | ATM | 600000 |
| 8 | 1801.8 | 1862 | 3.2 | 0 | ATM | 600000 |
| 9 | 765.09 | 800 | 1.7 | 0 | ATM | 600000 |

**Table 7.7 SONET** Network Switches (TGF = 1.5)

LINK # ( 3)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 23

| SW # | TRAFFI C | TRUNK | EXIST DS3 | REQUIR E | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 11905.02 | 10865 | 9.825 | 4.322135 | ATM | 3193281.3 |
| 2 | 5980.29 | 5500 | 6.070833 | 5.3875 | MW | 3232499.9 |
| 3 | 8410.141 | 7703 | 8.570833 | 1.459115 | ATM | 1475468.7 |
| 4 | 3091.08 | 2884 | 3.1 | 2.908333 | MW | 1745000 |
| 5 | 4126.081 | 3827 | 3.95 | 4.022917 | MW | 2413750.1 |
| 6 | 3009.69 | 2797 | 3.020833 | 2.80625 | MW | 1683750.1 |
| 7 | 1021.2 | 978 | 2.1625 | 0 | MW | 0 |
| 8 | 3603.6 | 3356 | 3.208333 | 3.783333 | MW | 2270000 |
| 9 | 1530.18 | 1436 | 1.683333 | 1.308333 | MW | 785000 |

**Table 7.8** Two **ATM** Switches (TGF = 3)

LINK # ( 4)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 23

| SW # | TRAFFI C | TRUNK | EXIST DS3 | REQUIR E | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 11905.02 | 10865 | 9.825 | 4.322135 | ATM | 3193281.3 |
| 2 | 5980.29 | 5500 | 6.070833 | 1.090625 | ATM | 1254375.0 |
| 3 | 8410.141 | 7703 | 8.570833 | 1.459115 | ATM | 1475468.7 |
| 4 | 3091.08 | 2884 | 3.1 | 2.908333 | MW | 1745000 |
| 5 | 4126.081 | 3827 | 3.95 | 4.022917 | MW | 2413750.1 |
| 6 | 3009.69 | 2797 | 3.020833 | 2.80625 | MW | 1683750.1 |
| 7 | 1021.2 | 978 | 2.1625 | 0 | MW | 0 |
| 8 | 3603.6 | 3356 | 3.208333 | 3.783333 | MW | 2270000 |
| 9 | 1530.18 | 1436 | 1.683333 | 1.308333 | MW | 785000 |

**Table 7.9** Three **ATM** switches (TGF = 3)

LINK # ( 5)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 20

| SW # | TRAFFI C | TRUNK | EXIST DS3 | REQUIR E | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 20556.72 | 18659 | 9.825 | 14.47057 | ATM | 9282343.5 |
| 2 | 8970.436 | 8195 | 6.070833 | 4.59974 | ATM | 3359843.7 |
| 3 | 12615.21 | 11492 | 8.570833 | 6.392708 | ATM | 4435625 |
| 4 | 4636.62 | 4263 | 3.1 | 5.78125 | MW | 3468750 |
| 5 | 6189.12 | 5661 | 3.95 | 7.84375 | MW | 4706250 |
| 6 | 4514.535 | 4154 | 3.020833 | 5.633333 | MW | 3380000 |
| 7 | 1531.8 | 1426 | 2.1625 | .8083333 | MW | 485000.00 |
| 8 | 5405.4 | 4957 | 3.208333 | 3.246094 | ATM | 2547656.3 |
| 9 | 2295.27 | 2127 | 1.683333 | 2.747917 | MW | 1648750.2 |

**Table 7.10** Four **ATM** Switches, link 5 (TGF = 4.5)

LINK # ( 6)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 20

| SW # | TRAFFI C | TRUNK | EXIST DS3 | REQUIR E | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 20556.72 | 18659 | 9.825 | 14.47057 | ATM | 9282343.5 |
| 2 | 8970.436 | 8195 | 6.070833 | 4.59974 | ATM | 3359843.7 |
| 3 | 12615.21 | 11492 | 8.570833 | 6.392708 | ATM | 4435625 |
| 4 | 4636.62 | 4263 | 3.1 | 5.78125 | MW | 3468750 |
| 5 | 6189.12 | 5661 | 3.95 | 3.421094 | ATM | 2652656.2 |
| 6 | 4514.535 | 4154 | 3.020833 | 5.633333 | MW | 3380000 |
| 7 | 1531.8 | 1426 | 2.1625 | .8083333 | MW | 485000.00 |
| 8 | 5405.4 | 4957 | 3.208333 | 7.11875 | MW | 4271250.1 |
| 9 | 2295.27 | 2127 | 1.683333 | 2.747917 | MW | 1648750.2 |

**Table 7.11** Four **ATM** switches, link 6 (TGF = 4.5)

LINK # ( 7)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 20

| SW # | TRAFFIC | TRUNK | EXIST DS3 | REQUIRE | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 20556.72 | 18659 | 9.825 | 14.47057 | ATM | 9282343.5 |
| 2 | 8970.436 | 8195 | 6.070833 | 4.59974 | ATM | 3359843.7 |
| 3 | 12615.21 | 11492 | 8.570833 | 6.392708 | ATM | 4435625 |
| 4 | 4636.62 | 4263 | 3.1 | 5.78125 | MW | 3468750 |
| 5 | 6189.12 | 5661 | 3.95 | 3.421094 | ATM | 2652656.2 |
| 6 | 4514.535 | 4154 | 3.020833 | 5.633333 | MW | 3379999.9 |
| 7 | 1531.8 | 1426 | 2.1625 | .8083333 | MW | 485000.00 |
| 8 | 5405.4 | 4957 | 3.208333 | 3.246094 | ATM | 2547656.3 |
| 9 | 2295.27 | 2127 | 1.683333 | 2.747917 | MW | 1648750.2 |

**Table 7.12** Five **ATM** switches configuration (TGF = 4.5)

LINK # ( 8)

TOTAL NUMBER OF DIRECT CONNECTED NODES = 20

| SW # | TRAFFIC | TRUNK | EXIST DS3 | REQUIRE | SW TYPE | SW COST |
|---|---|---|---|---|---|---|
| 1 | 20556.72 | 18659 | 9.825 | 14.47057 | ATM | 9282343.5 |
| 2 | 8970.436 | 8195 | 6.070833 | 4.59974 | ATM | 3359843.7 |
| 3 | 12615.21 | 11492 | 8.570833 | 6.392708 | ATM | 4435625 |
| 4 | 4636.62 | 4263 | 3.1 | 5.78125 | MW | 3468750 |
| 5 | 6189.12 | 5661 | 3.95 | 7.84375 | MW | 4706250 |
| 6 | 4514.535 | 4154 | 3.020833 | 5.633333 | MW | 3379999.9 |
| 7 | 1531.8 | 1426 | 2.1625 | .8083333 | MW | 485000.00 |
| 8 | 5405.4 | 4957 | 3.208333 | 3.246094 | ATM | 2547656.3 |
| 9 | 2295.27 | 2127 | 1.683333 | 1.086198 | ATM | 1251718.8 |

**Table 7.13** Five **ATM** switches configuration, link 8 (TGF = 4.5)

TRAFFIC GROWTH FACTOR = 1.5
MULTIPLEXING FACTOR = ( 480) FOR MW & ( 2376) FOR **ATM**
LEVEL OF CONGESTION = .05
AMMAN RUNNING COST PER MINUTE

| TRUNKS | MW | SONET | 13 | 123 | 1238 | 1235 | 12358 | 13289 |
|---|---|---|---|---|---|---|---|---|
| 35 | 0.01276 | 0.00875 | 0.01249 | 0.01235 | 0.01217 | 0.01199 | 0.01169 | 0.01199 |
| 34 | 0.01233 | 0.00846 | 0.01206 | 0.01193 | 0.01175 | 0.01156 | 0.01126 | 0.01157 |
| 33 | 0.0119 | 0.00816 | 0.01163 | 0.01149 | 0.01132 | 0.01113 | 0.01083 | 0.01114 |
| 32 | 0.0113 | 0.00775 | 0.01103 | 0.0109 | 0.01072 | 0.01054 | 0.01024 | 0.01054 |
| 31 | 0.01099 | 0.00753 | 0.01072 | 0.01059 | 0.01041 | 0.01022 | 0.00993 | 0.01023 |
| 30 | 0.01049 | 0.00719 | 0.01022 | 0.01009 | 0.00991 | 0.00973 | 0.00943 | 0.00973 |
| 29 | 0.01 | 0.00685 | 0.00974 | 0.0096 | 0.00942 | 0.00924 | 0.00895 | 0.00925 |
| 28 | 0.00951 | 0.00651 | 0.00925 | 0.00911 | 0.00894 | 0.00875 | 0.00846 | 0.00876 |
| 27 | 0.00905 | 0.0062 | 0.00879 | 0.00866 | 0.00849 | 0.00831 | 0.00801 | 0.00831 |
| 26 | 0.00861 | 0.00589 | 0.00835 | 0.00822 | 0.00804 | 0.00787 | 0.00758 | 0.00787 |
| 25 | 0.00828 | 0.00565 | 0.00802 | 0.00789 | 0.00772 | 0.00754 | 0.00726 | 0.00762 |
| 24 | 0.00774 | 0.00528 | 0.00748 | 0.00735 | 0.00718 | 0.00701 | 0.00673 | 0.00708 |
| 23 | 0.00716 | 0.00489 | 0.00691 | 0.00678 | 0.00661 | 0.00644 | 0.00616 | 0.00651 |
| 22 | 0.00674 | 0.0046 | 0.00649 | 0.00637 | 0.0062 | 0.00603 | 0.00576 | 0.0061 |
| 21 | 0.00666 | 0.00429 | 0.00641 | 0.00629 | 0.00612 | 0.0056 | 0.00543 | 0.00602 |
| 20 | 0.00615 | 0.00395 | 0.00591 | 0.00579 | 0.00563 | 0.00511 | 0.00495 | 0.00553 |
| 19 | 0.00588 | 0.00376 | 0.00564 | 0.00552 | 0.00536 | 0.00485 | 0.00469 | 0.00531 |
| 18 | 0.0057 | 0.00352 | 0.00546 | 0.00535 | 0.00502 | 0.00469 | 0.00437 | 0.00498 |
| 17 | 0.00529 | 0.00325 | 0.00506 | 0.00495 | 0.00463 | 0.00431 | 0.00399 | 0.00459 |
| 16 | 0.00535 | 0.00289 | 0.00512 | 0.0048 | 0.00449 | 0.00417 | 0.00386 | 0.00445 |
| 15 | 0.00507 | 0.00259 | 0.00485 | 0.00435 | 0.00404 | 0.00383 | 0.00353 | 0.004 |

**Table 7.14** Running cost per minute (Amman area network)

TRAFFIC GROWTH FACTOR = 3
MULTIPLEXING FACTOR = ( 480) FOR MW & ( 2376) FOR **ATM**
LEVEL OF CONGESTION = .05
AMMAN NETWORK HARDWARE COST PER MONTH

| TRUNKS | MW | SONET | 13 | 123 | 1238 | 1235 | 12358 | 12389 |
|---|---|---|---|---|---|---|---|---|
| 35 | 406812 | 1165084 | 296588 | 277206 | 272387 | 358912 | 387295 | 283162 |
| 34 | 407269 | 1128951 | 296749 | 277367 | 272547 | 359073 | 387456 | 283385 |
| 33 | 408389 | 1093258 | 297294 | 277912 | 273170 | 359618 | 388079 | 284007 |
| 32 | 409842 | 1031224 | 298030 | 278648 | 273907 | 360355 | 388815 | 284744 |
| 31 | 412498 | 1019603 | 299472 | 280091 | 275349 | 361797 | 390258 | 286295 |
| 30 | 414490 | 974508 | 301465 | 282083 | 277341 | 362863 | 391324 | 288287 |
| 29 | 417312 | 933109 | 303026 | 283644 | 278903 | 364425 | 392885 | 289950 |
| 28 | 422334 | 896612 | 306040 | 286658 | 281917 | 367439 | 395899 | 292964 |
| 27 | 428145 | 867041 | 309423 | 290041 | 285299 | 370946 | 399406 | 296471 |
| 26 | 433748 | 837548 | 312668 | 293418 | 288676 | 374323 | 402784 | 299849 |
| 25 | 441799 | 832619 | 317412 | 298310 | 293569 | 379215 | 407676 | 294920 |
| 24 | 448855 | 787226 | 321565 | 302463 | 297722 | 383500 | 411961 | 299073 |
| 23 | 456865 | 735788 | 326291 | 307189 | 302448 | 388227 | 416687 | 303799 |
| 22 | 467552 | 716022 | 332745 | 313643 | 308901 | 394836 | 423297 | 310253 |
| 21 | 478010 | 689356 | 338994 | 319892 | 315290 | 401233 | 396631 | 316642 |
| 20 | 490254 | 653845 | 346327 | 327225 | 322787 | 408566 | 404127 | 324138 |
| 19 | 502580 | 658229 | 353891 | 334789 | 330351 | 416129 | 411691 | 328522 |
| 18 | 518642 | 654987 | 363602 | 344501 | 340226 | 425841 | 421566 | 338397 |
| 17 | 534828 | 638541 | 373384 | 354282 | 350007 | 435794 | 431519 | 348179 |
| 16 | 553172 | 596883 | 384522 | 365584 | 361309 | 447096 | 442821 | 359481 |
| 15 | 575957 | 574601 | 398421 | 379661 | 375387 | 424814 | 420539 | 373558 |

**Table 7.15** Network hardware cost per month (Amman area network)

TRAFFIC GROWTH FACTOR = 1.5
MULTIPLEXING FACTOR = ( 480) FOR MW & ( 2376) FOR **ATM**
LEVEL OF CONGESTION = .05
AMMAN NETWORK INVESTMENT YEARS

| TRUNKS | SONET | 13 | 123 | 1238 | 1235 | 12358 | 12389 |
|---|---|---|---|---|---|---|---|
| 35 | 3.6 | 1.1 | 1.6 | 1.5 | 2.8 | 2.7 | 1.5 |
| 34 | 3.6 | 1.1 | 1.6 | 1.5 | 2.8 | 2.7 | 1.5 |
| 33 | 3.6 | 1.1 | 1.6 | 1.5 | 2.8 | 2.7 | 1.5 |
| 32 | 3.5 | 1.1 | 1.6 | 1.5 | 2.8 | 2.7 | 1.5 |
| 31 | 3.6 | 1.1 | 1.5 | 1.5 | 2.8 | 2.7 | 1.5 |
| 30 | 3.5 | 1.1 | 1.5 | 1.5 | 2.8 | 2.6 | 1.5 |
| 29 | 3.5 | 1 | 1.5 | 1.4 | 2.7 | 2.6 | 1.5 |
| 28 | 3.4 | 0.9 | 1.4 | 1.4 | 2.7 | 2.6 | 1.5 |
| 27 | 3.4 | 0.7 | 1.3 | 1.3 | 2.6 | 2.5 | 1.4 |
| 26 | 3.4 | 0.5 | 1.2 | 1.2 | 2.6 | 2.5 | 1.4 |
| 25 | 3.4 | 0.3 | 1 | 1.1 | 2.5 | 2.5 | 1.2 |
| 24 | 3.3 | 0.1 | 0.9 | 1 | 2.4 | 2.4 | 1.1 |
| 23 | 3.2 | -0.1 | 0.8 | 0.9 | 2.4 | 2.3 | 1 |
| 22 | 3.1 | -0.4 | 0.6 | 0.8 | 2.3 | 2.3 | 0.9 |
| 21 | 2.6 | -0.7 | 0.4 | 0.7 | 1.4 | 1.4 | 0.8 |
| 20 | 2.5 | -1.1 | 0.1 | 0.5 | 1.4 | 1.4 | 0.7 |
| 19 | 2.5 | -1.4 | -0.1 | 0.4 | 1.3 | 1.3 | 0.6 |
| 18 | 2.2 | -1.8 | -0.4 | 0.1 | 1.2 | 1.1 | 0.3 |
| 17 | 2.2 | -2 | -0.5 | 0.1 | 1.1 | 1 | 0.2 |
| 16 | 1.5 | -2.2 | -0.4 | 0 | 0.9 | 0.9 | 0.1 |
| 15 | 1.2 | -2.8 | -0.5 | -0.1 | 0.4 | 0.5 | 0 |

**Table 7.16** Number of investment years

TRAFFIC GROWTH FACTOR = 4.5
MULTIPLEXING FACTOR = ( 480) FOR MW & ( 2376) FOR **ATM**
LEVEL OF CONGESTION = .05
AMMAN TOTAL NETWORK COST PER MINUTE

| TRUNKS | MW | SONET | 13 | 123 | 1238 | 1235 | 12358 | 12389 |
|---|---|---|---|---|---|---|---|---|
| 35 | 0.05054 | 0.0814 | 0.04045 | 0.03776 | 0.03646 | 0.0411 | 0.04162 | 0.03668 |
| 34 | 0.05041 | 0.07918 | 0.04028 | 0.0376 | 0.03631 | 0.04094 | 0.04146 | 0.03653 |
| 33 | 0.05027 | 0.07701 | 0.04013 | 0.03745 | 0.03616 | 0.04078 | 0.0413 | 0.03638 |
| 32 | 0.05017 | 0.07328 | 0.04 | 0.03733 | 0.03604 | 0.04065 | 0.04117 | 0.03626 |
| 31 | 0.05018 | 0.07233 | 0.03995 | 0.03728 | 0.036 | 0.0406 | 0.04111 | 0.03617 |
| 30 | 0.05005 | 0.06956 | 0.03984 | 0.03719 | 0.03591 | 0.04042 | 0.04093 | 0.03608 |
| 29 | 0.04993 | 0.06695 | 0.03967 | 0.03702 | 0.03575 | 0.04023 | 0.04075 | 0.03592 |
| 28 | 0.04986 | 0.06448 | 0.03951 | 0.03688 | 0.03562 | 0.04007 | 0.04058 | 0.03579 |
| 27 | 0.04995 | 0.06239 | 0.03948 | 0.03687 | 0.03562 | 0.03992 | 0.04042 | 0.0358 |
| 26 | 0.05004 | 0.06034 | 0.03946 | 0.03688 | 0.03564 | 0.0399 | 0.04041 | 0.03581 |
| 25 | 0.05008 | 0.05953 | 0.03935 | 0.03681 | 0.03558 | 0.0398 | 0.0403 | 0.03526 |
| 24 | 0.05003 | 0.05661 | 0.03917 | 0.03665 | 0.03544 | 0.03963 | 0.04012 | 0.03511 |
| 23 | 0.04999 | 0.05337 | 0.03899 | 0.03649 | 0.03529 | 0.03943 | 0.03992 | 0.03497 |
| 22 | 0.05004 | 0.05175 | 0.03886 | 0.0364 | 0.03521 | 0.03931 | 0.03979 | 0.0349 |
| 21 | 0.05026 | 0.04982 | 0.0389 | 0.03647 | 0.03525 | 0.03924 | 0.03801 | 0.03494 |
| 20 | 0.05044 | 0.04741 | 0.03889 | 0.0365 | 0.0353 | 0.03922 | 0.03802 | 0.03499 |
| 19 | 0.05068 | 0.04712 | 0.03892 | 0.03657 | 0.03539 | 0.03925 | 0.03807 | 0.03489 |
| 18 | 0.05097 | 0.04629 | 0.03897 | 0.03666 | 0.03546 | 0.03929 | 0.03809 | 0.03497 |
| 17 | 0.0511 | 0.04483 | 0.03887 | 0.0366 | 0.03542 | 0.03919 | 0.03801 | 0.03494 |
| 16 | 0.05141 | 0.04216 | 0.03892 | 0.03664 | 0.03548 | 0.03918 | 0.03802 | 0.03501 |
| 15 | 0.05177 | 0.04038 | 0.03899 | 0.0367 | 0.03557 | 0.03746 | 0.03633 | 0.03512 |

**Table 7.17** Network cost per minute, hardware included

***Sub NATIONAL***

Since national network nodes connected only with national and international centers by a STAR topology, analyzing this network will have a different approach from Amman area. Nine cases will be studied for traffic growth factors 1, 1.5, 3, and 4.5:

1) Complete national microwave network.

2) Complete national **SONET** network.

3) Nodes # 03, national, and International as **ATM** switches.

4) Nodes # 08, national, and International as **ATM** switches.

5) Nodes # 05, national, and International as **ATM** switches.

6) Nodes # 09, national, and International as **ATM** switches.

7) Nodes # 02, national, and International as **ATM** switches.

8) Nodes # 04, national, and International as **ATM** switches.

9) Nodes # 05, #09, #08, national, and International as **ATM** switches.

Numbers 03, 08, 05, 09, 02, and 04 represents the area code for the regional exchanges. Output files for this subroutines will be CPM, Hardware cost, TCPM, and number of return on investment years .

| TGF | 1 | 1.5 | 3 | 4.5 |
|---|---|---|---|---|
| MW | 0.12138 | 0.08092 | 0.04202 | 0.03222 |
| **SONET** | 0.08105 | 0.05403 | 0.02702 | 0.01801 |
| 03 | 0.10965 | 0.0731 | 0.03812 | 0.02961 |
| 08 | 0.11729 | 0.0782 | 0.04066 | 0.03131 |
| 05 | 0.11511 | 0.07674 | 0.03994 | 0.03083 |
| 09 | 0.11839 | 0.07892 | 0.03946 | 0.02947 |
| 02 | 0.11184 | 0.07456 | 0.03884 | 0.02694 |
| 04 | 0.11566 | 0.0771 | 0.04012 | 0.03095 |
| (05-9-8) | 0.10804 | 0.07202 | 0.03601 | 0.02717 |

**Table 7.18** National Cost per minute, Traffic growth versus link type

| TGF | 1 | 1.5 | 3 | 4.5 |
|---|---|---|---|---|
| MW | 0.12138 | 0.1035 | 0.08677 | 0.08424 |
| **SONET** | 1.62141 | 1.08094 | 0.55849 | 0.3862 |
| 03 | 0.59074 | 0.40482 | 0.22961 | 0.1752 |
| 08 | 0.28943 | 0.20358 | 0.12877 | 0.10785 |
| 05 | 0.37552 | 0.26068 | 0.15706 | 0.12658 |
| 09 | 0.24638 | 0.17062 | 0.10798 | 0.09135 |
| 02 | 0.50465 | 0.3446 | 0.19769 | 0.14972 |
| 04 | 0.35399 | 0.24596 | 0.1495 | 0.12141 |
| (05-9-8) | 0.6156 | 0.41515 | 0.22897 | 0.17141 |

**Table 7.19** National Total Cost per Minute, (congestion =.05)
Traffic growth versus link type

| TGF | 1 | 1.5 | 3 | 4.5 |
|---|---|---|---|---|
| MW | 0 | 25482.82 | 100976.7 | 176097.1 |
| **SONET** | 1158763 | 1158763 | 1199430 | 1246381 |
| 03 | 361905.8 | 374315.2 | 432167.7 | 492860.6 |
| 08 | 129489.2 | 141483.6 | 198848.5 | 259105.6 |
| 05 | 195894 | 207556.3 | 264335 | 324140.7 |
| 09 | 96286.87 | 103466.9 | 154634.8 | 209475.8 |
| 02 | 295501.1 | 304714.7 | 358494.8 | 415639.2 |
| 04 | 179292.8 | 190540.1 | 246846.6 | 306232.2 |
| (05-9-8) | 381827.2 | 387181.1 | 435459.4 | 488292.7 |

**Table 7.20** National Hardware Cost per month (congestion = .05)
Traffic growth versus link type

| TGF | 1 | 1.5 | 3 | 4.5 |
|---|---|---|---|---|
| **SONET** | 3.2 | 3.1 | 2.7 | 1.9 |
| 03 | 3.4 | 3.3 | 3.1 | 3 |
| 08 | 3.5 | 3.1 | 2.7 | 2.3 |
| 05 | 3.5 | 3.2 | 2.9 | 2.6 |
| 09 | 3.6 | 2.9 | 0.8 | 0.3 |
| 02 | 3.4 | 3.2 | 3 | 1.1 |
| 04 | 3.5 | 3.2 | 2.8 | 2.5 |
| (05-9-8) | 3.2 | 3 | 2.1 | 1.5 |

**Table 7.21** National Return on Investment(congestion .05)
Traffic growth versus link type

# CHAPTER 8

## SIMULATION RESULTS

Simulation results will be analyzed in two areas:

1) Amman metropolitan area

2) National network area.

For both cases, the following plans will be implemented:

a) One-year plane.

b) Five-year plan.

c) Ten-year plan.

## 8.1 Amman Metropolitan Area

The Amman area is where the national and international tandems located in addition to seven of the thirteen nodes in Jordan. Therefore, it means that optimizing the Amman area network will have a major effect on the national network. Due to the mesh topology for the Amman area, I will start by analyzing all the characteristics of that topology and comparing it with a partially connected network.

### 8.1.1 The One-year plan

The simulation program, as described in the previous chapter, started with mesh topology, 35 connected routes down to 15 direct connected routes. Cost per minute figure 8.1, shows that adding **ATM** switches to all nodes will produce the minimum running cost per minute (CPM). The graphs form a straight lines with approximately the same slope for all topologies. The slop decreases slightly starting at 25 links. All other connection options are almost parallel. The lowest CPM in the (123) connection which will have **ATM** switches at the three locations 1, 2, and 3 only. We can also see a higher CPM when we have a totally microwave link. Figure 8.2 shows the hardware cost for each direct connection. The cost for a complete **SONET** network with 20 direct connections is about $435,273 per month more than microwave. This indicates that implementing a complete **SONET** network in this stage is not economically acceptable. Meanwhile, the difference between microwave and a three nodes **SONET** is only $4,275 per month. In mesh microwave, where there is not much hardware to be added for rerouting, the increase in cost will be $42,877. Even though this may seem to be a big difference, it will be covered by the drop in transmission cost, as we will see in the investment chart. Figure 8.3 illustrates the graph of total cost per minute (TCPM) versus the number of direct routes connected. This figure shows that the highest cost will be for a totally **SONET** network, and indicates that links(13) and (123) intersect with complete MW links in the interval [25,20]. Figure 8.4 shows number of years versus the number of direct connections. It indicates that the (13) link type is the best link implemented in one year plans regarding both hardware and transmission factors. It shows that when direct connected routes equal (20), their transmission difference from Microwave will cover hardware cost in less than one year. The only problem with using only two **ATM** switches is that there is no backup route in case of disaster, since having three **ATM** switches has a slightly different investment period of about half year, it is more efficient to choose this option for the one year plan. The number of directly connected routes, shown in graph, could be chosen to be between 20 and 25 connections.

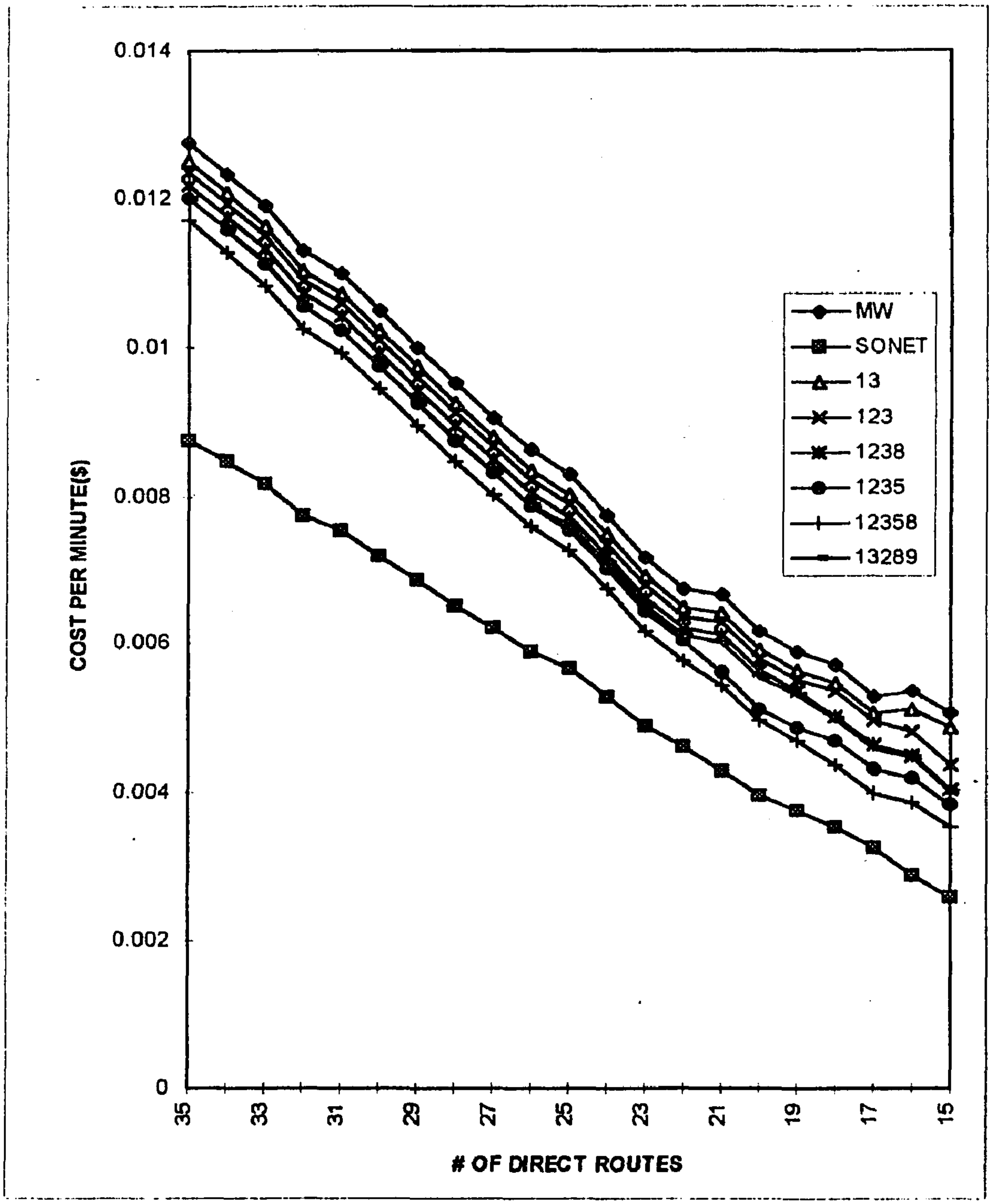


**Figure 8.1** Running CPM for one year plan ( TGF = 1.5 )

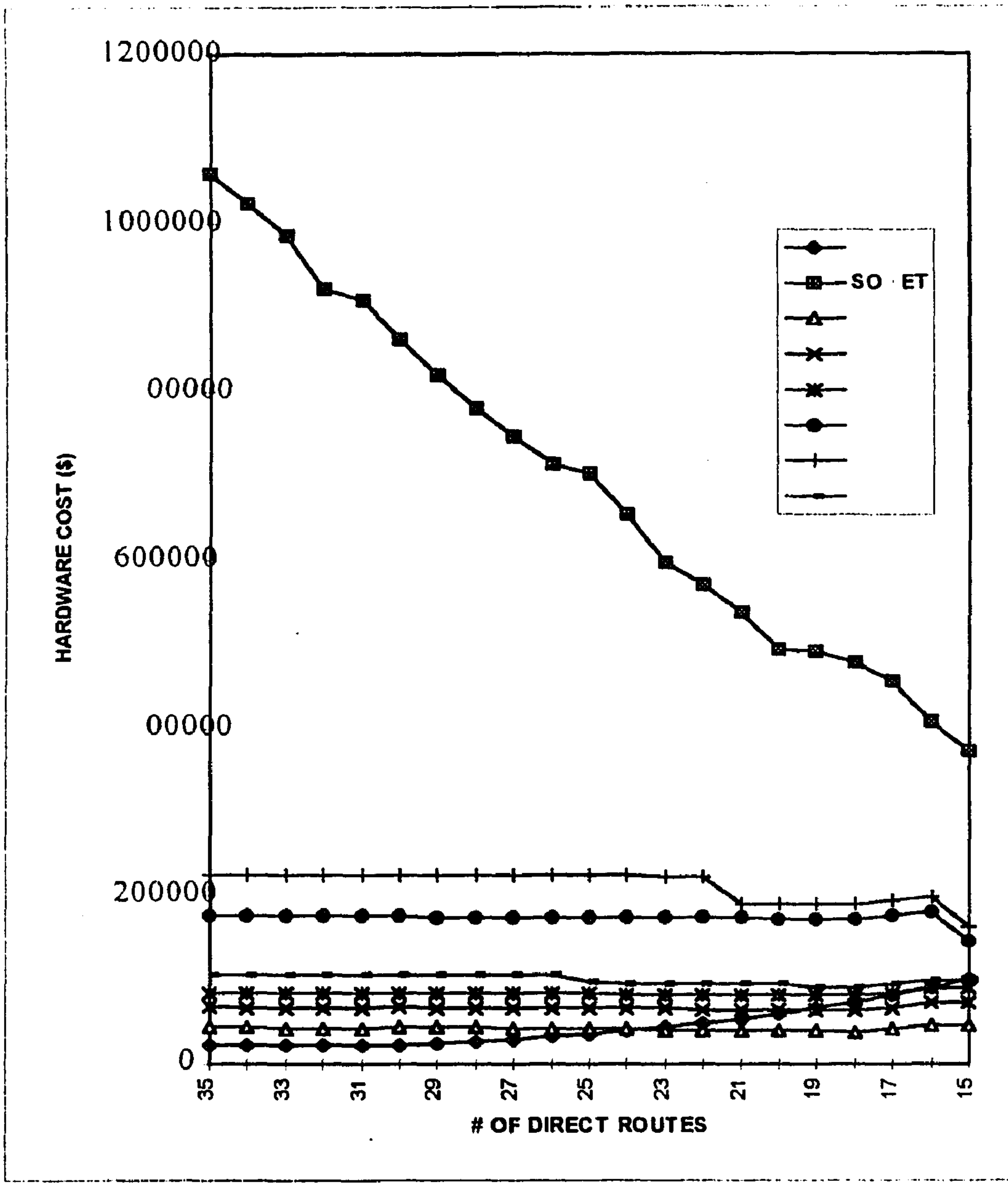


**Figure 8.2** Hardware cost per month one year plan ( TGF = 1.5 )

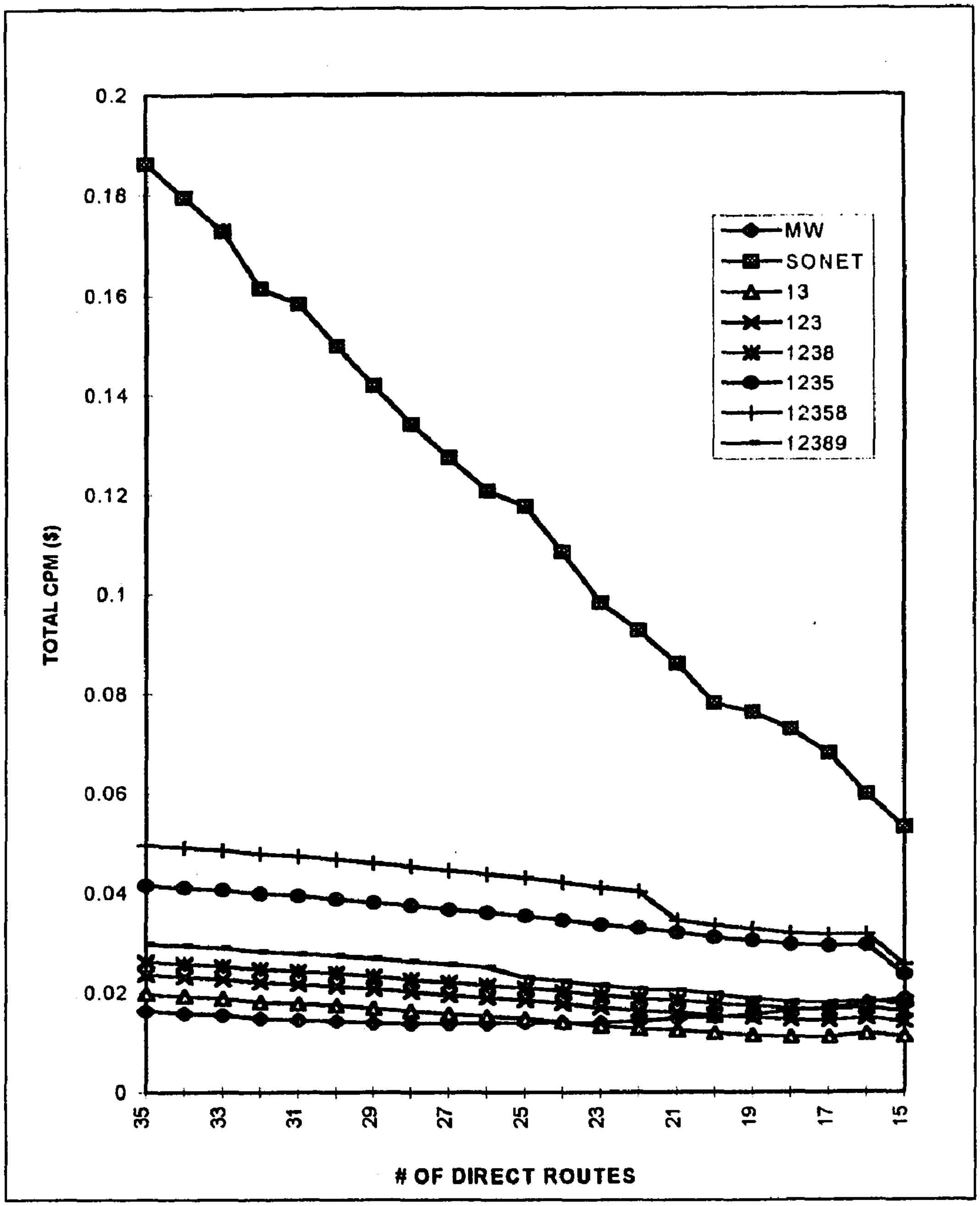


**Figure 8.3** Total CPM for one year plan ( TGF = 1.5 )

(Hardware CPM + Running CPM)

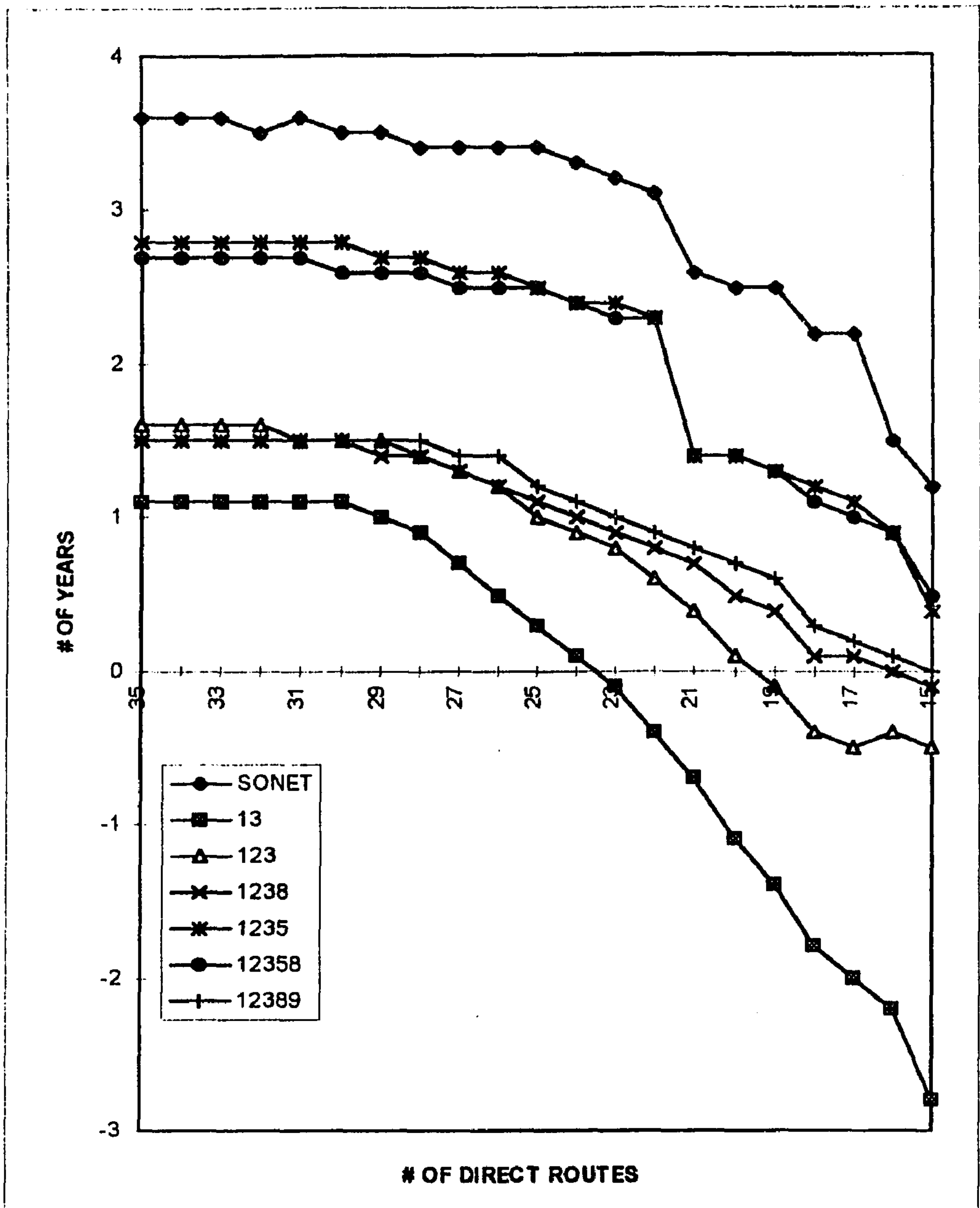


**Figure 8.4** Investment years for one year plan ( TGF = 1.5 )

Number 20 is suggested here because each node has at least three routes to allow handling of overflow and emergency situations.

Figure 8.5 shows the topology for 20 connections with three **ATM** switches. This option has two advantages: low cost and high efficiency. The three high traffic nodes will have **SONET** backbone links while all other nodes will be kept as they are for this period of time. Even more money could be saved because there may an underground construction which constructed for metallic trunks before microwave network installed.

A mobile cellular technology will start in Jordan this year. Because there is no traffic data available, I assumed that it will start for low traffic in the first year due to the high charges they asking for, which is about $1000 per subscriber. This will not be the case in the future when competition starts between this private investment and TCC when the last is turned into a partially private company next year. So we will start with the right connection and will save some money in the near future as more cellular subscribers call for this service. Therefore, an optical carrier link node (ABD) with the Mobile switching center will be economically significant in the next few years.

### 8.1.2 The Five-year plan

The one-year plan will solve the existing overload traffic and could handle some of the growing demand. Growing demand is not for telephone service only. It also includes data communications locally and as an international service, connected to the rest of the world in the information highway. This demand represented by the increased number of high-education institutions. In 1985 when the microwave network was implemented

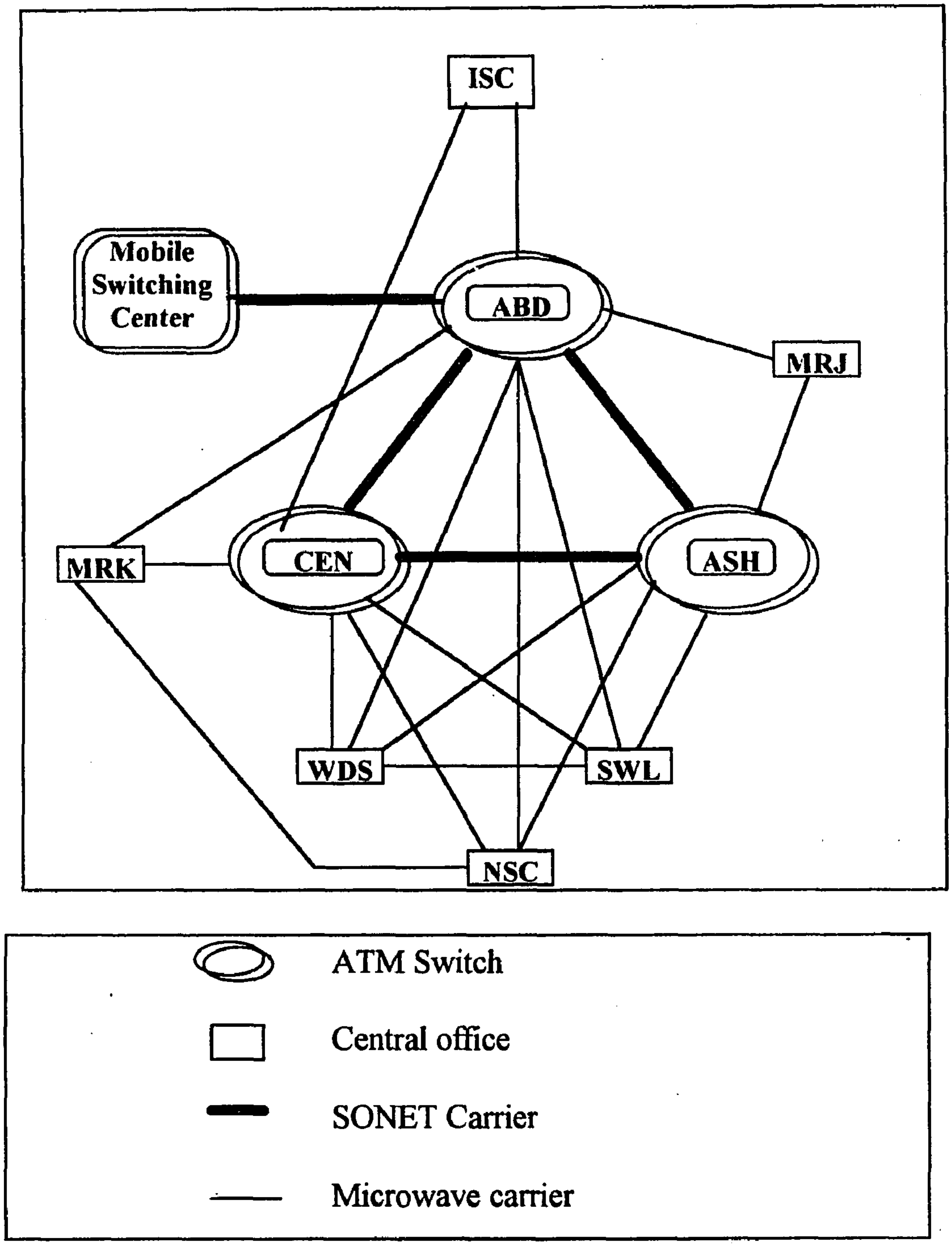


**Figure 8.5** Network topology for the one year plan in Amman area

there was only three universities in Jordan. Today, there is more than twenty one universities and more than forty community colleges, in addition to public and private schools. Now its is necessary for the central offices to have more capabilities for Centrex service, PBX, and more international communication. The five year plan expected traffic growth factor is three times the existing one. Figure 8.6 for CPM shows a significant decrease in cost per minute for our suggested (20) direct connections.

CPM was $0.006 for the network with three **ATM** switches, while it is $0.004 for the same network when traffic growth doubles. The same shows that between 24 and 15 direct routes, the connection curves for all link types, except for the complete **SONET** network are almost parallel to the horizontal axis. This means that there is no significant difference between 24 and 15 connections, which will give us another three connections we can use for rerouting. The CPM for 24, 23, and 22 are almost equal. The CPM for 24 connections is equal to $.00404 while it is $.00409, and $.00406 for 23 and 22 connections respectively.

The main conclusion drown from that chart is that when we add the national and international nodes as a **SONET** link, the cost will be the same as the three node **SONET** network. So in the five-year plan, adding two **ATM** switches for these nodes will be economically justifiable. Another result shown in this chart is a complete **SONET** network intersecting with a complete microwave at the 15 route network. The TCPM charts support the same conclusion. The TCPM for 24 direct routes will be $0.02736 if we add the national node only, while it will be $0.03597 if we add both the national and international nodes. For 20 direct routes, the TCPM is $0.02777 in the national node while it is $0.03336 for both national and international nodes which is higher than that of the 24 routes for national only but lower by $0.00261 for both nodes. The chart also shows that complete **SONET** and complete microwave intersected at 16 direct routes.

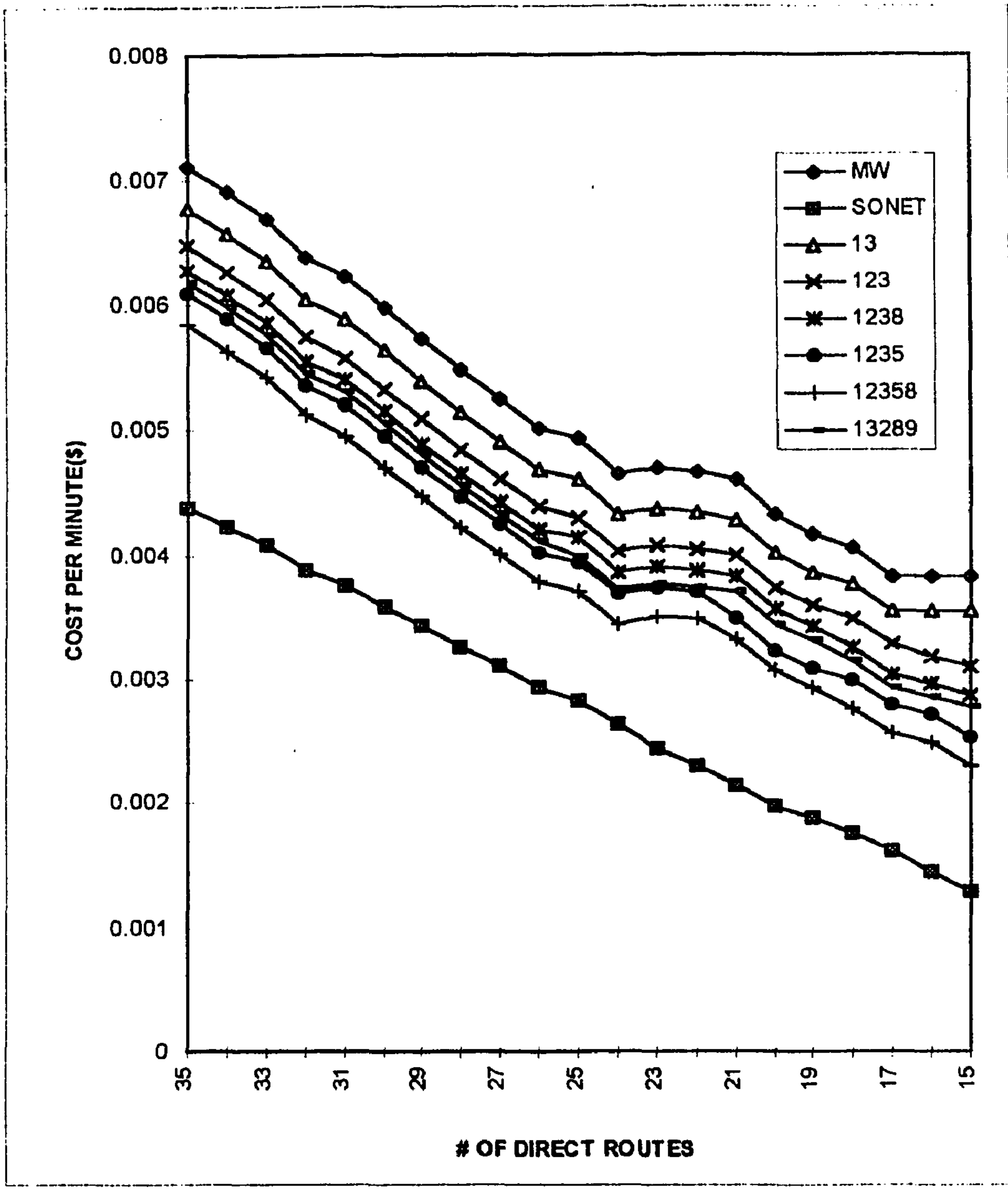


**Figure 8.6** CPM for Amman area (TGF = 3)

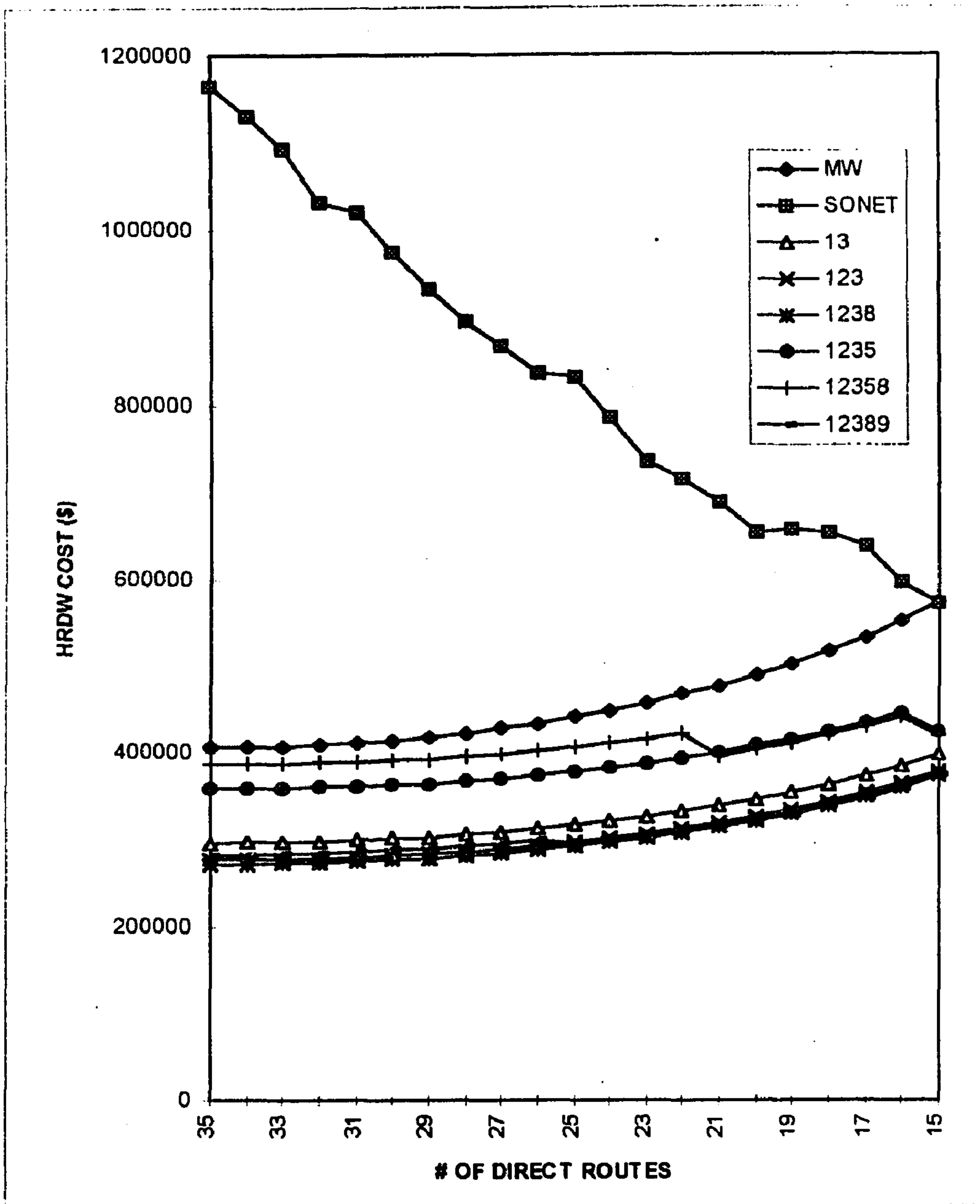


**Figure 8.7** Hardware cost per month for Amman area (TGF = 3)

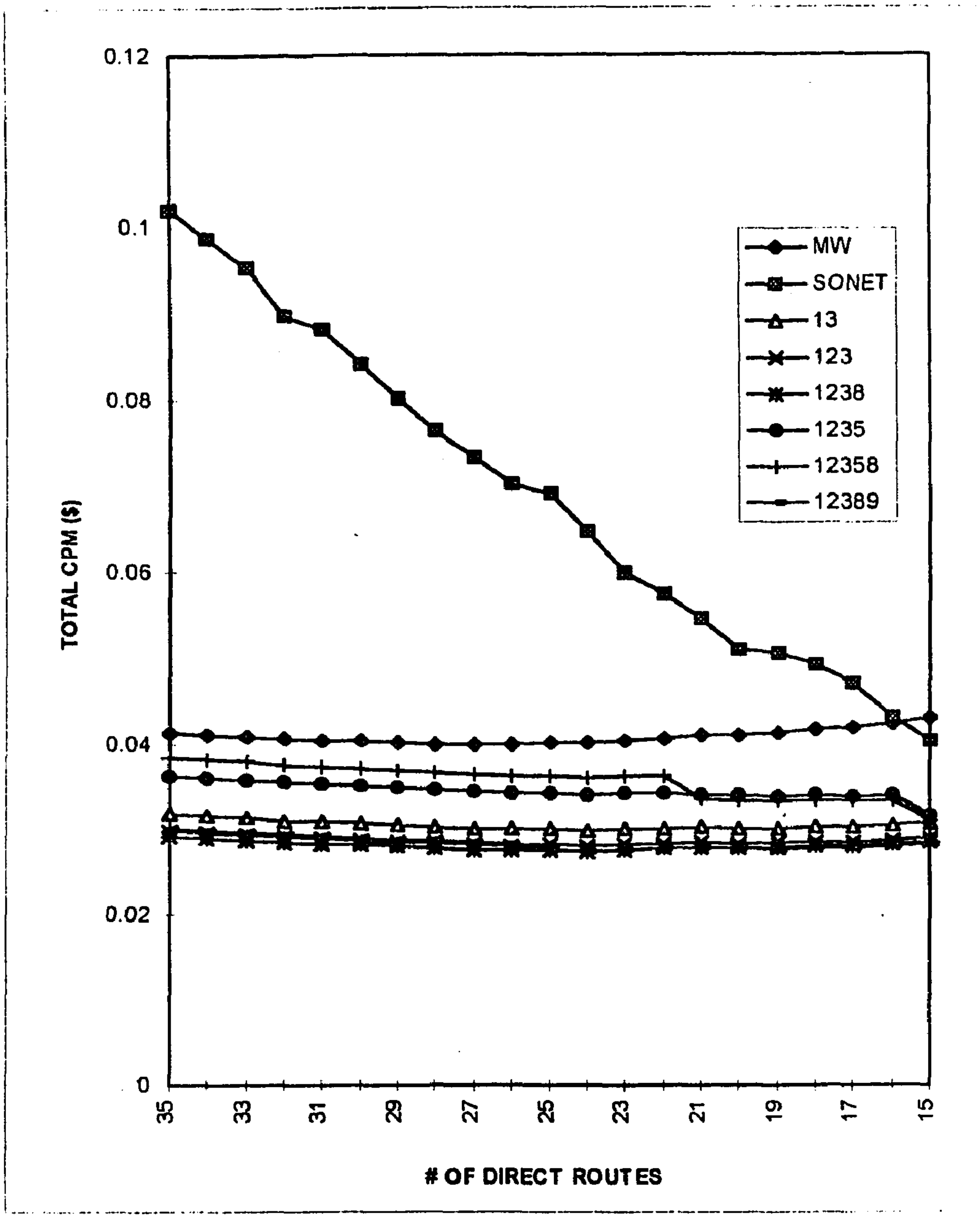


**Figure 8.8** Total CPM for Amman area (TGF = 3)

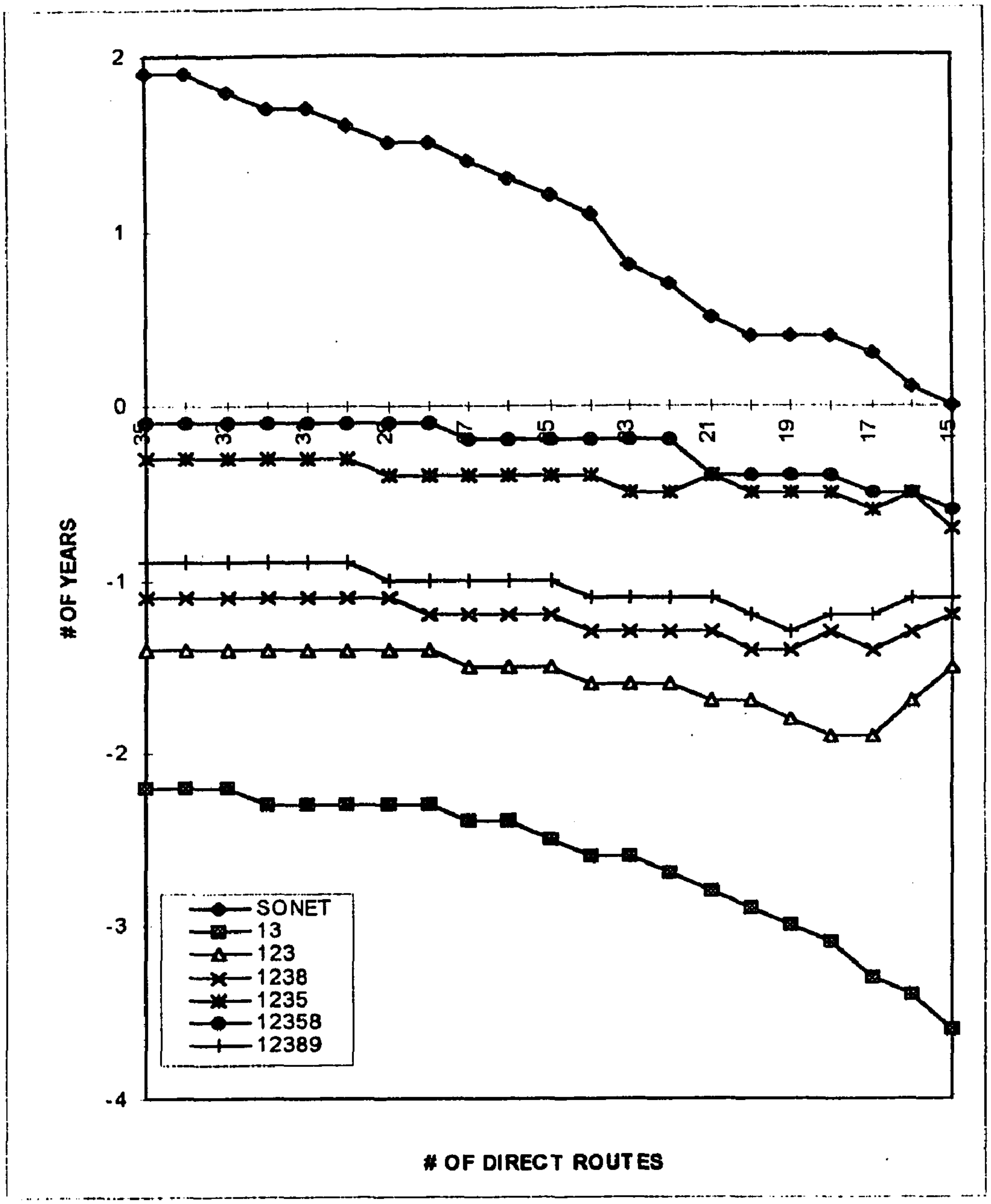


**Figure 8.9** Investment for five-year plan ( TGF = 3 )

The return on investments figure 8.9, Indicates that suggested five node **SONET** backbone curve has three steps, its worst case is when there is (27) direct connected links, the minimum value occurred between 18-15 direct connections, meanwhile, all other possibilities have a straight line parallel to the horizontal axis. Consider the interval [20,24] we can see that there is no difference in return investment among them, this lead us to say that we have two options, the first option is to continue with the same number of connections suggested in the one year plan, or as another option add three more links to have total of (24) directly connected link. Whatever option we choose hardware cost will be covered from running cost in the first year of the plan. Figures 8.10 and 8.11 shows the two network options mentioned before.

The computer age revolution today and the huge cost reduction due to competition war between vendors opened the door for small countries to IN implementation in an affordable cost. A third option suggested will not have a significant difference in costing but it will increase network efficiency and IN services. By including an SSP and SCP units located at the same location of exchange (ABD) will only cost the price of these unit. Common signaling system **SS7** is suggested in this plan. Two units are needed here: **MTP** and **TUP**. These two units will handle telephone network by providing telephone signaling between exchanges. SCCP, ISP, and TCAP are all necessary for the support of IN network. DUP and ISUP could be added in the next plan depending on users demands. Connection price will be eliminated. The connection with other **SONET** nodes will only be the cost of activation for the existing optical carrier. Two cables are needed for traffic in both opposite directions and another two as backup.

Therefore, we will have 20 more cables waiting for new service. Figure 8.12 shows the suggested network configuration, including IN.

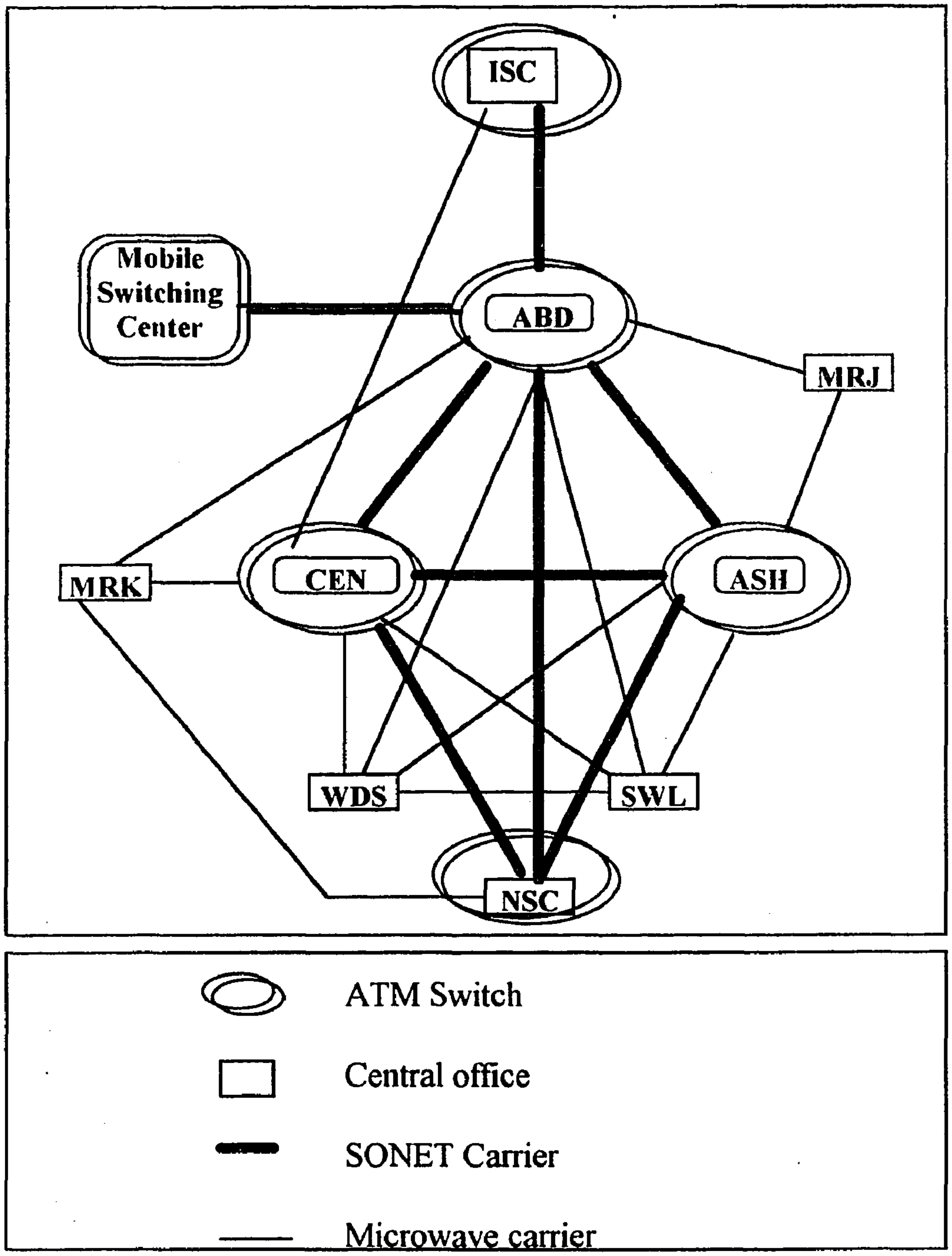


**Figure 8.10** Network topology for the five-year plan in Amman area (DC=20)

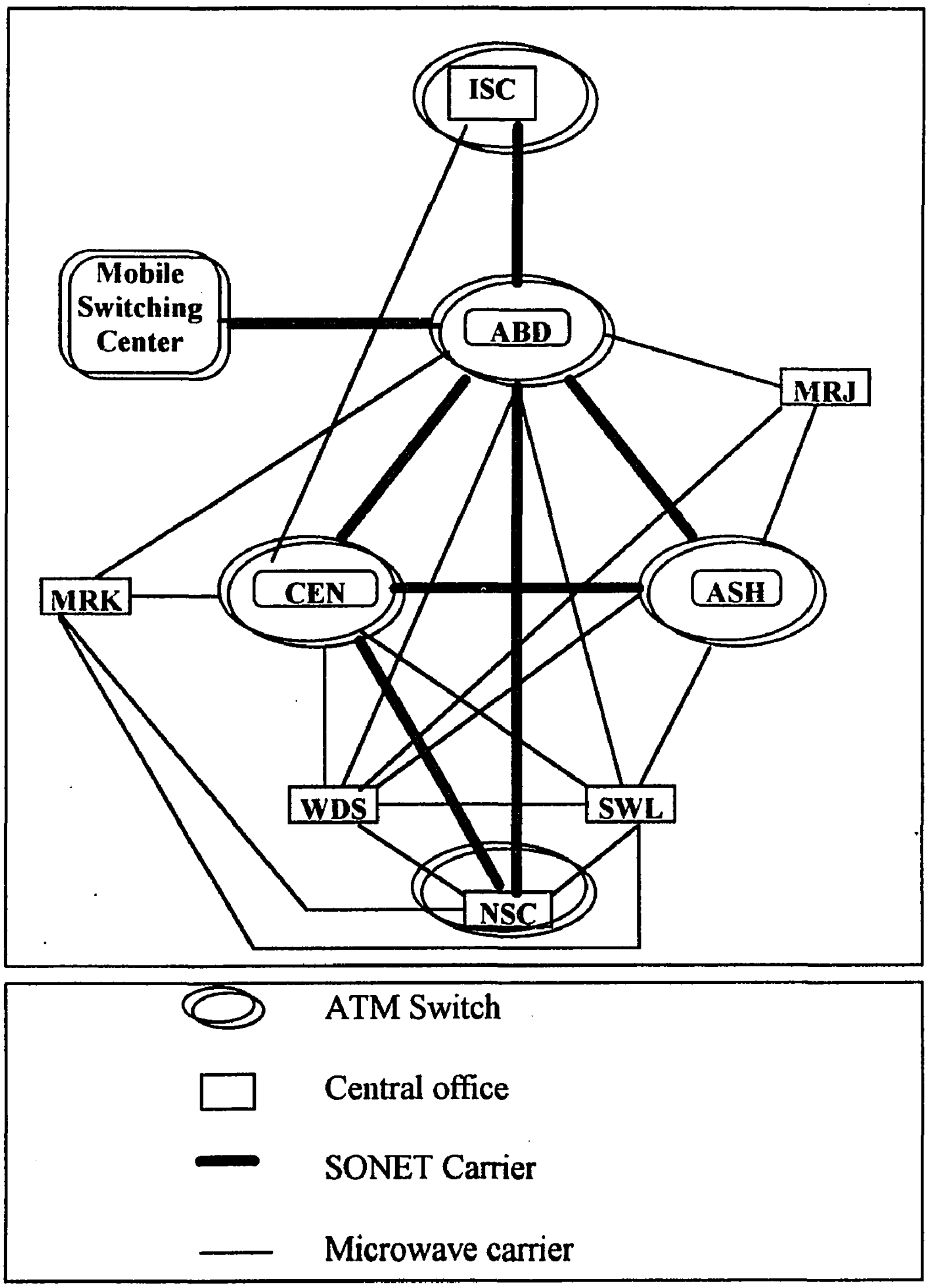


**Figure 8.11** Network topology (DC = 24 )

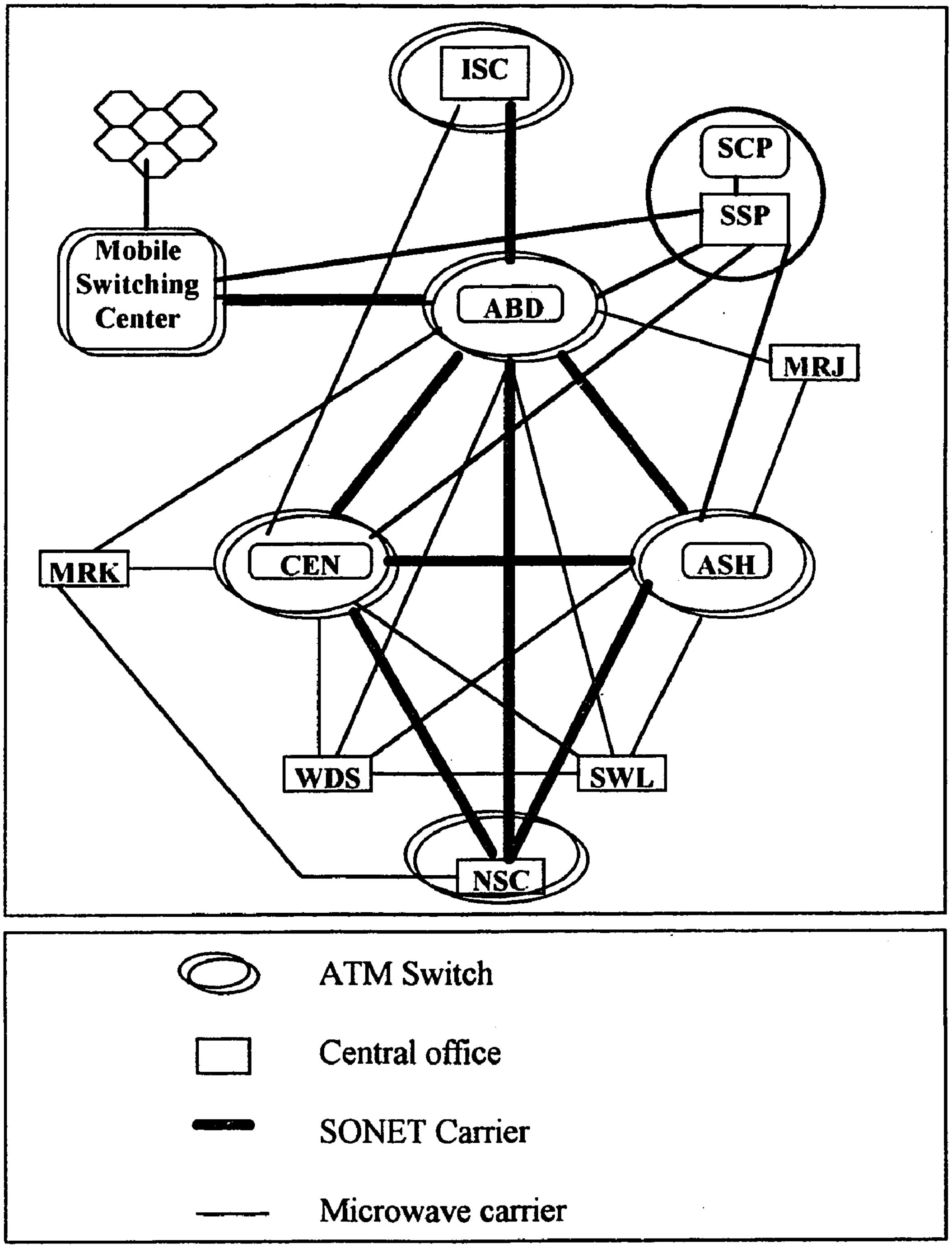


**Figure 8.12** Network topology (DC=20 ) , IN network

### 8.1.3 The Ten-year plan

This plan may start in the first year of the twenty-first century. The world will be connected with high speed-carriers traveling with information all around the glob. Call charges, as all research show, will be very low and the call duration will be increased due to the huge number of services which will be available. This includes transmission of voice, data, and multimedia. This new era of our future will have the developed countries compete in selling their products to the developing countries in the third world. All of this will have a direct effect on the grad of service and network component prices. In small countries like Jordan, new technology has a direct effect because of the high percentage of educated population as indicated by large number of the high education institutions. Therefore, they will try to have the best new technology they can afford. Consequently the ten-year plan must account for all of these factors. The main point we have to account for here is that Centrex service and PBX will take the most concern at that period. Demand for educational, medical, and other networks services will force the telecommunication companies to add more services and increase capacity of their networks. Microwave technology will still available but it will run out of bandwidth like it did in some places in the US. This will reduce the reliability and increase interference which is not acceptable for data and multimedia transmission.

Before I continue my predictions, I will show how the analysis of the present data will lead us in the right direction. CPM figure 8.13 shows a significant difference between the five year plan with five **ATM** nodes and the complete **SONET** network. I will concentrate here on the case of 20 direct connections because we can see that it will be the preferred option to be implemented for all plans. The CPM is $.00249 for a five-node **ATM**, while it is $0.00132 for a complete **SONET**, which is almost one to two ratio. Figure 8.14 shows that **SONET** intersects with microwave at 20 direct links. This means that hardware cost **SONET** and **MW** will be equal. In the other hand, updating the five-year plan to handle the traffic increased will cost about $324,138 per month while updating to a complete **SONET** network will cost $640,707 per month. This is a $316,463 per month difference. Now will shall how difference will be covered by transmission savings and for how many years. Figure 8.15 TCPM for complete **SONET** is $0.04741 while it is $0.0.3499 for the five node **SONET**. The ratio is 74 %, in this plan compared to 25% ratio for the five-year plan. We can see that it is the right time for a complete **SONET** network. Investment figure 8.16 shows that **SONET** intersects with the x- axis at zero years for 20 direct connection which means that the first year of investment will cover all hardware costs. Figure 8.17 shows the suggested network configuration utilizing IN and Mobile switching centers. This network will be complete **SONET** link. Switching centers will have the capability of handling Centrex, PBX, and multimedia transmission. Replacement of outdated equipment and any addition required are priced in the last period of the five-year plan. This may have presented some changes in the costing charts, but the cost is expected to be reduced. A direct connections are added between MSC and both of the national and international nodes to meet the expected traffic growth for that MSC center.

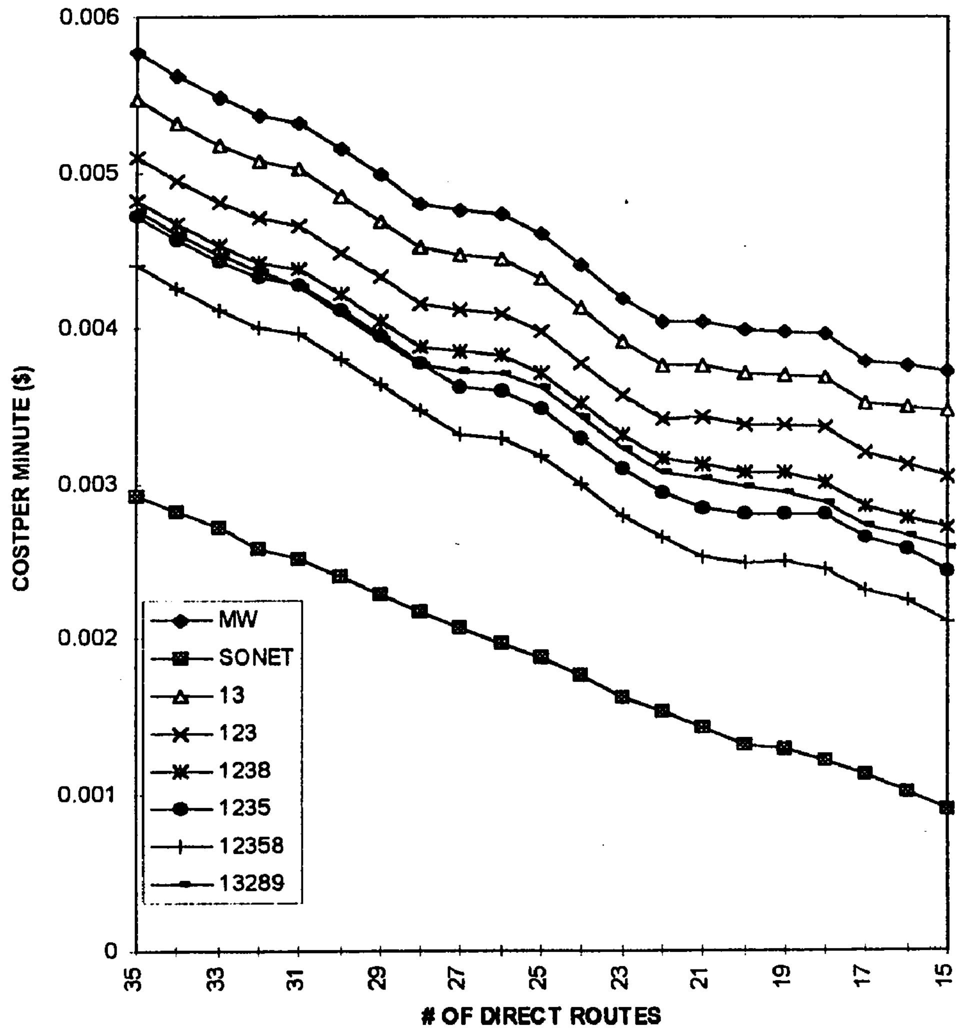


**Figure 8.13** CPM for Amman area (TGF = 4.5)

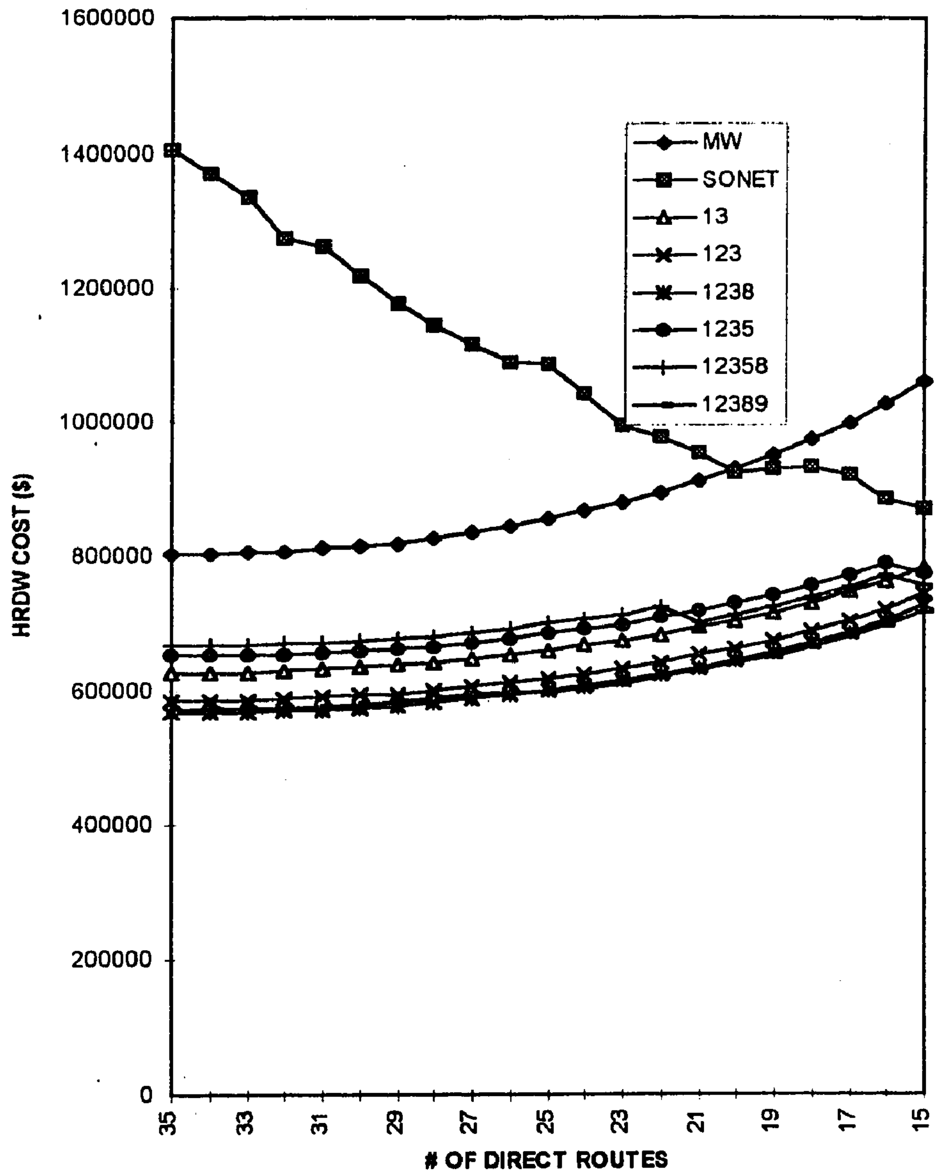


**Figure 8.14** Hardware cost per month for Amman area (TGF = 4.5)

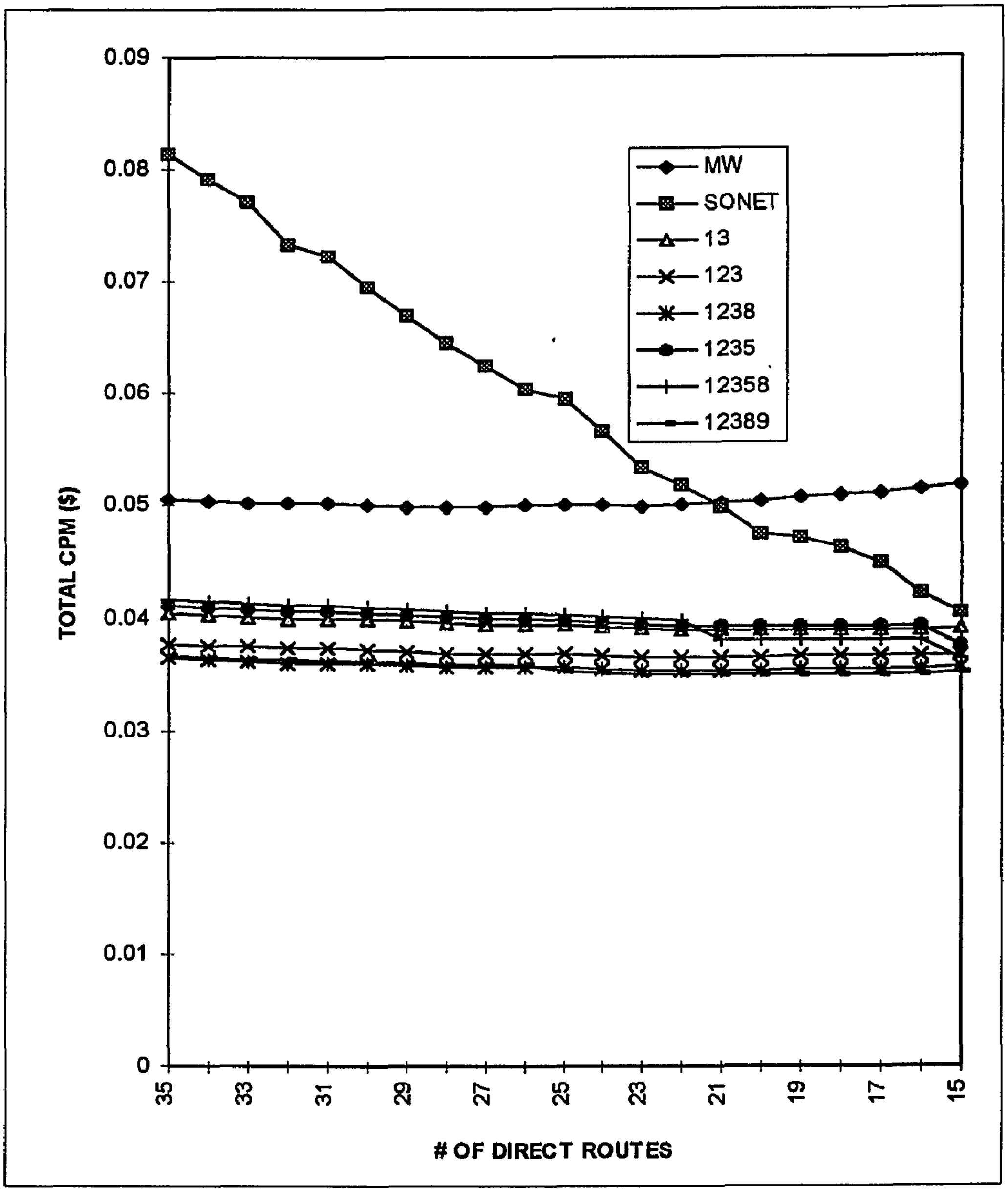


**Figure 8.15** Total CPM for Amman area (TGF = 4.5)

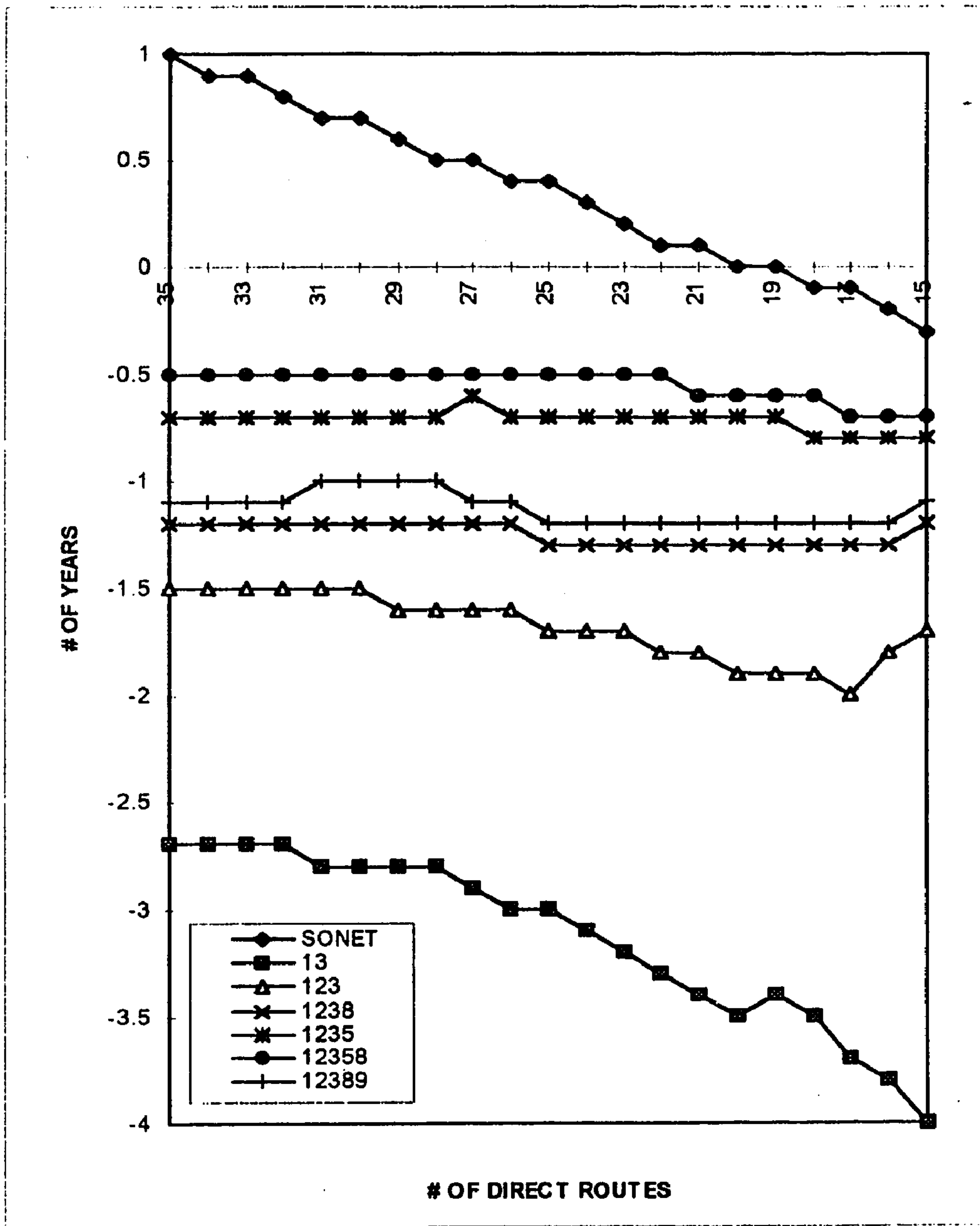


**Figure 8.16** Investment for ten-year plan ( TGF = 4.5 )

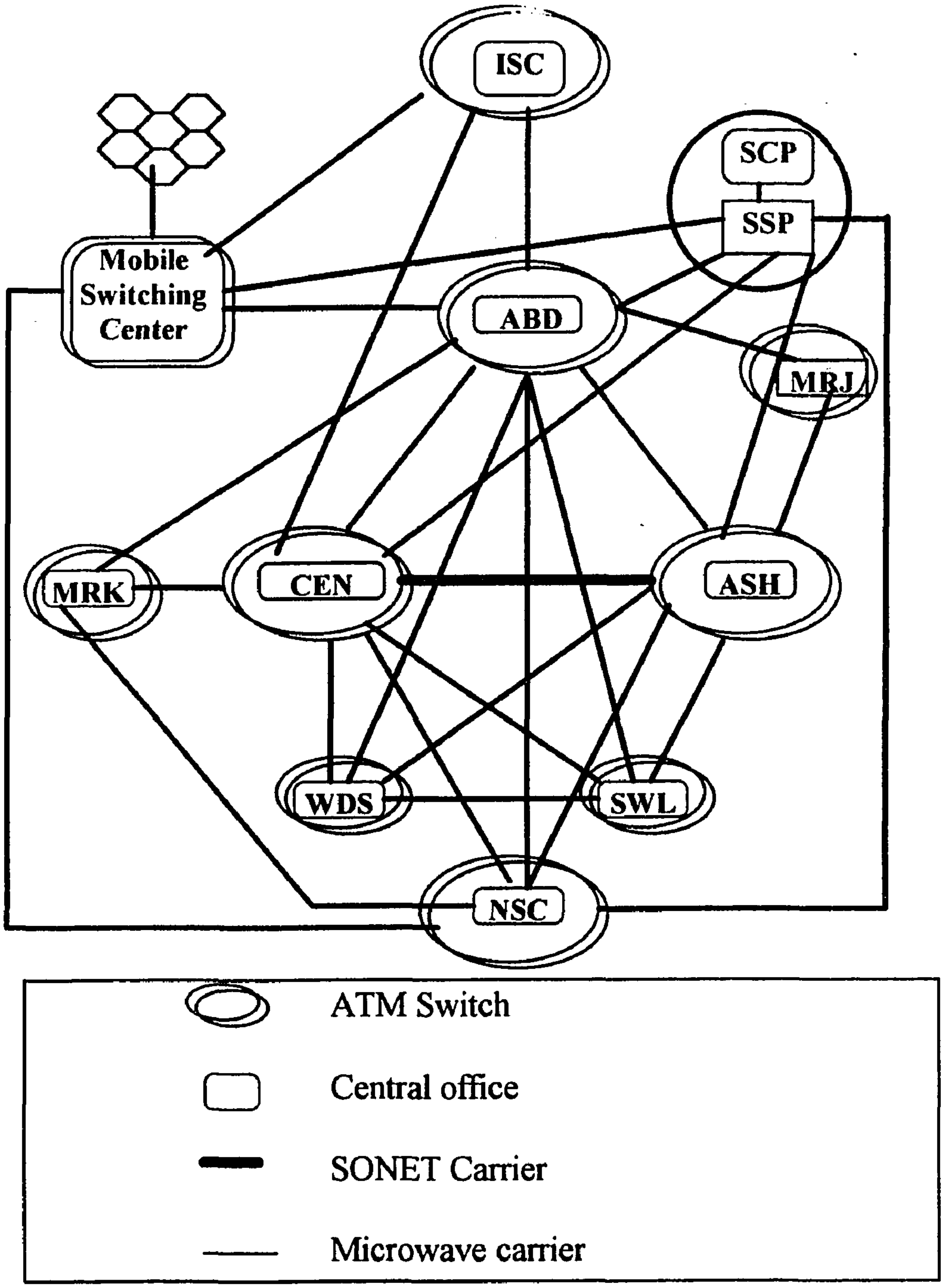


**Figure 8.17** Network topology for the ten-year plan in Amman area

## 8.2 GENERAL OPTIMIZATION RESULTS

### 8.2.1 Return on Investment

Tables 8.1, 8.2, and 8.3 illustrate a comparison between one, five, and ten year planes. First column shows number of direct connected routes, each plan has two column: (profit) which contains profit returned at the end of the plan, and (year) indicates number of years needed to have MW monthly payment intersect with each of the suggested planes. Note that negative sign in (profit) column means that it is not profitable to implement the plan at that stage and it returned lost quantity in case of implementation.

Analyzing data for the 20 direct connected routes which proved that it is the best connection for all of the three planes, tables 8.1 shows $20,526.5 profit end of the one year-plan, also the table shows a lost of $19,757, and $3,000,000 if five year or ten year plans implemented respectively when traffic growth factor = 1.5.

Table 8.2, for traffic growth factor 3, indicates that at the second half of the second year microwave payment will intersect with five- year plan payment, the total profit will be $1,086,144 at the end of the plan. Same table shows that implemented the ten-year plan at this period is also significant.

Table 8.3, for traffic growth factor 4.5 shows $3,578,294 profit when ten year plan implemented. The table indicates that at the first year monthly payment for a complete **SONET** will intersect with the monthly payment of complete microwave.

The main conclusion is to have all of the above plans return the right investment, a parallel increase in service and number of subscriber must be implemented which will increase traffic intensity.

### 8.2.2 Traffic Growth

The relationships between network running cost per minute(CPM) and traffic growth factors(TGF) have a significant effect on any network design. Figures 8.18, 8.19, and 8.20 show a non-linear relationship between CPM and TGF. Increasing network traffic will decrease cost per minute for both **SONET** and microwave networks. This result will motivate the national network planner to increase services and number of subscribers to reduce CPM. Meanwhile, Figures 8.21, 8.22, and 8.23 shows the relation between total cost per minute (TCPM) [includes both hardware cost and running cost] and traffic growth factor, these charts indicates that there is a non-linear relation for **SONET** and microwave network . **SONET** and microwave TCPM curves intersect when TGF = 4 as shown in figure 8.21 which give us the exact time when **SONET** network will start return investment. Exponential smoothing charts 8.19, 8.20, 8.22, and 8.23 generated by using the probability density function $\mathbf{f(x\,;\lambda)= \lambda e^{-\lambda x}}$ , where x is the traffic growth factor.

### 8.2.3 Level Of Congestion

Decreases in CPM will also depend on level of network congestion. This dependency as more effect in a microwave network than **SONET** backbone network. This can be seen from both figures 8.24 and 8.25 for MW and **SONET** backbone networks. The curves for the three level of congestion have a smaller gap between them in **SONET** than in MW. Figure 8.26 indicates that decreasing congestion does not affect CPM in **SONET** as it does in MW this is due to the fact that **SONET** carriers and switches are designed to handle high traffic intensity with negligible delay using very efficient rerouting techniques.

| TGF= 1.5 | ONE-YEAR PLAN | | FIVE-YEAR PLAN | | TEN-YEAR PLAN | |
|---|---|---|---|---|---|---|
| TRUNKS | PROFIT($) | YEARS | PROFIT($) | YEARS | PROFIT($) | YEARS |
| 35 | -61940 | 3.13027 | -113487 | 3.06594 | -1E+07 | 37.7674 |
| 34 | -61940 | 3.13027 | -113777 | 3.07123 | -1E+07 | 36.443 |
| 33 | -61940 | 3.13027 | -114068 | 3.07652 | -9E+06 | 35.1185 |
| 32 | -61940 | 3.13027 | -114068 | 3.07652 | -8E+06 | 32.827 |
| 31 | -60902 | 3.09458 | -113445 | 3.06518 | -8E+06 | 32.3397 |
| 30 | -60902 | 3.09458 | -113445 | 3.06518 | -7E+06 | 30.608 |
| 29 | -57541 | 2.97896 | -110540 | 3.0123 | -6E+06 | 28.9912 |
| 28 | -52311 | 2.79911 | -105311 | 2.9171 | -6E+06 | 27.4454 |
| 27 | -45837 | 2.57644 | -99334 | 2.8083 | -5E+06 | 26.1383 |
| 26 | -40068 | 2.37803 | -93565 | 2.70328 | -5E+06 | 24.8244 |
| 25 | -31850 | 2.09541 | -70806 | 2.42175 | -5E+06 | 26.8217 |
| 24 | -24089 | 1.82849 | -63045 | 2.26591 | -4E+06 | 24.6883 |
| 23 | -15249 | 1.52445 | -54204 | 2.0884 | -4E+06 | 22.2666 |
| 22 | -3918.7 | 1.13478 | -42874 | 1.86089 | -3E+06 | 20.9857 |
| 21 | 7370.08 | 0.74652 | -32208 | 1.64672 | -3E+06 | 19.4506 |
| **20** | **20526.5** | **0.29404** | **-19757** | **1.39671** | **-3E+06** | **17.4806** |
| 19 | 32852.9 | -0.1299 | -4935.3 | 1.1081 | -3E+06 | 18.6522 |
| 18 | 49786.1 | -0.7123 | 24981.4 | 0.57935 | -2E+06 | 13.6325 |
| 17 | 58211.2 | -1.002 | 33406.6 | 0.43748 | -2E+06 | 12.6213 |
| 16 | 82712.9 | -0.756 | 57908.2 | 0.25197 | -2E+06 | 8.23576 |
| 15 | 122301 | -0.92 | 97496 | -0.0371 | -1E+06 | 5.76832 |
| | | | | | | |

**Table 8.1** One, five, and ten year plans investment (TGF=1.5)

| TGF= 3 | ONE-YEAR PLAN | | FIVE-YEAR PLAN | | TEN-YEAR PLAN | |
|---|---|---|---|---|---|---|
| TRUNKS | PROFIT($) | YEARS | PROFIT($) | YEARS | PROFIT($) | YEARS |
| 35 | 729332 | -2.7569 | 958212 | -2.1717 | -377205 | 10.9584 |
| 34 | 729924 | -2.7632 | 958679 | -2.1752 | -157918 | 10.4107 |
| 33 | 731075 | -2.7754 | 959675 | -2.1826 | 52690.7 | 9.85965 |
| 32 | 732507 | -2.7906 | 961107 | -2.1933 | 395278 | 8.90933 |
| 31 | 734935 | -2.8165 | 963317 | -2.2099 | 465398 | 8.69562 |
| 30 | 734935 | -2.8165 | 963317 | -2.2099 | 695688 | 7.99077 |
| 29 | 737457 | -2.8433 | 965636 | -2.2272 | 898021 | 7.32883 |
| 28 | 741472 | -2.886 | 969651 | -2.2573 | 1075468 | 6.70735 |
| 27 | 746328 | -2.9376 | 974258 | -2.2918 | 1215665 | 6.17773 |
| 26 | 750779 | -2.985 | 978710 | -2.3251 | 1345455 | 5.65238 |
| 25 | 757098 | -3.0522 | 1047671 | -2.367 | 1549633 | 5.12801 |
| 24 | 762903 | -3.1139 | 1053476 | -2.4078 | 1722311 | 4.39038 |
| 23 | 769471 | -3.1838 | 1060044 | -2.454 | 2235423 | 3.55433 |
| 22 | 777937 | -3.2738 | 1068511 | -2.5135 | 2534434 | 3.12606 |
| 21 | 786357 | -3.3634 | 1076650 | -2.5708 | 2870966 | 2.60395 |
| **20** | **796178** | **-3.4678** | **1086144** | **-2.6375** | **3050532** | **1.93236** |
| 19 | 805703 | -3.5691 | 1081304 | -2.8318 | 3038422 | 1.87532 |
| 18 | 818403 | -3.7042 | 1162330 | -2.6572 | 3266286 | 1.45134 |
| 17 | 831212 | -3.8404 | 1175139 | -2.7415 | 3362381 | 1.0214 |
| 16 | 935433 | -3.3483 | 1279360 | -2.5335 | 4048025 | 0.20633 |
| 15 | 1035824 | -3.0517 | 1379751 | -2.4013 | 4621743 | -0.2955 |

**Table 8.2** One, five, and ten year plans investment (TGF=3)

| TGF= 4.5 | ONE-YEAR PLAN | | FIVE-YEAR PLAN | | TEN-YEAR PLAN | |
|---|---|---|---|---|---|---|
| TRUNKS | PROFIT($) | YEARS | PROFIT($) | YEARS | PROFIT($) | YEARS |
| 35 | 1153007 | -3.0176 | 1222332 | -3.4997 | -2E+06 | 7.899 |
| 34 | 1154717 | -3.0295 | 1223871 | -3.5104 | -1E+06 | 7.38354 |
| 33 | 1155590 | -3.0356 | 1224604 | -3.5155 | -1E+06 | 6.87311 |
| 32 | 1157691 | -3.0502 | 1226705 | -3.5301 | -592431 | 5.98604 |
| 31 | 1161364 | -3.0757 | 1230145 | -3.554 | -474381 | 5.77904 |
| 30 | 1161364 | -3.0757 | 1230145 | -3.554 | -70891 | 5.11847 |
| 29 | 1165130 | -3.1019 | 1233647 | -3.5784 | 296827 | 4.49547 |
| 28 | 1171278 | -3.1447 | 1239794 | -3.6211 | 634599 | 3.90352 |
| 27 | 1178546 | -3.1952 | 1246782 | -3.6697 | 960026 | 3.39523 |
| 26 | 1185347 | -3.2425 | 1253584 | -3.717 | 1305714 | 2.89108 |
| 25 | 1194935 | -3.3092 | 1282781 | -3.92 | 1419557 | 2.68805 |
| 24 | 1203619 | -3.3696 | 1291465 | -3.9804 | 1845595 | 1.93914 |
| 23 | 1213455 | -3.438 | 1301302 | -4.0488 | 2310522 | 1.09009 |
| 22 | 1226108 | -3.5259 | 1313955 | -4.1368 | 2542726 | 0.64114 |
| 21 | 1238684 | -3.6134 | 1326188 | -4.2219 | 3023135 | 0.0967 |
| **20** | **1253407** | **-3.7158** | **1340569** | **-4.3219** | **3578294** | **-0.6012** |
| 19 | 1288467 | -3.7085 | 1381942 | -4.3403 | 3735280 | -0.7239 |
| 18 | 1307486 | -3.8371 | 1400603 | -4.4665 | 4099313 | -1.0271 |
| 17 | 1326707 | -3.967 | 1419824 | -4.5964 | 4379076 | -1.5112 |
| 16 | 1438040 | -3.6639 | 1531157 | -4.2249 | 5059850 | -2.1126 |
| 15 | 1547209 | -3.4743 | 1640326 | -3.9843 | 5573877 | -2.462 |

**Table 8.3** One, five, and ten year plans investment (TGF=4.5)

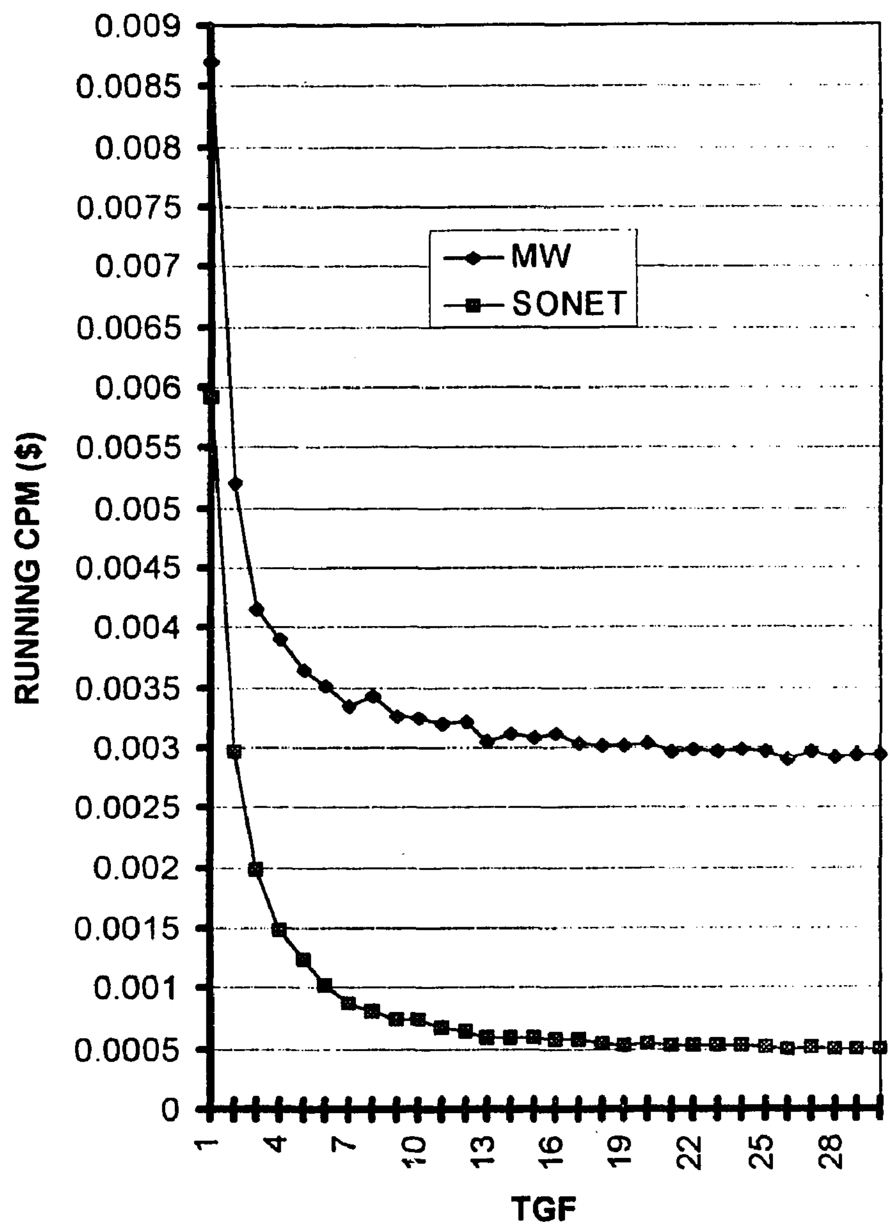


**Figure 8.18** Traffic growth factor versus CPM

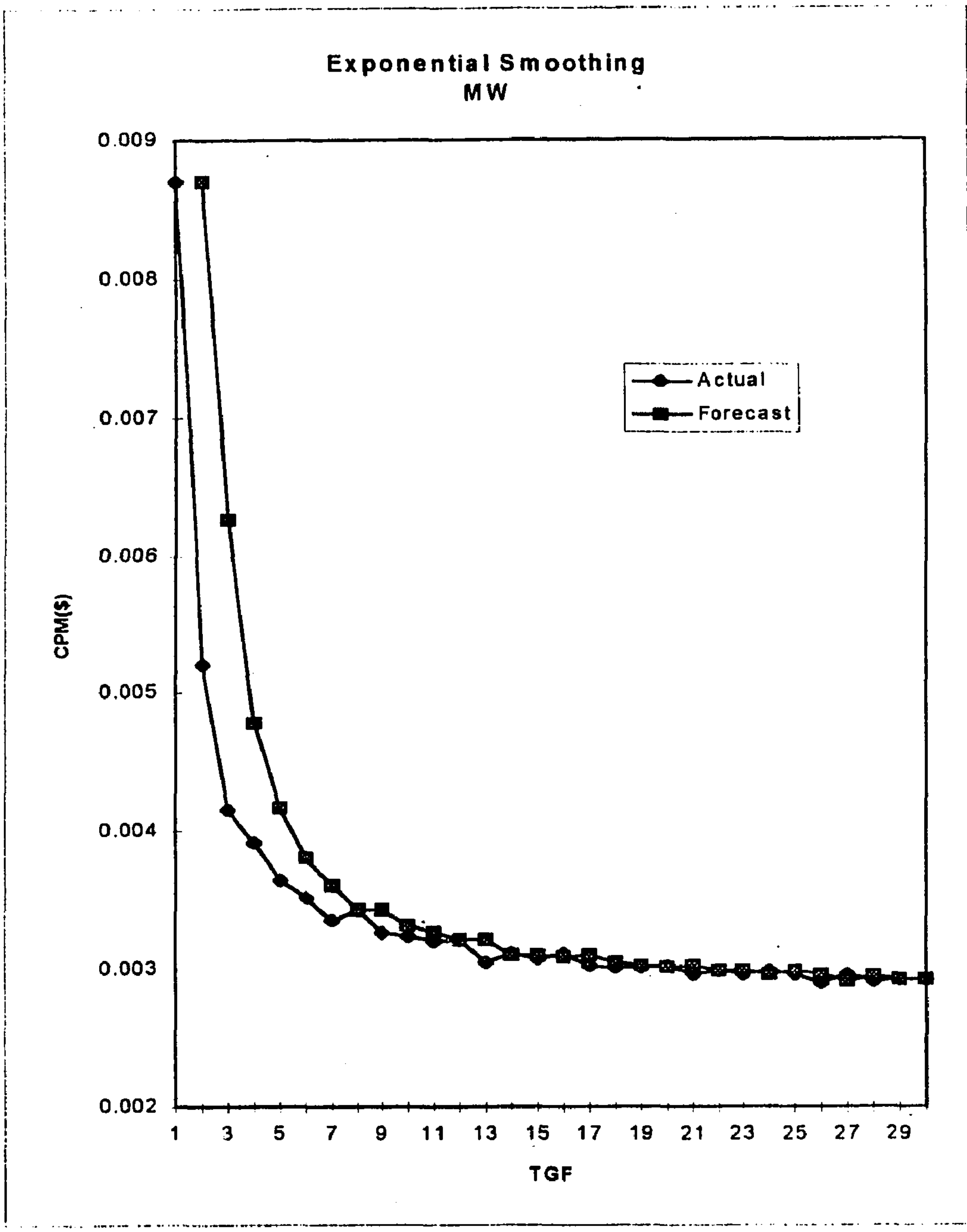


**Figure 8.19** Exponential smoothing for Microwave network

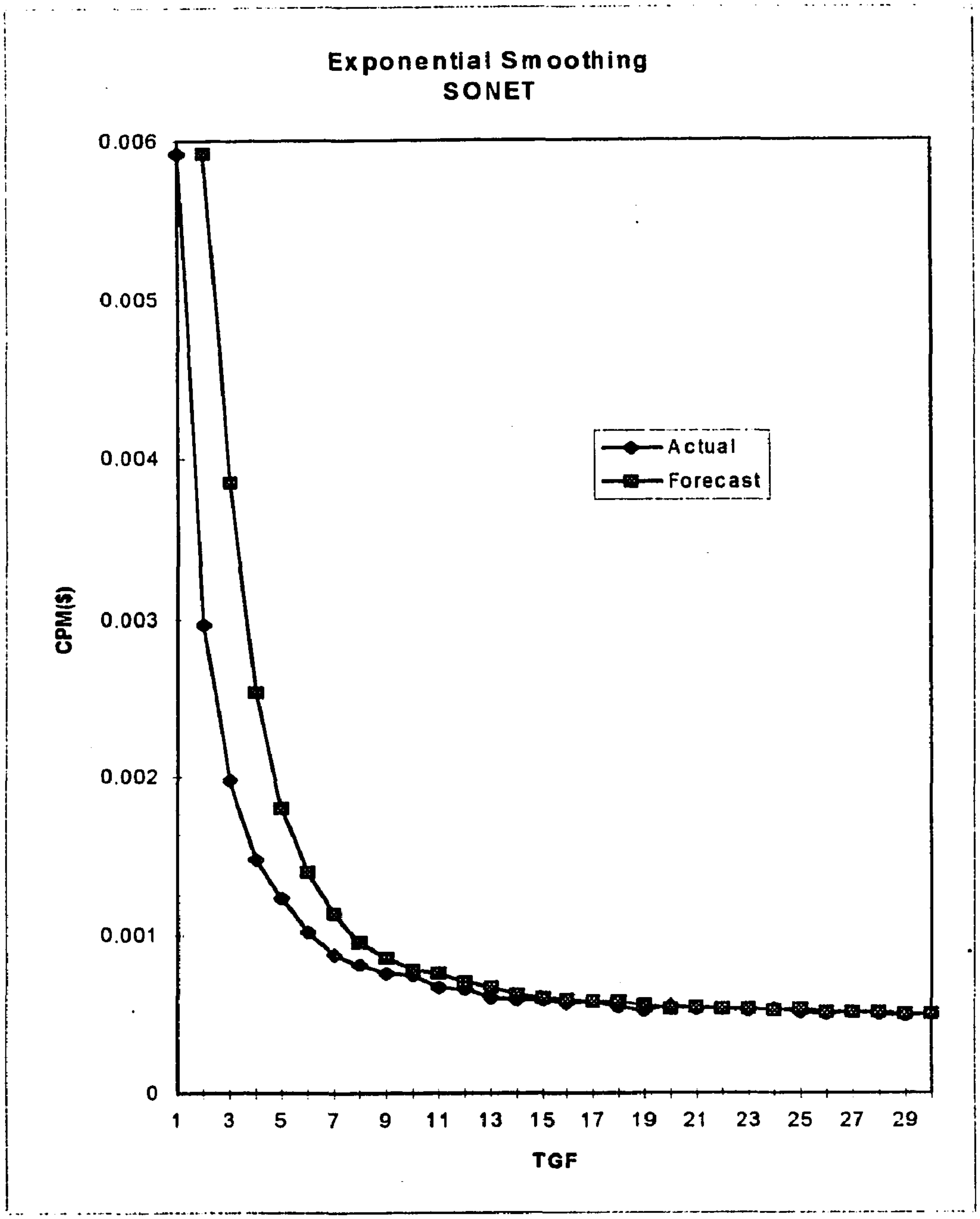


**Figure 8.20** Exponential smoothing for **SONET** network CPM vs. TGF

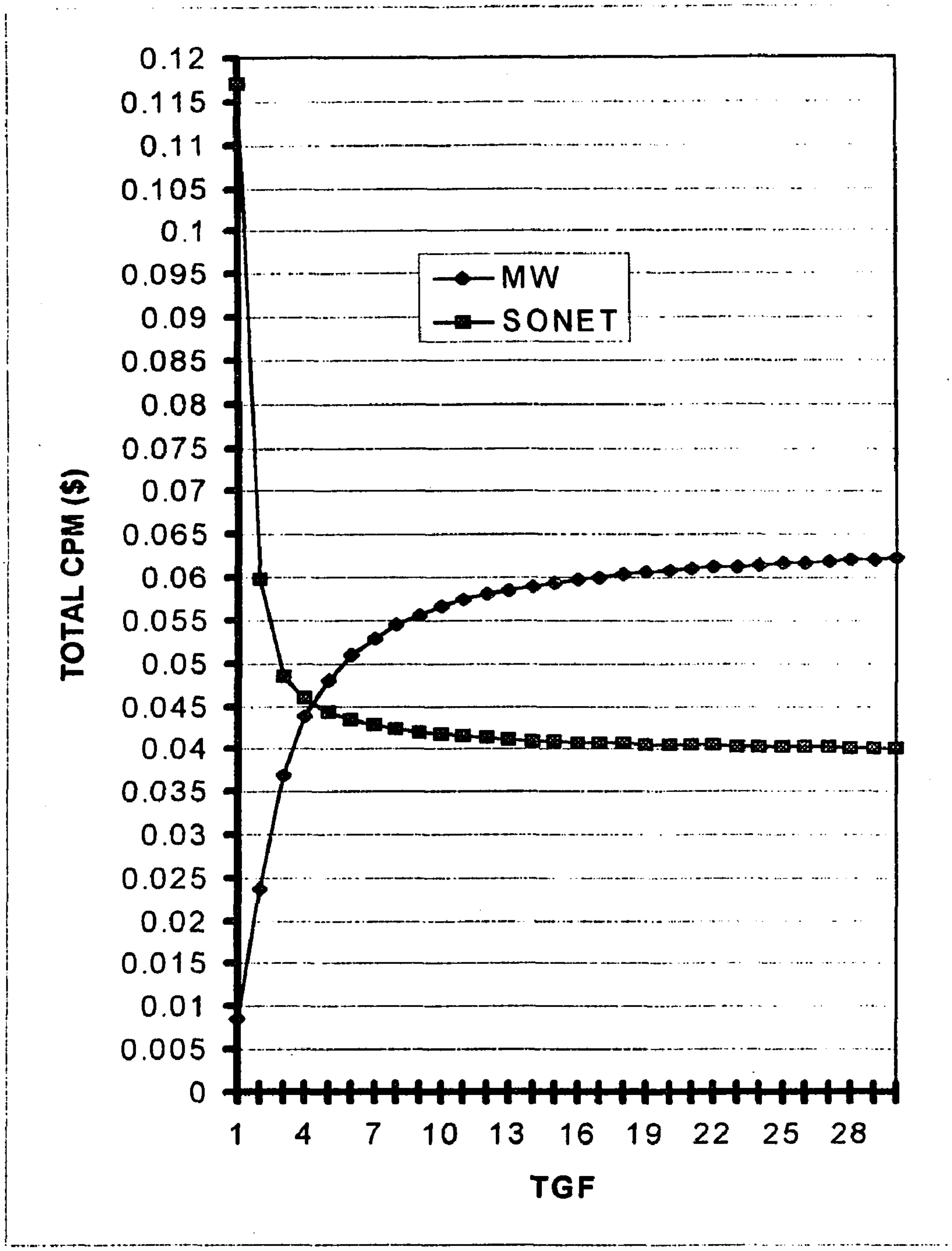


**Figure 8.21** TPM versus TGF

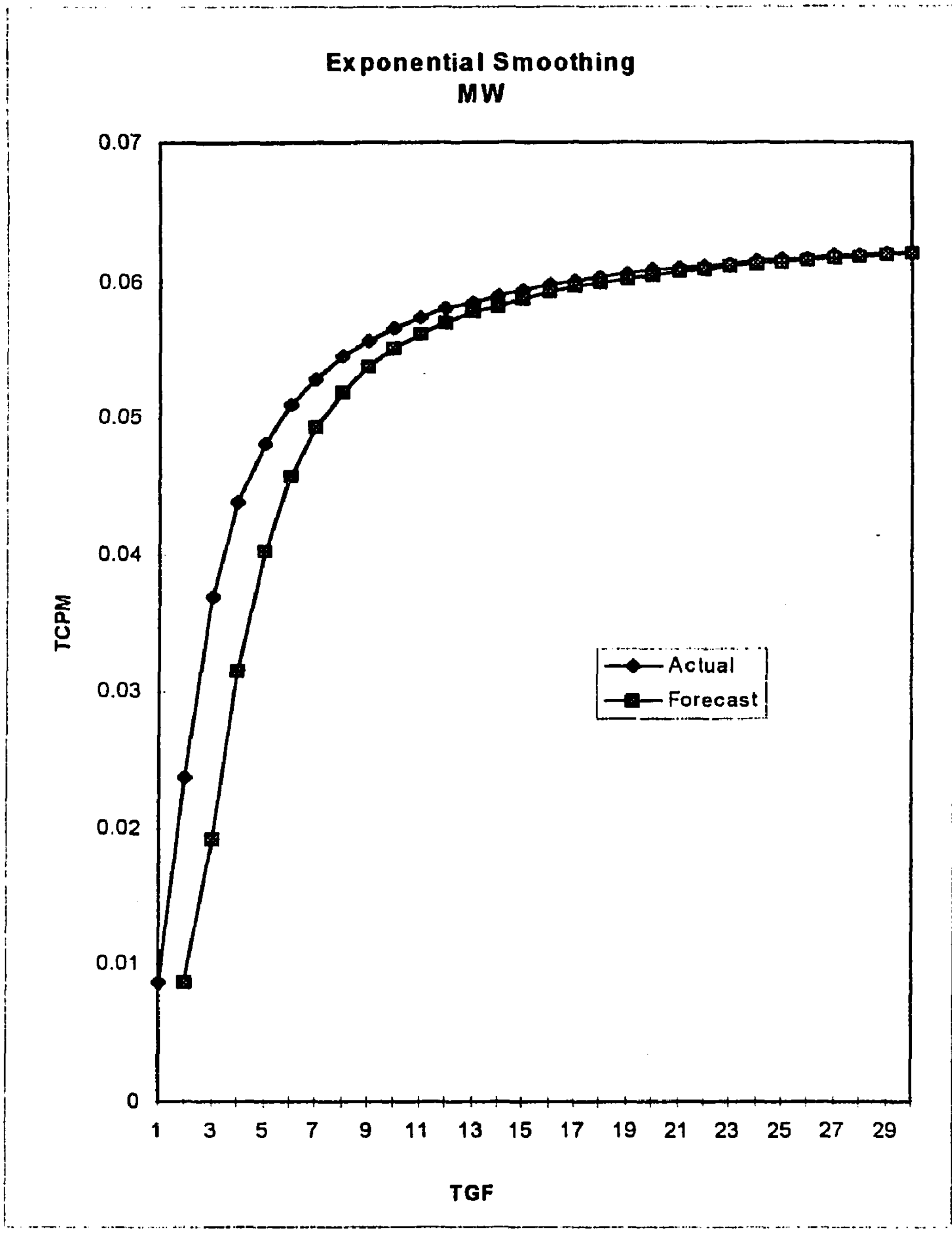


**Figure 8.22** Exponential smoothing for Microwave network TCPM vs. TGF

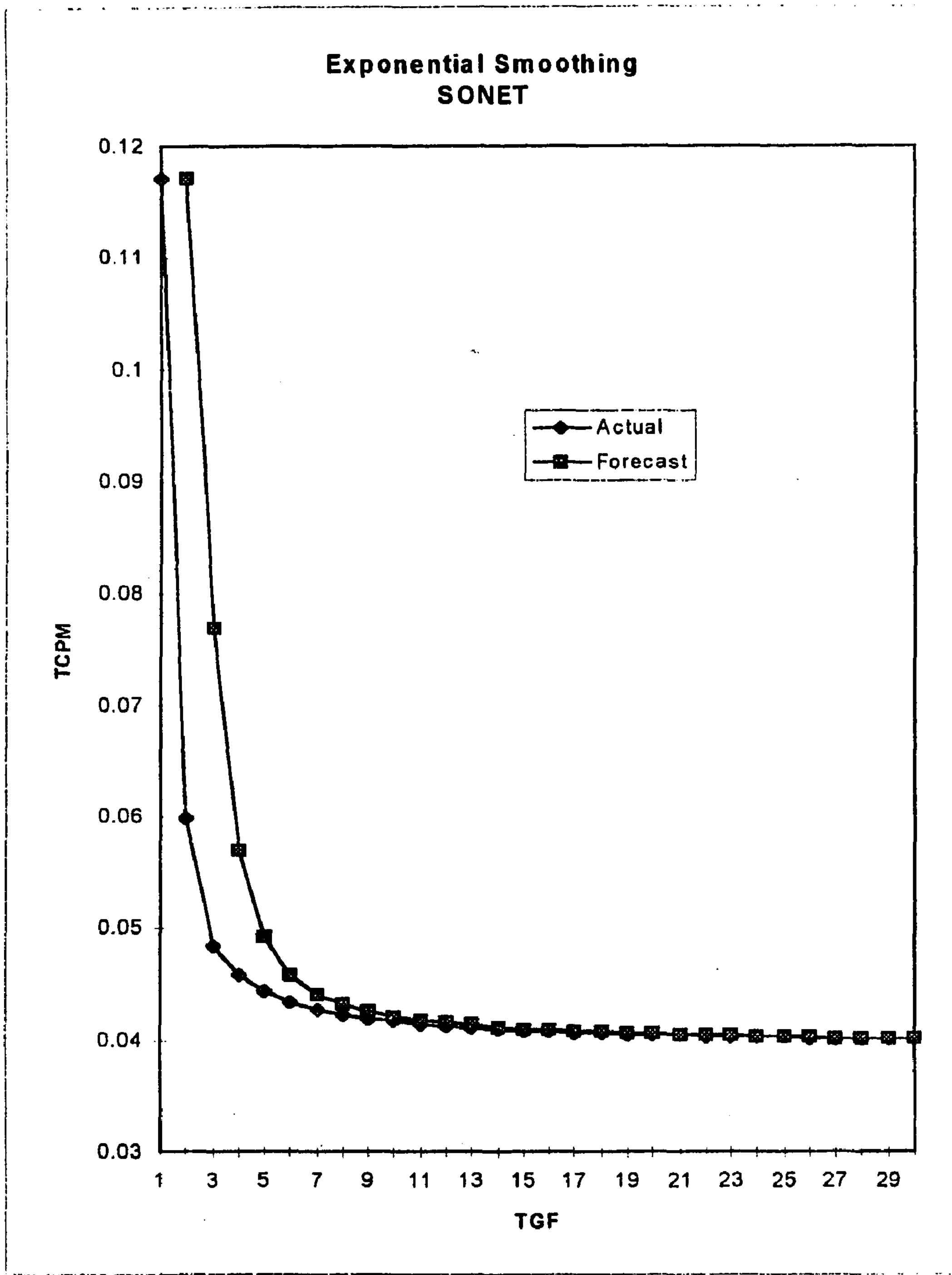


**Figure 8.23** Exponential smoothing for SONET network TCPM vs. TGF

Some significant results are shown in figures 8.27 and 8.28. They indicates that TCPM increased when TGF increased for the MW network, while it decreased for the **SONET** network. This is because installed fiber optical fiber cables and **ATM** switches can handle more traffic than what is available, so increasing traffic will decrease the total cost. But in the case of microwave, same new equipment must be added and we will have to face the problems we discussed before about bandwidth limitation and interference which will result by increasing traffic. Figure 8.29 shows that decreasing congestion has more effect on MW than **SONET**.

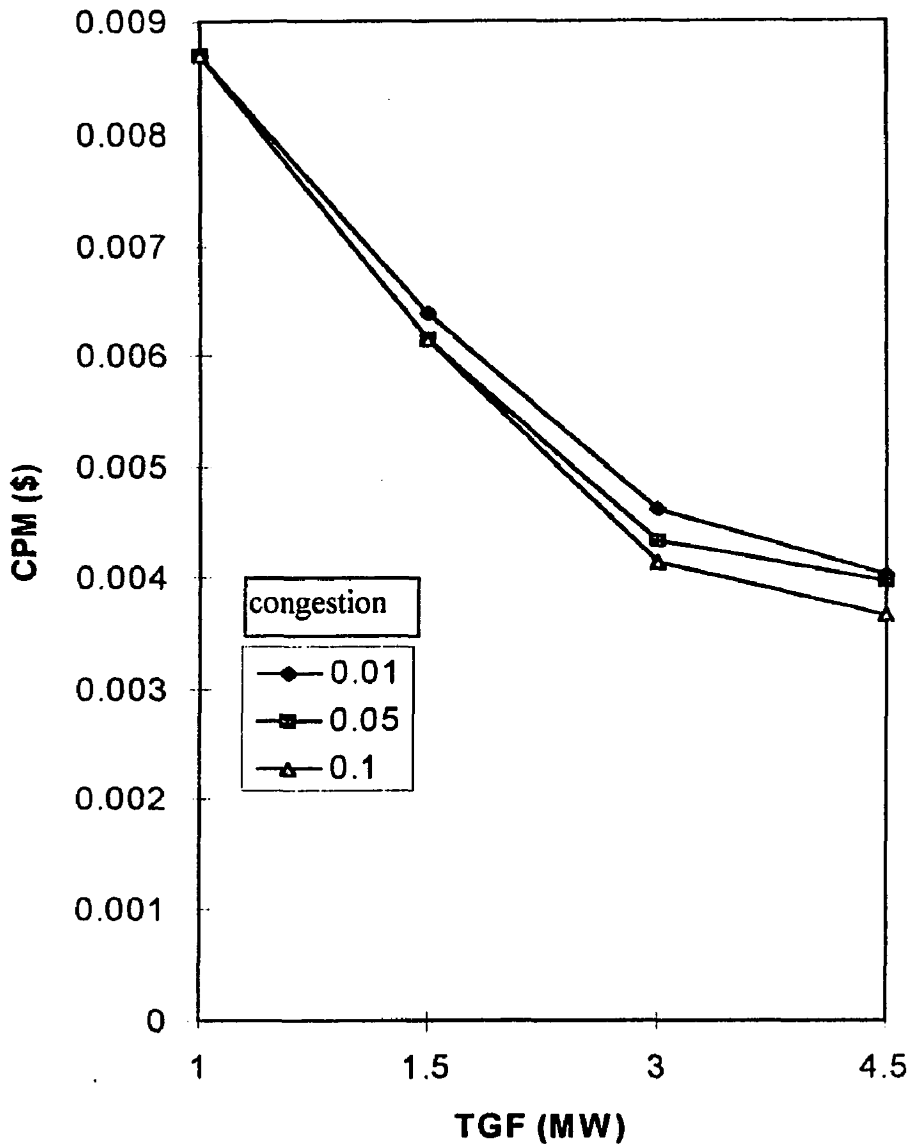


**Figure 8.24** CPM versus TGF (Microwave network).

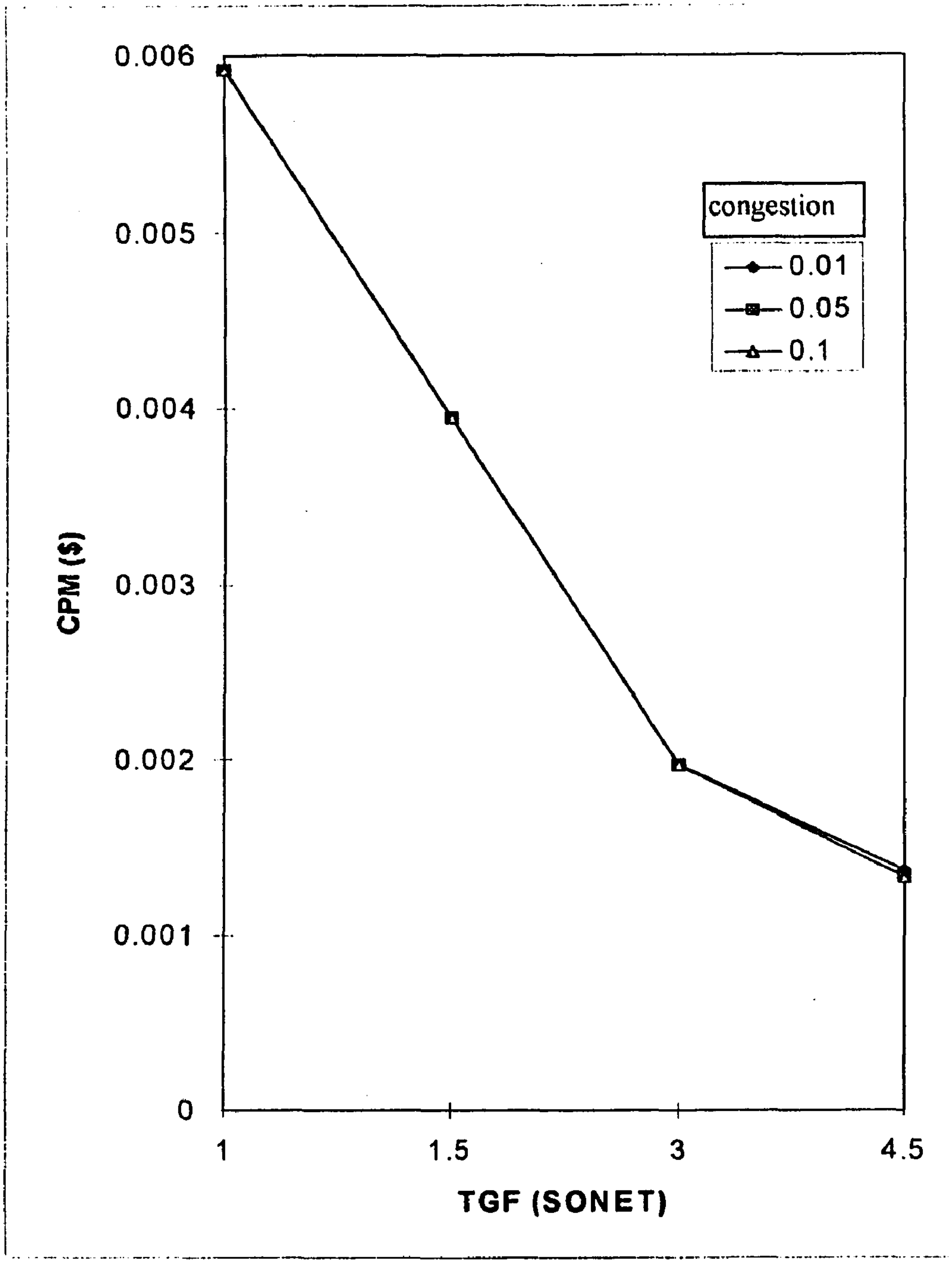


**Figure 8.25** TPM versus TGF (**SONET** network).

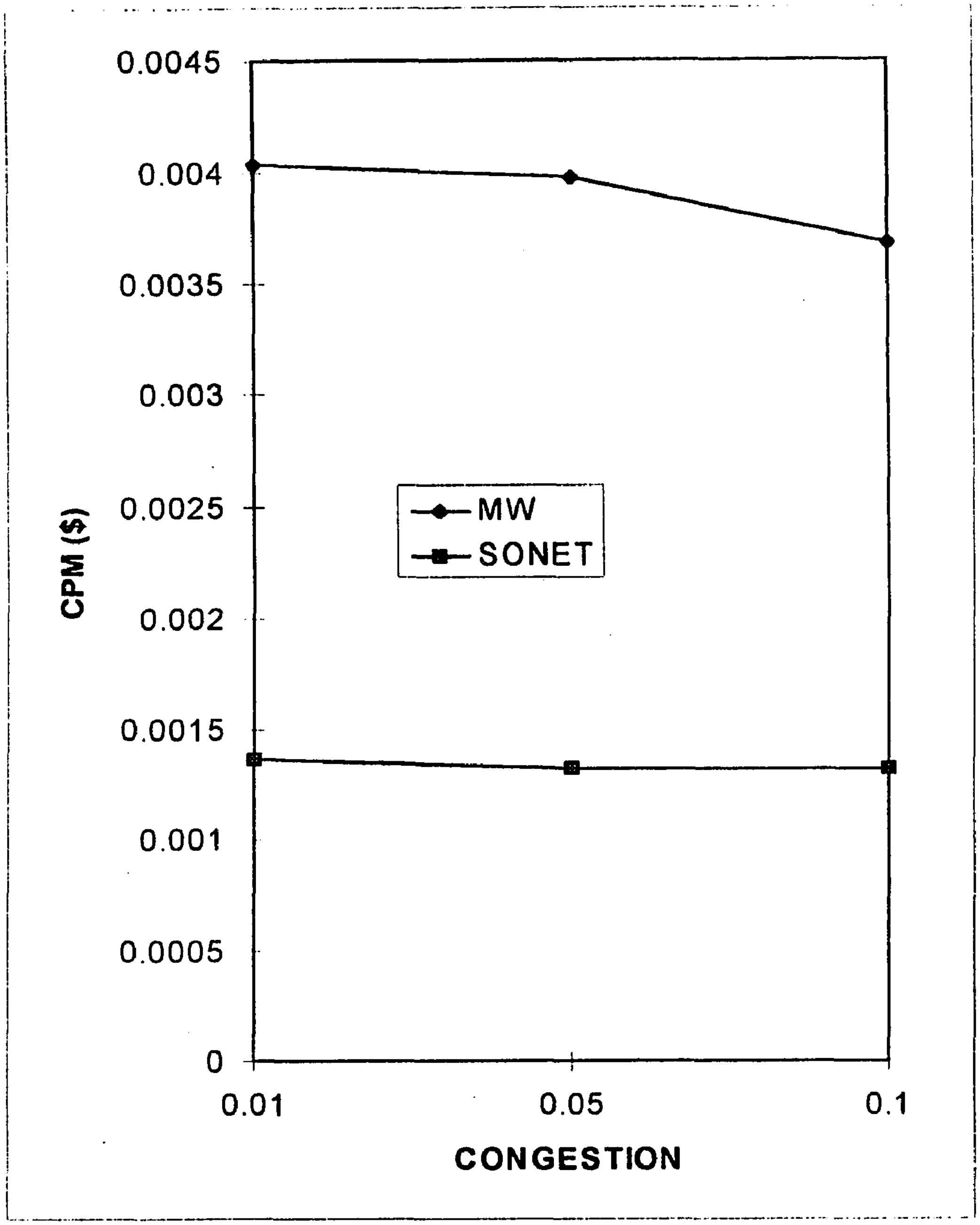


**Figure 8.26** CPM versus Congestion( TGF = 4.5)

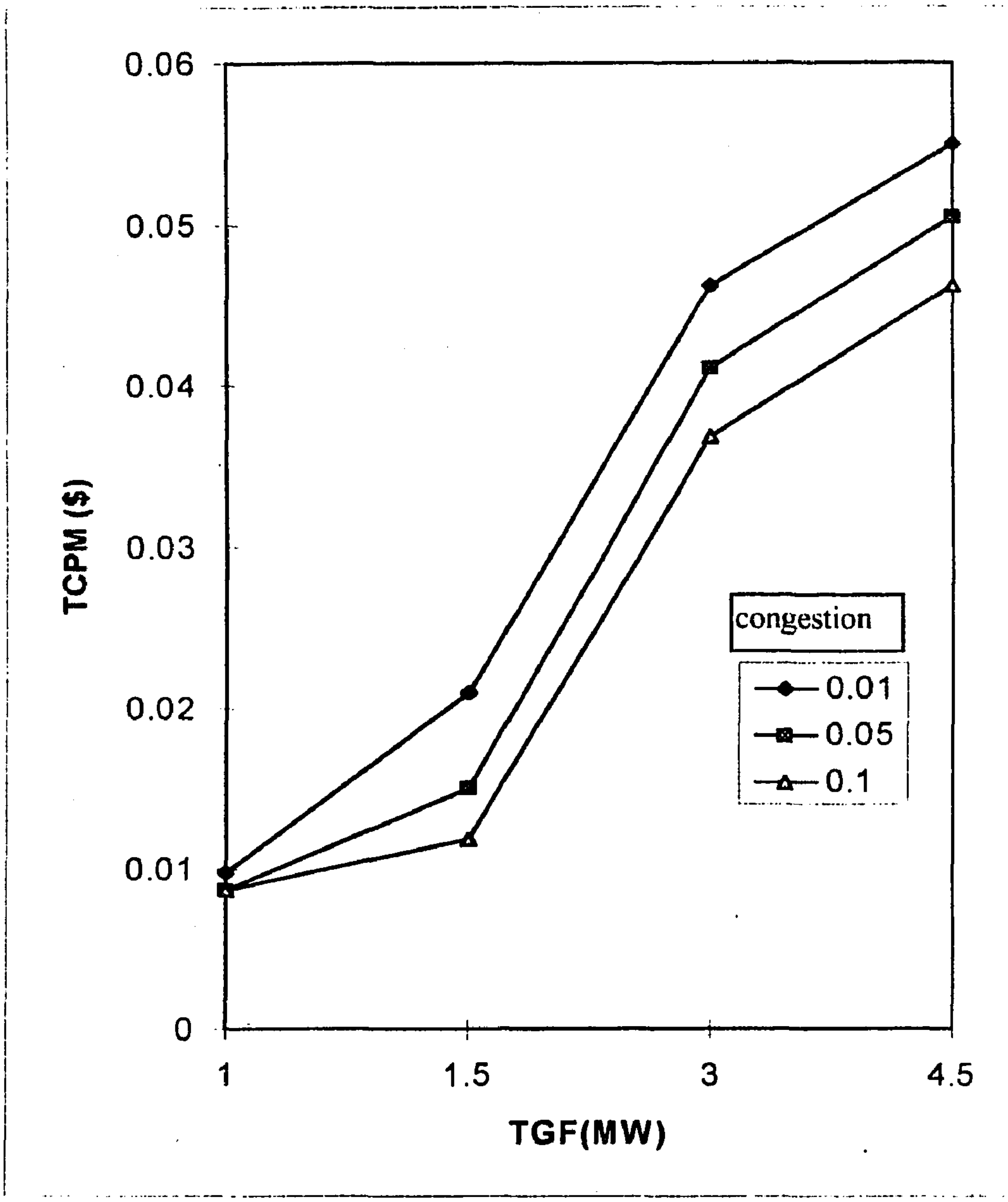


**Figure 8.27** TCPM versus TGF (Microwave network)

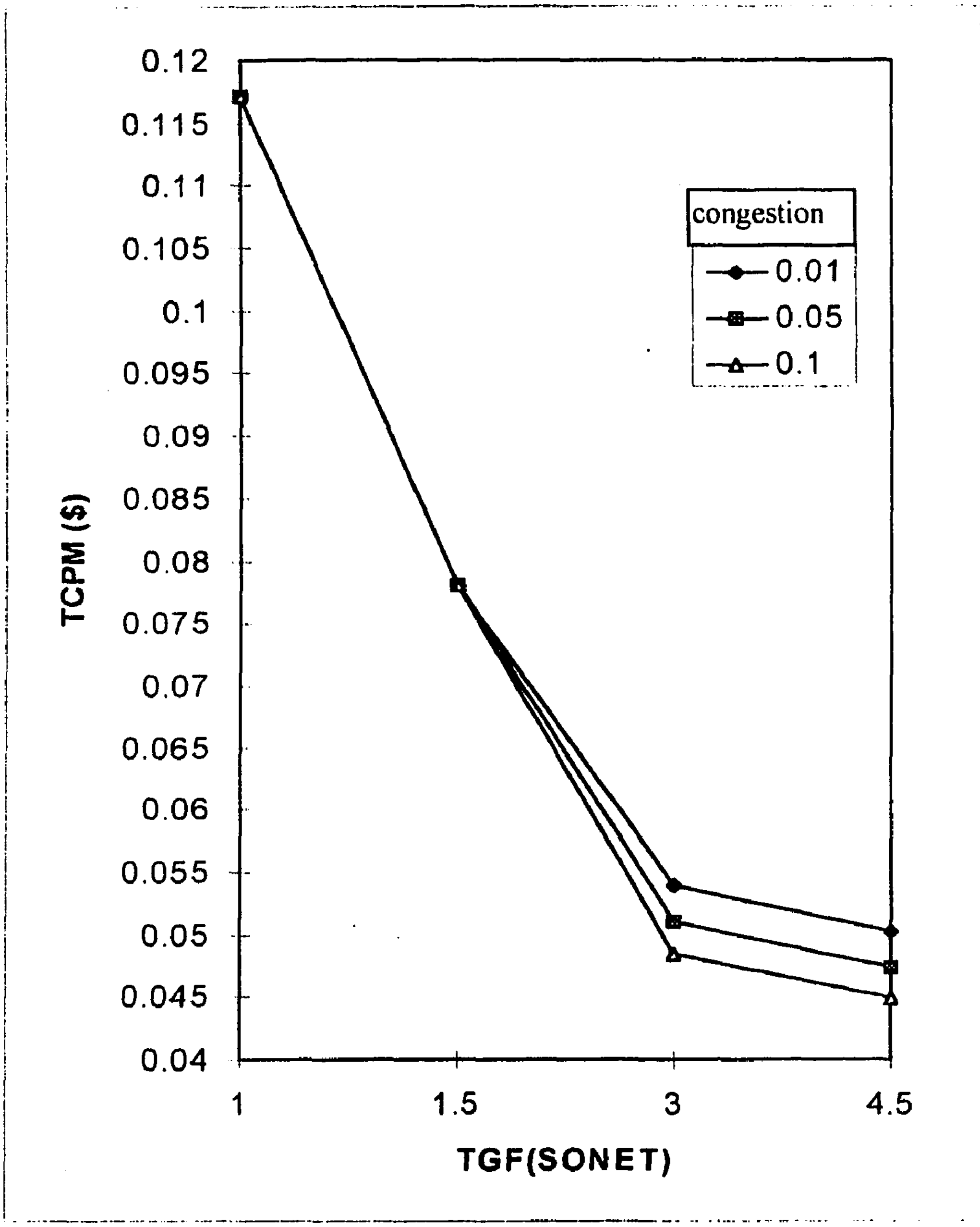


**Figure 8.28** TCPM versus TGF (Microwave network).

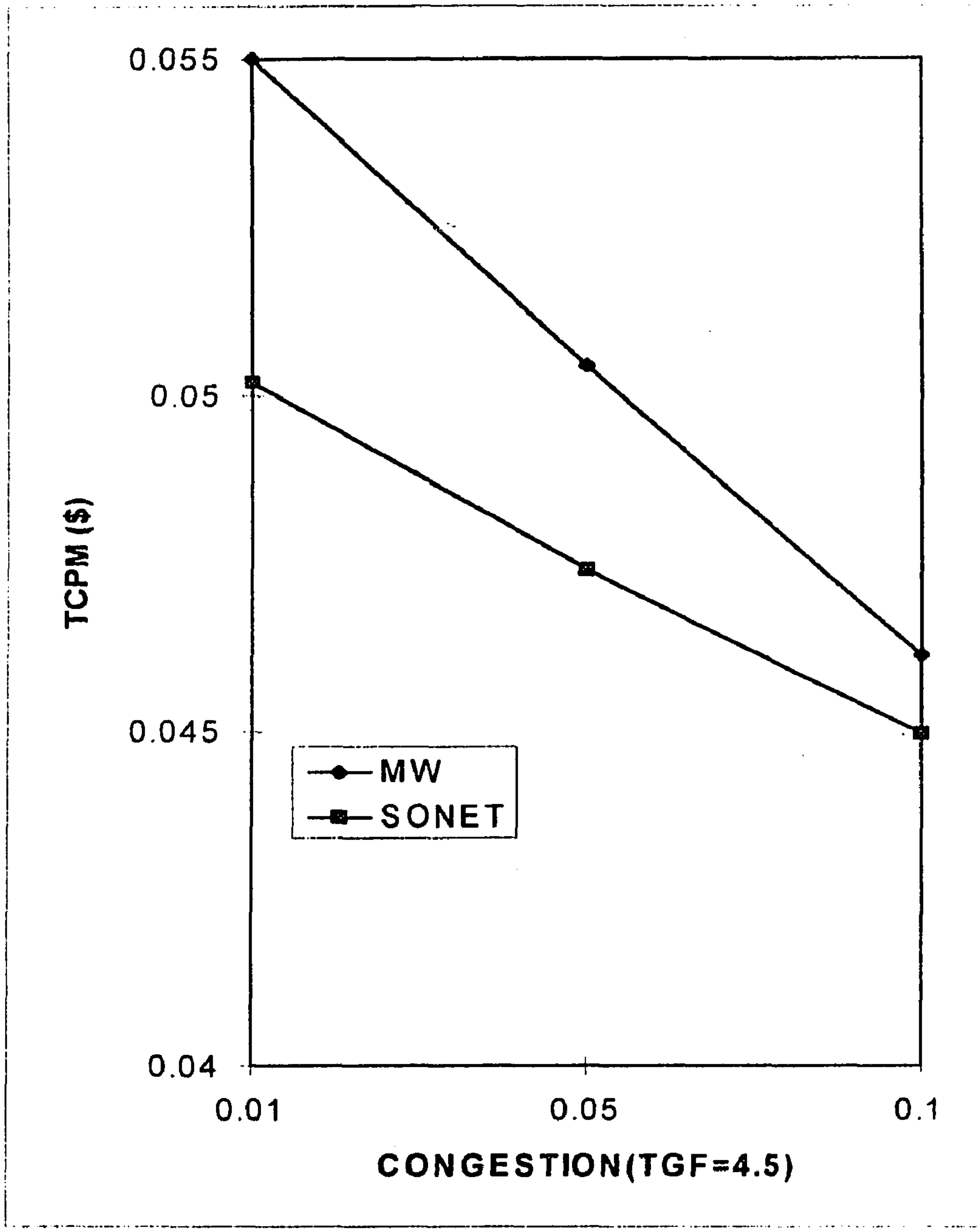


**Figure 8.29** TCPM versus Congestion for (TGF = 4.5)

## 8.3 NATIONAL NETWORK ANALYSIS

The national network in Jordan has a total of fifteen main exchanges nine of which are located in Amman, including national and international centers. The other six are located in the other main cities. Each node has a number of remote link units (RLU) connected to it by a multidrop topology. The numbering system uses seven digit. The two left most digits represented the national area codes as :

| | |
|---|---|
| 02 | Irbid |
| 03 | Karak, Ma'an, Aqaba |
| 04 | Jeresh, Ajloan |
| 05 | Salt |
| 06 | Amman |
| 08 | Madaba |

In the Amman area the network is thick and short. In the rest of Jordan it is long and thin. Choosing a microwave network was the right discussion when installing a metallic media need more time and cost. Analyzing the national network here will take a different approach than the one used in Amman. Implementing changes in the national network require handling more traffic and more services demands. Some exchanges have a significant amount of local traffic which may needs more capacity. Analyzing the star topology for Jordan is concerned with the direct connections with the national and the international nodes. As mentioned in chapter seven, nine cases are analyzed to see if and when we can add **ATM** switches in some locations and to see how much of these changes will reduce the cost per minute. Four plots are illustrated in each chart as the following:

1) ) Traffic growth = 1 for the existing network.

2) Traffic growth = 1.5 for the one year plan.

3) Traffic growth = 3 for the five year plan.

4) Traffic growth = 4.5 for the ten year plane.

The reason for including the existing network here is to compare the actual tariff used today with the expected one when any network changes are implemented.

Figure 8.30 shows the CPM versus link types. In the existing network, CPM = $0.12, compared with the $.20 average tariff used today the difference will be $.08 per minute. This number may seems to be good profit, but with a **SONET** network already in place, CPM will be $.08 as the chart shows. Implementing a complete **SONET** at this time will add cost larger than this difference.

The analysis of the national network will be based on three plans, as was the analysis of the Amman area.

### 8.3.1 The One-year plan

For a 1.5 traffic growth factor, figure 8.31 shows that complete microwave has the minimum hardware cost. The next minimum is at node (09). Return on investment figure 8.33, indicates that adding an **ATM** switch at node (09) requires about three years to recover hardware cost. In the same charts it can be seen that cost will be recovered in less than one year if TGF =4. Figure 8.32 shows that total CPM after adding an **ATM** switch at node (09) is $0.171, where it is only $.104 for microwave. Therefore, the microwave network should be left as is for the first year while subscriber services are being increased on the national and international levels. This will prepare the network for the five-year plan.

### 8.3.2 The Five-year plan

The five-year plan must go parallel with the Amman plan where the Intelligent network will be installed and more traffic will be generated with more services. It will be justified which national exchange could be connected with **SONET**. This will be less expensive because in the Amman network, the national tandem will have an **ATM** switch. Figure 8.33 shows that in less than one year, hardware installation for **ATM** switch will be paid and start returning profit from the transmission difference. CPM having node (09) as **ATM** will be \$0.0399, where it is \$0.042 without **ATM**. There is a significant improvement in the TCPM. Total cost per minute for microwave network is \$0.087, while adding **ATM** switch at node (09) will make it \$.108. The difference will be only \$0.021 while it is \$0.076 for when TGF = 1.5.

All other nodes will to return some profit at the same time, but that will not happen before the end of the five-year plan. Figure 8.34 shows a suggested five year plan.

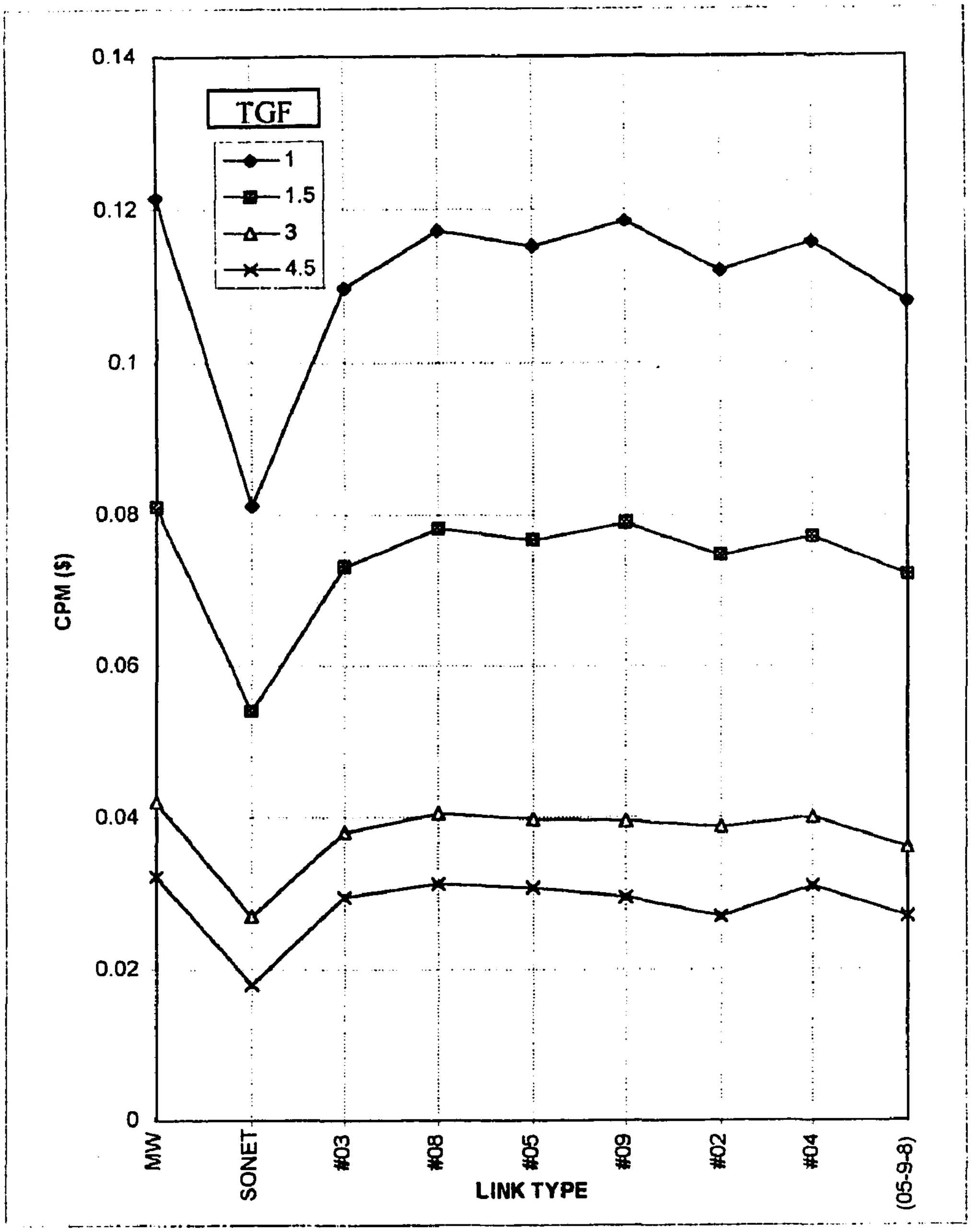


**Figure 8.30** CPM for the national network

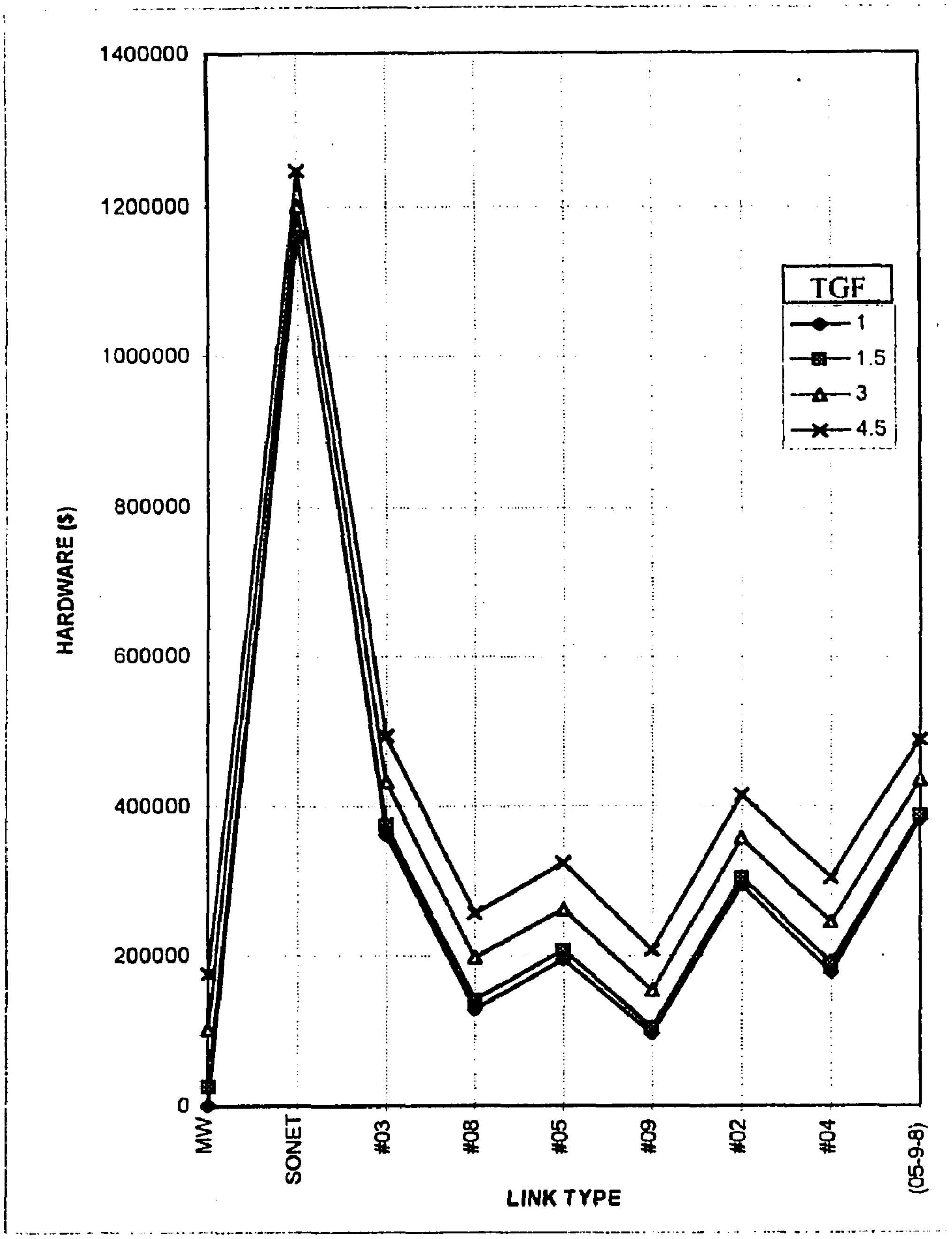


**Figure 8.31** Hardware cost per month for the national network

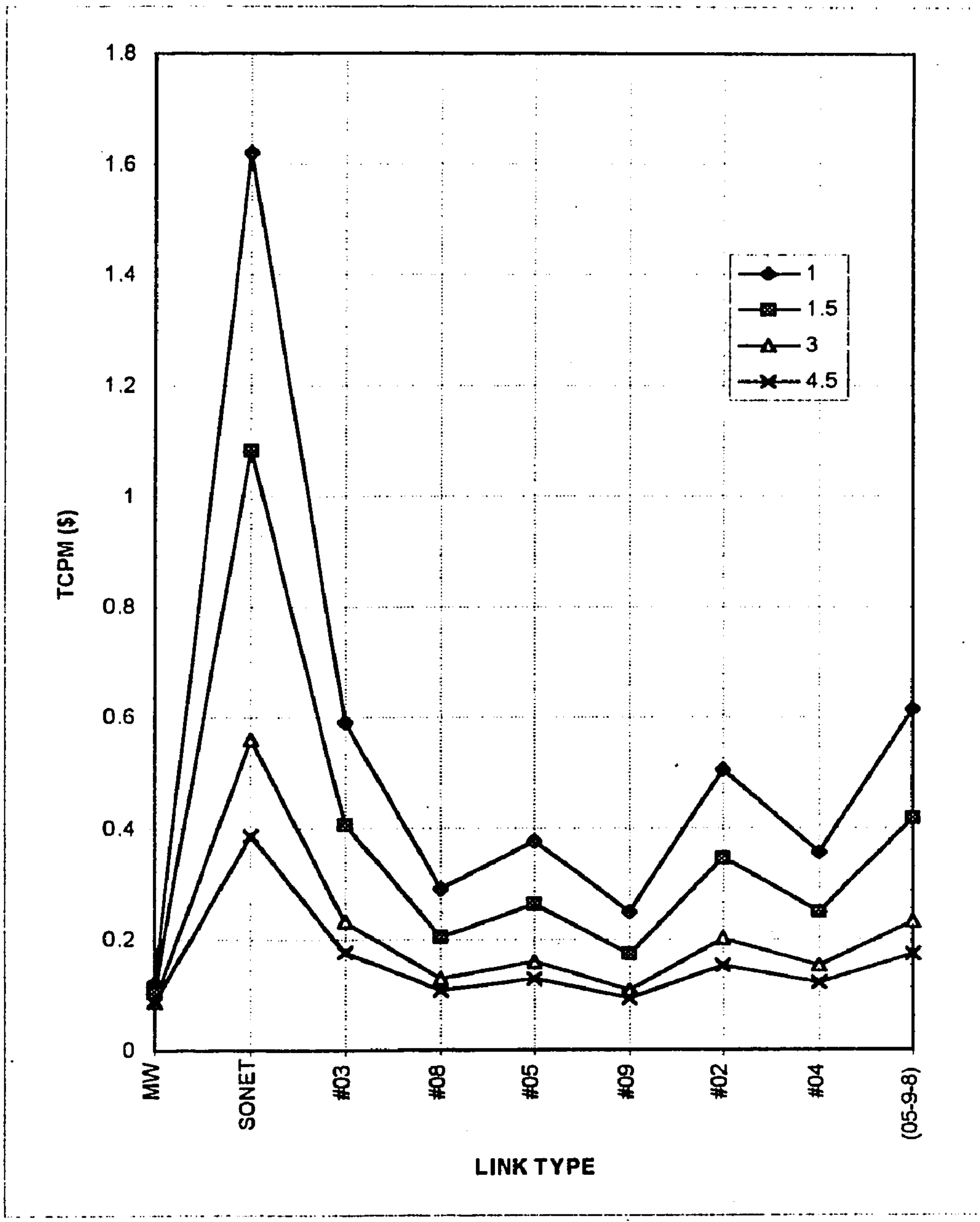


**Figure 8.32** TCPM for the national network

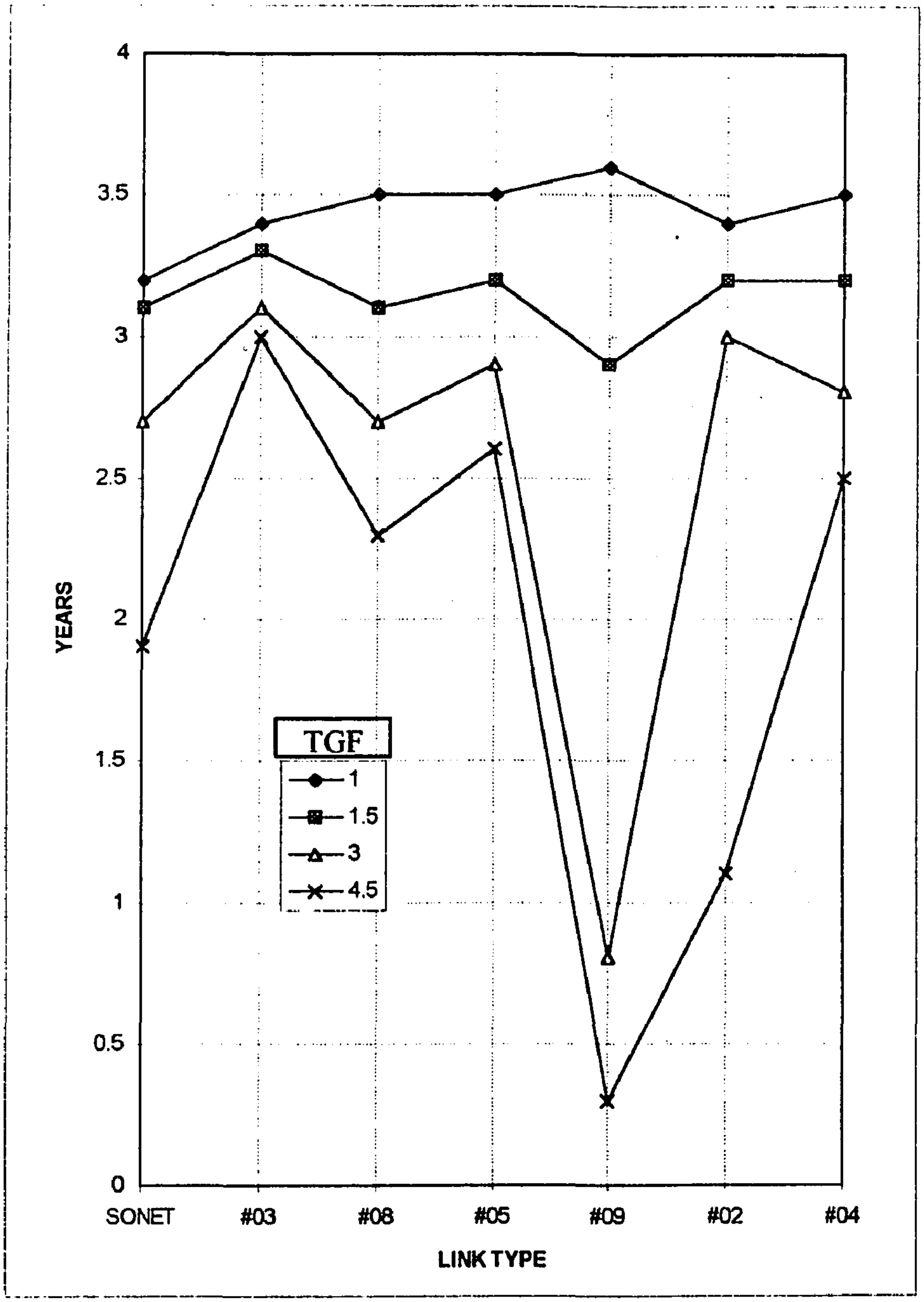


**Figure 8.33** Return on investments for the national network

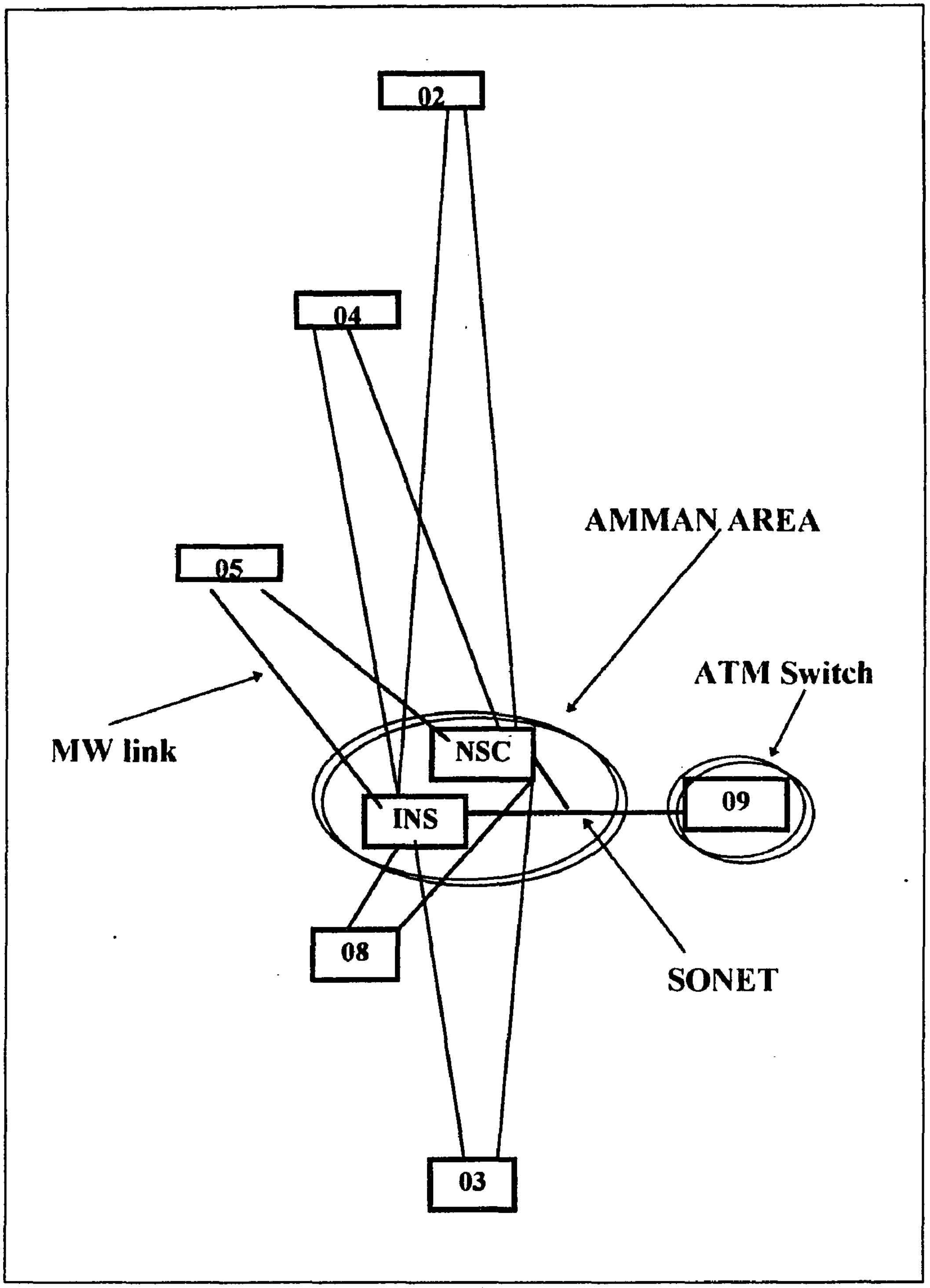


**Figure 8.34** National Network topology for the five years plan

## 8.3.3 The Ten-year plane

Three options could be suggested for the ten-year plan as a result of analyzing the above charts for 4.5 traffic growth factor. Keep in mind that the Amman area is a **SONET** network in this plan and both national and international centers have an Intelligent network. The three options are:

1) Add an **ATM** switch for node (02) which has the minimum return on investment years beside node (09) which is already **ATM** as shown in figure 8.34. This node will also have the minimum CPM after a complete **SONET** network is implemented.
2) Since node (02) links to the national and international centers it will pass by the location of node (04) location. This could save cabling connection for this node, so installing **ATM** switch for node (4) will cost only the switch installation and cost.
3) From the return of investment chart we can see that having a complete **SONET** network in this plan could be more efficient than adding more single nodes. The chart shows that expenses will be covered by the transmission cost difference in about two years which is better than adding any of the other nodes only as (03), (08), or (04). This difference is due to the fact that a main installation cable will run over the whole country from north to south and only minor cabling will be required to connect each node with the main one. Figure 8.35 shows the approximate location of these nodes and the way they can be connected to produce a complete **SONET** network. The main advantage of having a complete **SONET** network all over the country including the Amman area is that intelligent network services will be available for both national and international communication. This will come at the right time since the global

800 service and other IN services are about to be distributed all over the world in the near future.

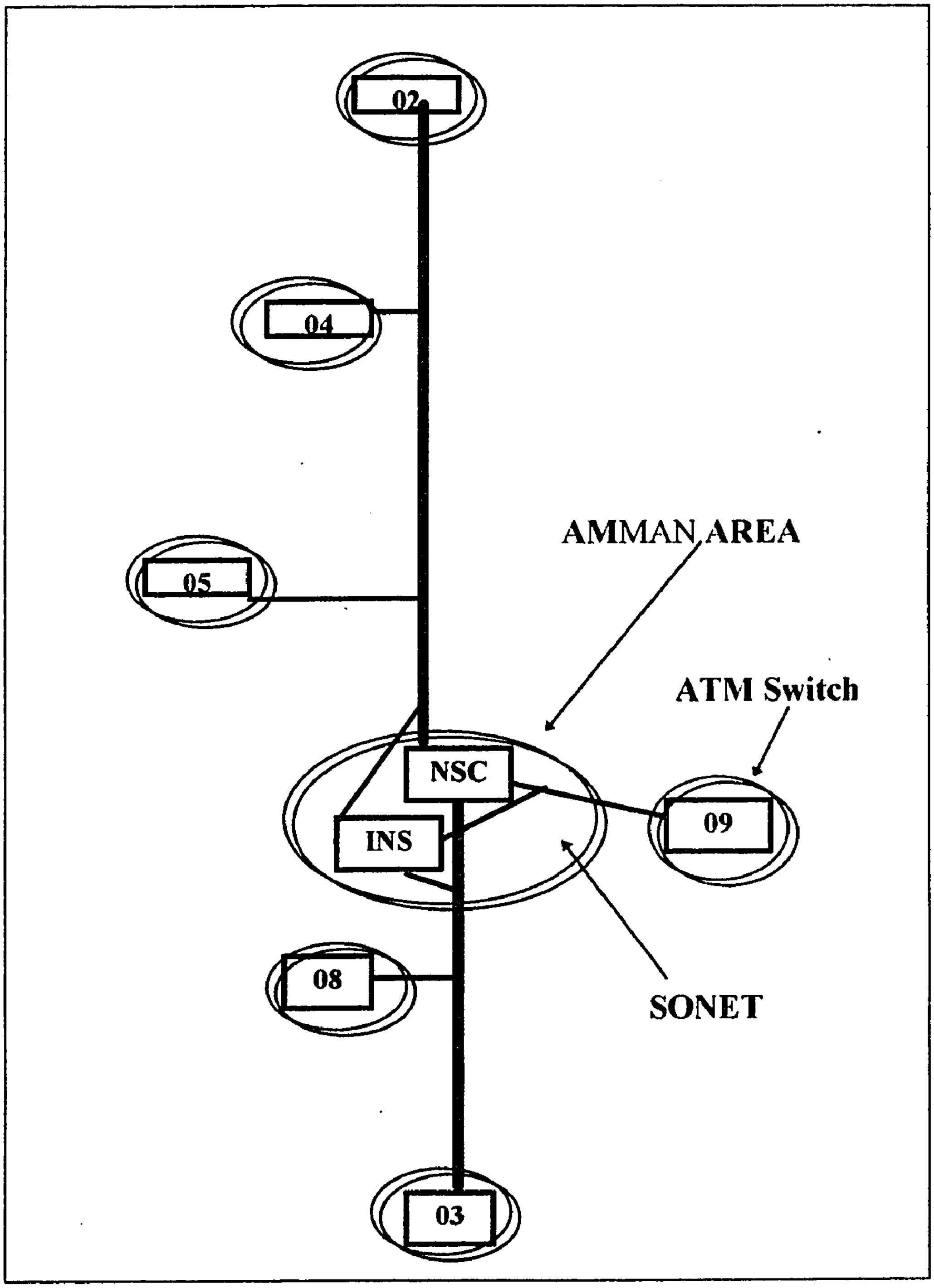


**Figure 8.35** National Network topology for the Ten-year plan

## 8.4 NATIONAL NETWORK SECURITY

National network security is one of the most critical factors which must be accounted for when designing or updating a network.

Security involves both data and voice transmission. Most small countries cannot afford to have a private secure network to use for national security communication and other areas where security is required.

Encryption techniques can be used to detect and correct duplicated, deleted, and replaying data and to protect communicated data from unauthorized disclosure. Cryptographic-based message authentication can be used to prevent masquerade on a broadcast channel.

This study is introducing An **ATM** switches with optical fiber links as a backbone replacement for the existing microwave links. There is a security system already functioning in the existing network. This system, however, is dealing with microwave links which can be jammed by an external source, putting whole national network in jeopardy. Using of **ATM** technology will eliminate this problem by using optical fiber cables, and possibly adding security encryption devices to the **ATM** switch. Security for **ATM** swishes is still evolving to produce an encryption program built in within the **ATM** switch itself.

In 1995, the **ATM** Forum established a network security working group, which is chaired by Mohammad Peyravian, advisory engineer on network architecture at IBM. The main goal of this group is to generate functional specifications covering user, signaling, and management information to protect both ATM network infrastructure and user data.

Some of the Forum's efforts focused on security information such as the authentication and privacy of ATM's 53-byte cell structure. Meanwhile, Peyravian sees that ATM functions will be established for the data channel in two settings: endpoint-to-endpoint and switch-to-switch, and development will support services such as a certification infrastructure, key exchanges, basic negotiation of security requirements, capabilities to support multiple levels of security assurance as well as signaling and network management flows for endpoint-to-endpoint, endpoint-to-switch, and switch-to switch setting as shown in figure 8.36. Some of this work is expected to be finished by October 1996.

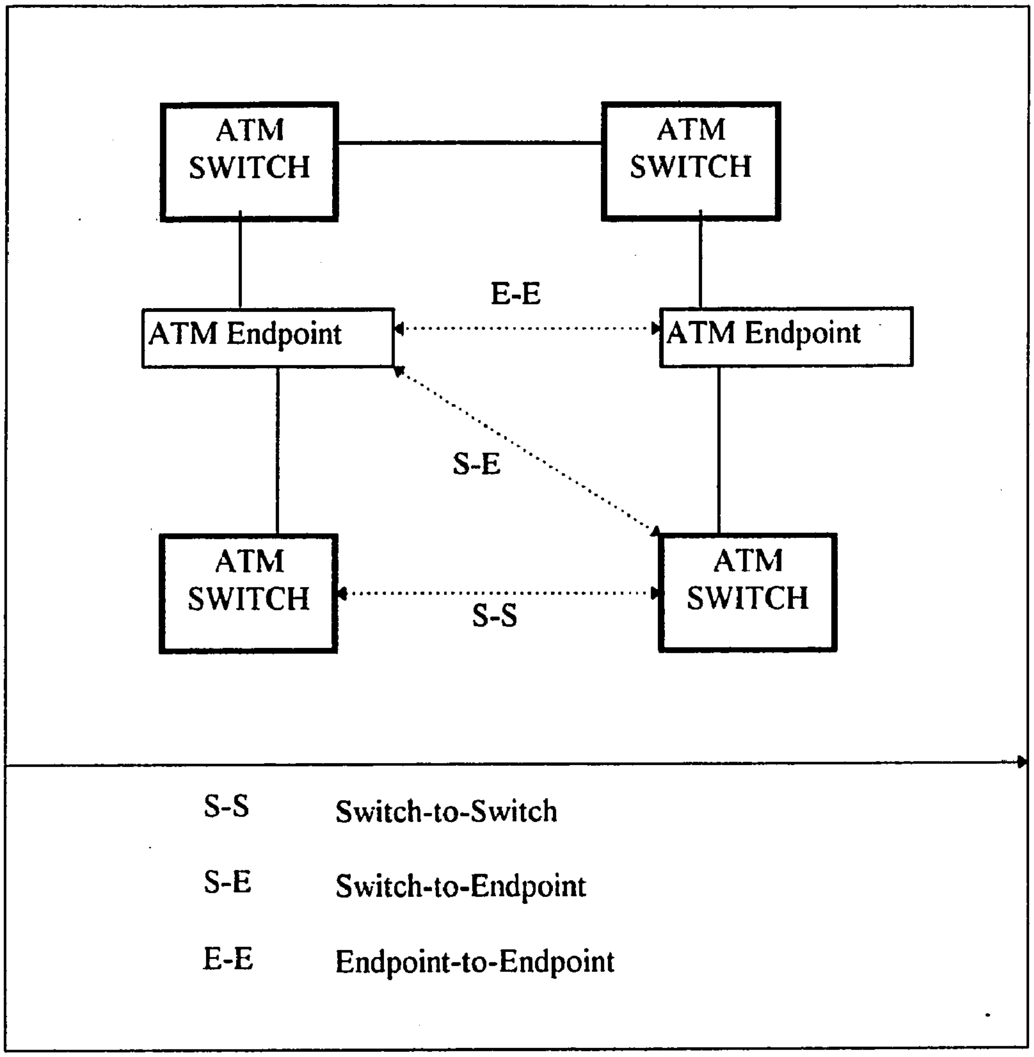


**Figure 8.36 ATM** Security Model

# CONCLUSION

The major contribution of this dissertation is to evolve a methodology for optimizing and enhancing national networks. This methodology has provided the following:

- Development of a software package to solve national networks existing problems and to increase network performance and capacity with minimum cost and maximum profit.
- Providing methods for identifying the critical location of high speed switches.
- Optimal topology for both switches and links.
- Cost effect analysis for both fixed cost and running cost of national networks.
- The first contribution methodology of broadband networks to third world countries when there is a high demand for high speed transmission facilities. This methodology is applicable to any developing country throughout the period of its utilization.

The general plan in this study was broken into one, five, and ten years for more efficiency. This break-down makes the general plan more flexible to adapt to changes in telecommunication technology. The three plans can be combined and implemented in either a ten-year period or a sixteen-year period, depending on the availability of funds for these plans. The analysis of the data shows that increasing traffic intensity will reduce cost per minute when **SONET** is used as a backbone network for **ATM** switches.

The analysis and results suggested in the dissertation can be used to create a national telecommunication network model for any developing country. Nevertheless, the results can be applied to other small countries, big cities, or sections of large countries. To apply the results to a national network of a large country, the national network has to be divided into smaller subnets to which the study can apply.

**SONET** introduces cost reduction in monthly transmission. These results are achieved when **SONET** is used as a backbone for **ATM** switches for a national telecommunication network instead of a microwave backbone network.

Depending on national network organization of the country, this research will help designers make the right decision regarding the changes they want to make. Changes to a current network can be: extending existing exchanges, adding new exchanges, replacing all exchanges, making long term strategy for a small number of large exchanges, or making long term strategies for a large number of small geographically dispersed exchanges.

# GLOSSARY

* **Analog** Information represented by continuous and smoothly varying signal amplitude or frequency over a certain range, such as in the human speech or music.

* **Asynchronous** Refers to circuitry and operations without common timing

* **Asynchronous transmission** Method of sending data in which the interval between characters may be of unequal length. Also called start-stop transmission.

* **AT&T** American Telephone and Telegraph company. The US major common carrier for long distance lines.

* **Attenuation** The decrease in power that occurs when any signal is transmitted.

* **Backbone network** A transmission facility designed to interconnect switching devices.

* **Bandwidth** A frequency range, usually specified by the number of hertz in a band or between upper and lower limiting frequencies.

* **Carrier system** A transmission system for transmitting one or more channels of information by processing and converting to a form suitable for the transmission medium used.

* **CCITT** The International Consultative Committee for Telephone, a consultative committee to the International Telecommunication Union (ITU) which recommended international standards for telephone and telegraph services and facilities to aid international connectivity.

* **Cell** In cellular mobile telephone, the geographic area served by one transmitter. Subscribers may move from cell to cell during conversation.

* **Central Office** The switching equipment that provides local exchange telephone service for a given geographical area, designated by the first three digits (NNX or NXX) of the telephone number.

* **Channel** An electronic communications path connected two or more points in a network. "Channel" and "circuit" are often used interchangeably, however circuit can also describe a physical configuration of equipment that provides a network transmission capability for multiple channels. The characteristics of channels and circuits are determined by the network equipment and media used to support them.

* **Circuit-switching** A type of exchange or network designed to be capable of providing a direct connection between originating and terminating points of a communication or the entire duration of a call.

* **Common channel signaling(CCS)** A signaling system developed for use network components, in which all of the signaling information for one or more trunk groups is transmitting over a dedicating signaling channel, usually, completely separate from the user traffic bearing facilities.

* **Crosstalk** The interface of telephone and other signals resulting from the induction of an unwanted signal from an adjacent telephone line.

* **Decibel(dB)** A unit of measure of relative power or voltage, in terms of the ratio of two values. dB = 10 log P1/P2, where P1 and P2 are power levels in watts.

* **Demodulation** The process of extracting transmitted information from a carrier signal.

* **Demultiplexing** A circuit that distributes an input signal to a multiple output lines.

* **Distortion** The corruption of a signal brought about by electrical disturbance or nonuniform line properties, particularly causing different frequency components of a complex signal to be unequally affected.

* **End office(EO)** A switching system within the LATA where local loops to customer stations are terminated for purposes of interconnection with each other and with trunks. CO (central office) and EO are often used interchangeably.

* **Frequency Modulation(FM)** One of three basic ways to add information to a sine wave signal: the frequency of the carrier is minified in accordance with the information to be transmitted.

* **Integrated Services Digital Network(ISDN)** A **CCITT** standard, provides end-to-end digital connectivity to support a wide range of services, including voice and non-voice, to which users have access by a limited set of standard multipurpose user-network interfaces.

* **Local Area Network(LAN)** A data communication network confined to a limited geographical area. It is owned by its user, may includes some type of switching technology, and does not use common carrier circuits.

* **Metropolitan Area Network(MAN)** A technology supporting high speed networking across a metropolitan area. IEEE 802.6 defines a MAN protocol.

* **Microwave** All frequencies in the electromagnetic spectrum above one GHz.

* **Modulation** The systematic changing of the properties of an electronic wave, using a second signal, to convey the information contained in the first signal.

* **Multiplexing** The division of a transmission facility into two or more channels.

* **PBX** A private branch telephone exchange system providing telephone switching in an office or building.

* **Pulse Code Modulation(PCM)** A communication systems technique of coding signals with binary codes to carry the information.

* **Shortest path algorithm** A routing algorithm that uses knowledge of network's topology in making routing decisions.

* **Tandem** A non-direct connection between two exchanges. The term can also be used to describe the intermediate exchange in such a connection.

* **Tariff** A published rate for a specific telecommunications service, equipment, or facility that constitutes a public contract between the user and the telecommunications supplier.

* **TCC** Jordanian Telecommunication Corporation.

* **Time Division Multiplexing(TDM)** A communication system technique that separate information from channel inputs and places them on a carrier in specific positions in time.

* **Toll Center** A major telephone distribution center that distributed calls from one major metropolitan area to another.

* **Traffic** The flow of information within a telecommunications network.

* **Trunk** A transmission channel connecting two switching centers.

* **Voice Grade Circuit(VGC)** A channel or line that offers the minimum bandwidth suitable for voice frequencies, usually 300 to 3400 bps.

* **Wide Area Network(WAN)** A network that covers a large geographical area . Typical WAN technologies include point-to-point, X.25, and frame relay.

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