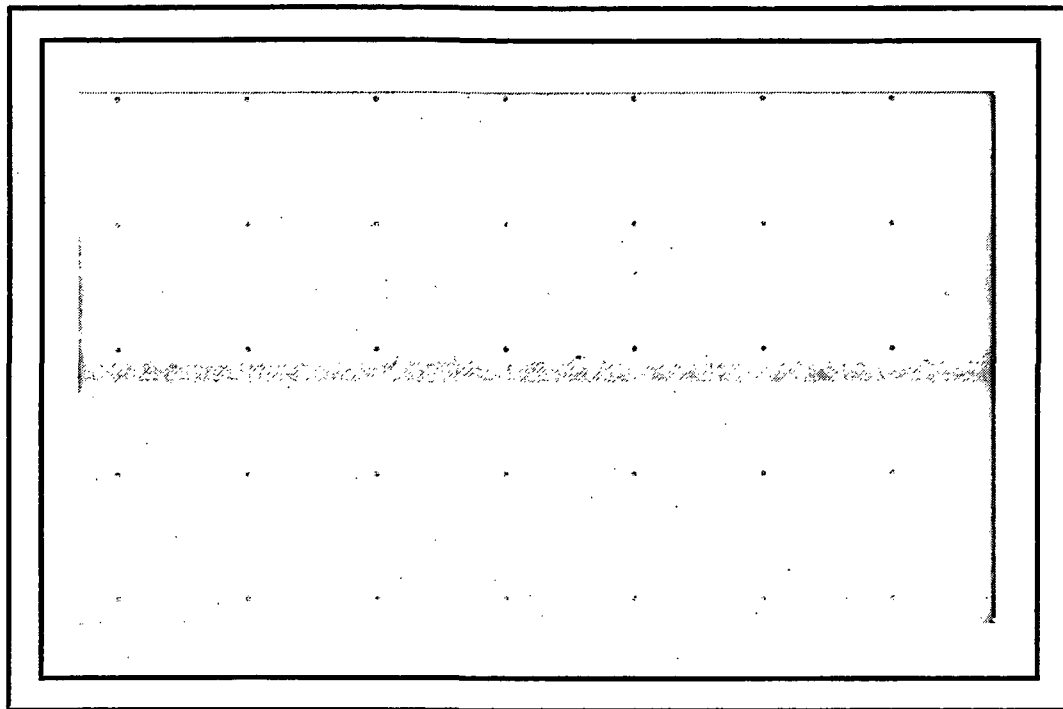


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**UNIVERSITY OF MARYLAND
COMPUTER SCIENCE CENTER
COLLEGE PARK, MARYLAND**

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NOTE NO. 1

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APPROVED BY : PROFESSOR JACK MINKER

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ABSTRACT

THE PURPOSE OF THIS NOTE IS TO DESCRIBE THE GENERAL FEATURES OF THE 'GENET' SYSTEM FOR SIMULATING NETWORKS UNDER DEVELOPMENT AT THE UNIVERSITY OF MARYLAND. A SET OF FEATURES WHICH ARE DESIRABLE FOR NETWORK SIMULATIONS IS PRESENTED IN THIS NOTE AND IT IS EXPECTED THAT THE FEATURES WILL BE ACHIEVED BY THE SYSTEM 'GENET'.

AMONG THESE FEATURES ARE:

- (A) TWO LEVEL OF NETWORK MODELING: A NETWORK CAN BE VIEWED AS A SET OF PROCESSORS CONNECTED BY A SET OF COMMUNICATION FACILITIES. EACH PROCESSOR PERFORMS ITS OWN FUNCTIONS AND COMMUNICATE WITH OTHERS THROUGH THE COMMUNICATION FACILITIES. IN THIS CONTEXT, A NETWORK CAN BE MODELED AS A TWO LEVEL TASK : A COMMUNICATION-SWITCHING ORIENTED SUBMODEL AND A SET OF PROCESSOR ORIENTED SUBMODELS. A CONCEPTUAL FRAMEWORK IS PRESENTED IN CHAPTER 2.
- (B) PROBLEM ORIENTED OPERATIONS: THE 'GENET' SYSTEM IS INTENDED AS A USER AND PROBLEM ORIENTED SIMULATION TOOL FOR USE IN NETWORK MODELING. A SET OF PRIMITIVE OPERATIONS SHOULD BE INCLUDED IN THE 'GENET' SYSTEM. EACH OF THESE PRIMITIVE OPERATION IS THOROUGHLY DISCUSSED IN CHAPTER 2.

IN CHAPTERS 3, 4, AND 5, THERE ARE SEVERAL TYPICAL NETWORK SYSTEMS ARE MODELED IN GENET FRAMEWORK TO ILLUSTRATE VARIOUS OF THE FEATURES AND TO SHOW ITS APPLICABILITY.

TABLE OF CONTENTS

ABSTRACT		
1.	INTRODUCTION	1-1
2.	ANATOMY OF A NETWORK	2-1
2.1.	SWITCHING ORIENTED TECHNIQUES:	2-8
2.1.1.	NETWORK STRUTURES:	2-9
2.1.2.	TRANSMISSION STRATEGIES	2-11
2.1.2.1.	MULTIPLEXING:	2-11
2.1.2.2.	BUFFERING	2-12
2.1.2.3.	CONCENTRATING	2-13
2.1.2.4.	STORE AND FORWARDING	2-13
2.1.3.	TECHNIQUES OF SWITCHING AND EXCHANGING	2-14
2.2.	PROCESSOR ORIENTED TECHNIQUES:	2-18
2.2.1.	PROCESSOR EFFICIENCY AND EFFECTIVITY	2-18
2.2.1.1.	INTERRUPTS AND TRAPS	2-18
2.2.1.2.	MUTUAL COOPERATION	2-19
2.2.1.3.	INTERLOCK AND PROTECTION	2-20
2.2.2.	RESOURCE ALLOCATION STRATEGIES	2-21
2.2.3.	PROCESSOR FAILURES AND RECOVERY	2-22
3.	TWO LEVEL VIEWS OF A COMMUNICATION NETWORK	3-1
3.1.	GLOBAL OR SWITCHING ORIENTED OPERATIONS:	3-2
3.2.	LOCAL OR PROCESSOR ORIENTED VIEW	3-6
3.2.1.	A COMMUNICATION LINK:	3-8
3.2.2.	A TERMINAL NODE:	3-10
3.2.3.	A SWITCHING CENTER	3-12
4.	A TWO LEVEL VIEW OF A COMPUTER NETWORK	4-1
4.1.	GLOBAL VIEW OF A COMPUTER NETWORK	4-2
4.2.	LOCAL OR PROCESSOR VIEW	4-6
4.2.1.	COMMUNICATION FACILITIES	4-6
4.2.2.	COMPUTER	4-8
4.2.3.	TERMINALS:	4-11
5.	TWO LEVEL VIEW OF A NETWORK OF COMPUTERS	5-1
5.1.	GLOBAL OR SWITCHING ORIENTED VIEW :	5-2
5.2.	LOCAL VIEW OF A NETWORK OF COMPUTERS	5-7
5.3.	EXAMPLES:	5-10
5.3.1.	ARPA NETWORK	5-11
BIBLIOGRAPHY		

NETWORK RESEARCH

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1. INTRODUCTION

THIS NOTE IS THE FIRST OF A SERIES OF NOTES ENTITLED 'A PROPOSED NETWORK RESEARCH TOOL'. THE AIM OF THIS RESEARCH IS TO DEVELOP ANALYTICAL AND SIMULATION TOOLS FOR THE MODELING, ANALYSIS AND SIMULATION OF A WIDE RANGE OF NETWORKS. SEPECIAL EMPHSIS HAS BEEN PLACED ON THE CAPABILITY OF MODELING AND ANALYSIS OF A COMPLEX NETWORK OF COMPUTERS.

IN GENERAL, THE STUDY OF A NETWORK SYSTEM CAN BE DIVIDED INTO FOUR STAGES; THEY ARE:

- (1) PHYSICAL SYSTEM INVESTIGATION AND MODEL CONSTRUCTION,
- (2) MODEL ANALYSIS,
- (3) MODEL SIMULATION, AND
- (4) RESULT DOCUMENTATION.

THE PHYSICAL (OR CONCEPTUAL) NETWORK SYSTEM UNDER QUESTION IS FIRST THOROUGHLY INVESTIGATED AND REPRESENTED BY A FUNCTIONAL MODEL. THEN, EITHER A PROPER MATHEMATICAL ALGORITHM IS SELECTED TO SOLVE OR ANALYZE SOME OF THE MATHEMATICAL PROPERTIES OF THE NETWORK, OR A SUITABLE SIMULATOR IS SELECTED TO SIMULATE AND OBSERVE THE DYNAMIC BEHAVIOR OR STATES OF THE NETWORK. THE RESULTS OBTAINED FROM THE ABOVE ANALYZER OR SIMULATOR ARE THEN CAREFULLY STUDIED AND DOCUMENTED. EACH OF THESE FOUR STAGES INTERACTS WITH ONE ANOTHER, YET, EACH HAS ITS OWN DISTINCT PROPERTIES.

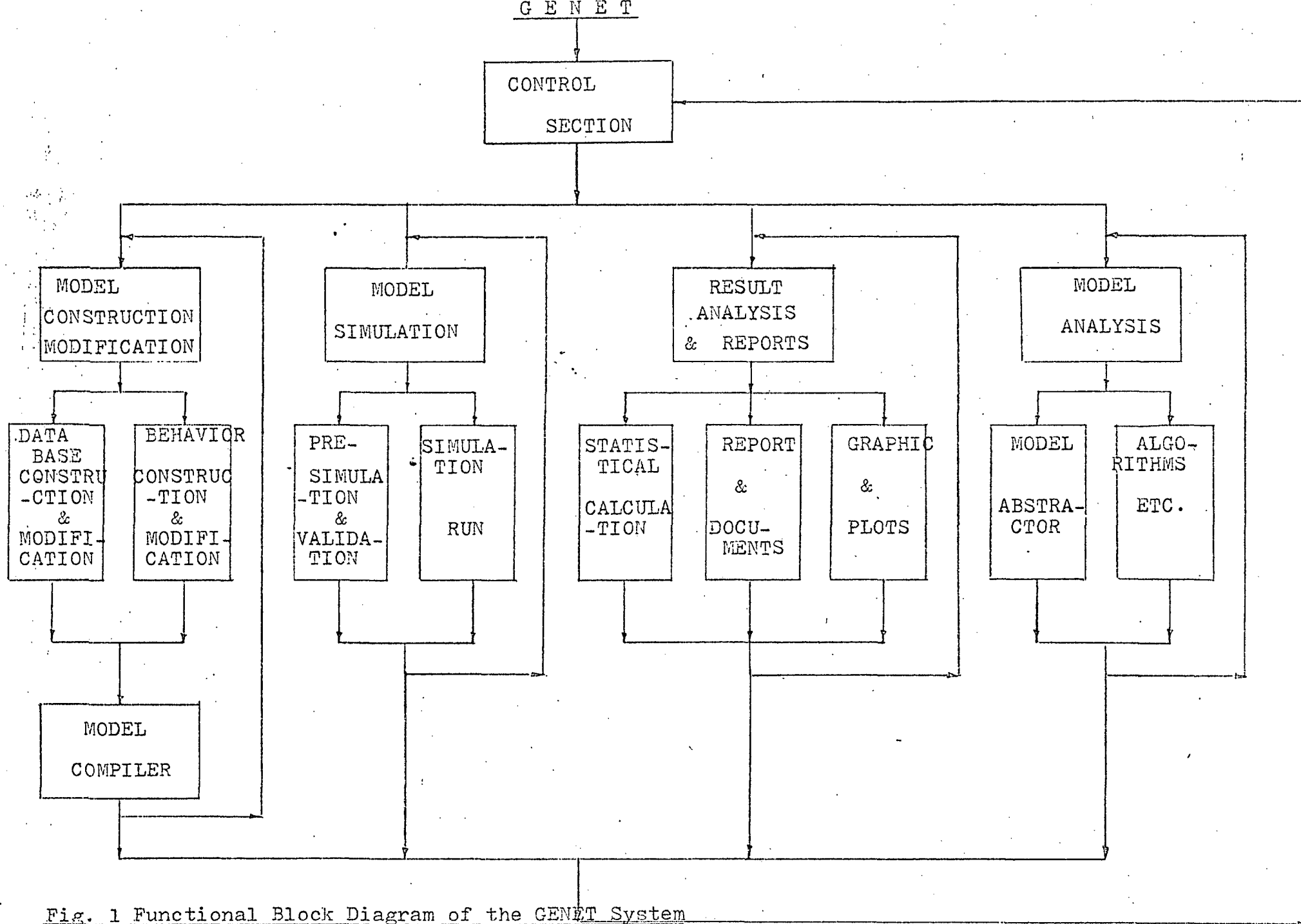


Fig. 1 Functional Block Diagram of the GENET System

THE GENERAL NETWORK SIMULATION AND ANALYSIS SYSTEM, 'GENET', UNDER DEVELOPMENT IS BEING DESIGNED TO SERVE ALL OF THE ABOVE FOUR STAGES. AS SHOWN IN FIGURE 1, THE 'GENET' SYSTEM IS TO BE STRUCTURED INTO FOUR INTERACTIVE SUBSYSTEMS. THEY ARE:

(1) MODEL CONSTRUCTION AND/OR MODIFICATION SUBSYSTEM:

THIS SUBSYSTEM IS EXPECTED TO CONSIST OF AN ASSEMBLER, AN EDITOR, AND A COMPONENT LIBRARY. A MODEL MAY BE BUILT BY MEANS OF ASSEMBLING THE PIECES OF COMPONENTS TOGETHER. EACH OF THESE COMPONENTS MAY BE OBTAINED FROM THE COMPONENT LIBRARY OR MAY BE A USER CREATED COMPONENT. THE USER MAY CREATE A NEW COMPONENT BY MEANS OF EDITING AND/OR MODIFYING AN EXISTING COMPONENT OR HE MAY BUILD THE COMPONENT FROM SCRATCH.

(2) MODEL ANALYSIS SUBSYSTEM:

THIS SUBSYSTEM IS EXPECTED TO CONSIST OF A SET OF NETWORK ANALYSIS PROGRAMS AND A MODEL ABTRACTOR. THE MODEL ABTRACTOR IS USED INTERACTIVELY TO EXTRACT THE NECESSARY INFORMATION FROM A NETWORK MODEL FOR A PARTICULAR ANALYSIS PROGRAM.

(3) MODEL SIMULATION SUBSYSTEM:

THIS IS THE CENTRAL PART OF THE 'GENET' SYSTEM. IT IS EXPECTED TO CONTAIN AN ON-LINE, INTERACTIVE SIMULATOR WHICH SIMULATES THE DYNAMIC BEHAVIOR OF THE NETWORK MODEL AND PRODUCES THE RESULTS ON-LINE AND/OR TO USER SPECIFIED FILES FOR FURTHER

ANALYSIS.

(4) RESULT ANALYSIS AND DOCUMENTATION SUBSYSTEM:

THIS SUBSYSTEM IS EXPECTED TO CONSIST OF A SET OF STATISTICAL PROGRAMS AND A SET OF DATA DISPLAY ROUTINES. THE STATISTICAL PROGRAMS ARE REQUIRED FOR CALCULATION, TABULATION, RECORDING AND REDUCTION OF STATISTICAL DATA. THE DISPLAY ROUTINES MAY BE ROUTINES FOR PRODUCING GRAPHS, HISTOGRAMS, FREQUENCY TABLES AND GENERAL REPORTS.

THE OPERATION OF ANY OF THESE FOUR SUBSYSTEMS MAY BE SUSPENDED AUTOMATICALLY OR MANUALLY AND RESUMED AT A LATER TIME. IN THE

STUDY OF NETWORK SYSTEMS, WE ARE PARTICULARLY INTERESTED IN THE OPERATIONS CARRIED OUT BY A NETWORK. THESE COMPLEX OPERATIONS CAN BEST BE CONSIDERED AS CONSISTING OF TWO POINTS OF VIEW: A GLOBAL AND A LOCAL POINT OF VIEW. IN THE GLOBAL POINT OF VIEW, A NETWORK, CONSISTS OF A SET OF NODES WHICH ARE IN TURN CONNECTED BY A SET OF LINKS. THE OPERATIONS CARRIED OUT BY THIS NETWORK CAN BE OBSERVED FROM THE FLOWS WHICH PASS THROUGH THE NETWORK. A TYPICAL OPERATION IS AS FOLLOWS: CREATE A MESSAGE AT ONE OF THE TERMINAL NODES, PROCESS THE MESSAGE, SEND THE MESSAGE FROM NODE TO NODE, AND TERMINATE THE MESSAGE. ON THE OTHER HAND, IN THE LOCAL POINT OF VIEW, A NETWORK CAN BE CONSIDERED AS A SET OF COMPONENTS. ALL COMPONENTS CAN ONLY RECOGNIZE THEIR OWN PROCESS FUNCTIONS AND SOME LIMITED INFORMATION ABOUT THEIR NEIGHBOURING COMPONENTS. THIS INFORMATION INVOLVES: ALLOCATING DEVICES AND

STORING, SCHEDULING FOR PROCESSING, AND PASSING THE FLOW TO ONE OF ITS NEIGHBOURING COMPONENTS. ONE MAY CONSIDER THE GLOBAL MODELING OF A NETWORK AS A TELESCOPE WHICH REVEALS THE OVERALL PERFORMANCE OF THE ENTIRE NETWORK, WHILE THE 'LOCAL MODELING' CAN BE REGARDED AS A MICROSCOPE WHICH GIVES DETAILED RESULTS OF INDIVIDUAL COMPONENTS.

THIS NOTE ATTEMPTS TO PRESENT A CONCEPTUAL FRAMEWORK IN TERMS OF THIS TWO-LEVEL MODELING. IN THIS FRAMEWORK, THE GLOBAL VIEW OF A NETWORK IS A FLOW (OR SWITCHING) ORIENTED NETWORK, AND THE LOCAL VIEW OF A NETWORK IS A PROCESSOR ORIENTED NETWORK. IN CHAPTER 2, THIS CONCEPTUAL FRAMEWORK IS PRESENTED IN DETAIL, AND SOME BASIC TECHNIQUES FOR DESIGNING AND ANALYZING A NETWORK SYSTEM ARE DISCUSSED BRIEFLY FOLLOWING THIS DISCUSSION, THREE NETWORK EXAMPLES - A COMMUNICATION NETWORK, A TIME-SHARING NETWORK, AND A COMPUTER NETWORK-ARE USED TO ILLUSTRATE THE CONCEPTUAL FRAMEWORK OF NETWORK STUDY. THERE ARE A NUMBER OF SPECIFIC FEATURES REQUIRED TO

ACCOMPLISH A GENERAL NETWORK SIMULATION. THESE FEATURES INCLUDE:

(A) COMMUNICATION ORIENTED OPERATIONS:

1. LINE CONNECTING AND DISCONNECTING,
2. MESSAGE SENDING AND RECEIVING,
3. MESSAGE PACKING AND UNPACKING,
4. LINE/MESSAGE CONCENTRATING AND MULTIPLEXING,
5. POLLING, ADDRESSING, AND CONTENTION TRANSMISSIONS, AND
6. POSITIVE AND NEGATIVE ACKNOWLEDGMENTS.

(B) PROCESSOR ORIENTED OPERATIONS:

1. FACILITY ALLOCATING, AND RELEASING,
2. INFORMATION STORING AND RETRIEVING,
3. FILE LOCATING AND MOVING,
4. AND FACILITY SELECTING AND SCHEDULING, AND
5. INTERRUPT RECIEVING AND HANDLING.

A REVIEW HAS BEEN MADE OF SEVERAL WELL-KNOWN SIMULATION SYSTEMS, WHICH INCLUDE (1) GENERAL PURPOSE SIMULATION SYSTEMS --GPSSC J, SIMSCRIPT J, SIMULAC J, OPS-4C J, JASPC J; AND OF SEVERAL COMMUNICATIO SYSTEM (2) COMMUNICATION NETWORK SIMULATION SYSTEMS -- UNSE J, COMSLC J; (3) COMPUTER SYSTEM SIMULATION SYSTEMS --CSSC J, AND ECSSE J,

BASED ON THE REVIEW WE HAVE CONCLUDED THAT:

- (1) GENERAL PURPOSE SIMULATION SYSTEM LANGUAGES (E.G. GPSS) ARE NOT FEASIBLE FOR NETWORK SIMULATIONS. IN THE USE OF GENERAL PRUPOSE SYSTEMS, A LARGE AMOUNT OF PROGRAMMING EFFORT WOULD HAVE TO BE PROVIDED BY THE INDIVIDUAL USER. IN ADDITION, BECAUSE OF THE LACK OF A CONCEPTUAL FRAMEWORK ORIENTED TOWARDS NETWORKS, IT MAY CAUSE PROGRAMMING AND EXPERIMENTATION DIFFICULTIES.
- (2) BOTH THE COMMUNICATION ORIENTED AND PROCESSOR ORIENTED SIMULATORS HAVE INSUFFICIENT OPERATIONS, WHICH ARE REQUIRED FOR A GENERAL NETWORK SIMULATION (SUCH AS THOSE OPERATIONS WHICH WE HAVE LISTED IN THE ABOVE PARAGRAPH). IN GENERAL, MOST OF THESE SIMULATORS HAVE THEIR OWN SPECIAL PURPOSE AND

LOSE GENERALITY. IN OTHER WORDS, IF THE SIMULATOR DOES NOT CONTAIN A REQUIRED OPERATION THEN THE USER CAN DO LITTLE TO OVERCOME THIS DIFFICULT.

- (3) A SPECIAL SIMULATION SYSTEM WHICH HAS THE ABILITY TO MODEL BOTH NETWORK PROCESSORS AND NETWORK FLOWS IS REQUIRED. THAT IS, A SYSTEM WHICH HAS THE OPERATIONS AS LISTED ABOVE IS REQUIRED TO PROVIDE USERS WITH THE CAPABILITY TO SIMULATE A WIDE RANGE OF NETWORKS.

A SPECIAL SIMULATION SYSTEM WHICH HAS THE ABILITY TO MODEL BOTH NETWORK PROCESSORS AND NETWORK FLOWS IS REQUIRED TO PROVIDE USERS WITH THE CAPABILITY TO ANALYZE SUCH SYSTEMS BEFORE LARGE EXPENDITURES ARE MADE IN THEIR IMPLEMENTATION AND STUDY.

2. ANATOMY OF A NETWORK

IN OUR STUDY OF NETWORKS, WE ARE PARTICULARLY INTERESTED IN THE OPERATIONS CARRIED OUT BY THE NETWORK. FIG. 2 ILLUSTRATES A CONCEPTUAL MODEL OF A GENERAL NETWORK. IN THIS MODEL, A NETWORK IS VIEWED AS A SET OF SPACE-SHARED DEVICES (E.G., MEMORIES, SECONDARY STORES, OR FILES IN THE COMPUTER NETWORKS) AND A SET OF TIME-SHARED DEVICES (E.G., COMPUTER SYSTEMS IN A COMPUTER NETWORK) WHICH ARE INTERCONNECTED BY A SPECIAL COMMUNICATION FACILITY CALLED AN EXCHANGE LOOP OR SWITCHING MECHANISM (E.G., COMMON CARRIER FACILITIES IN COMPUTER NETWORKS). EVERY DEVICE HAS ITS OWN PERFORMANCE FUNCTION AND IS INDEPENDENT OF THE OTHERS, BUT CAN COMMUNICATE WITH THE OTHERS BY MEANS OF THE EXCHANGE LOOP.

IN THIS NETWORK, A MESSAGE IS CREATED AND PROCESSED THROUGH ONE OF THE TIME-SHARED DEVICES. AFTER BEING PROCESSED IT IS SWITCHED BY THE EXCHANGE LOOP TO ANOTHER DEVICE (OR THE SAME DEVICE) WHICH MAY BE A TIME-SHARED DEVICE OR A SPACE-SHARED DEVICE. THIS MESSAGE WILL CONTINUE TO STAY IN THE LOOP OF PROCESS AT ONE DEVICE AND THEN SWITCH TO OTHER DEVICE, UNTIL IT REACHS ITS DESTINATION DEVICE, WHERE THE MESSAGE WILL BE PROCESSED AND MOVED OUT OF THE NETWORK. IN THIS CONTEXT, A NETWORK CAN BE MODELED AS A TWO-LEVEL TASK AS SHOWN IN FIG. 2, THE GLOBAL (SWITCHING ORIENTED) VIEW AND THE LOCAL (PROCESSOR ORIENTED) VIEW. SOME TYPICAL MODELS ARE PRESENTED IN FIG. 3.

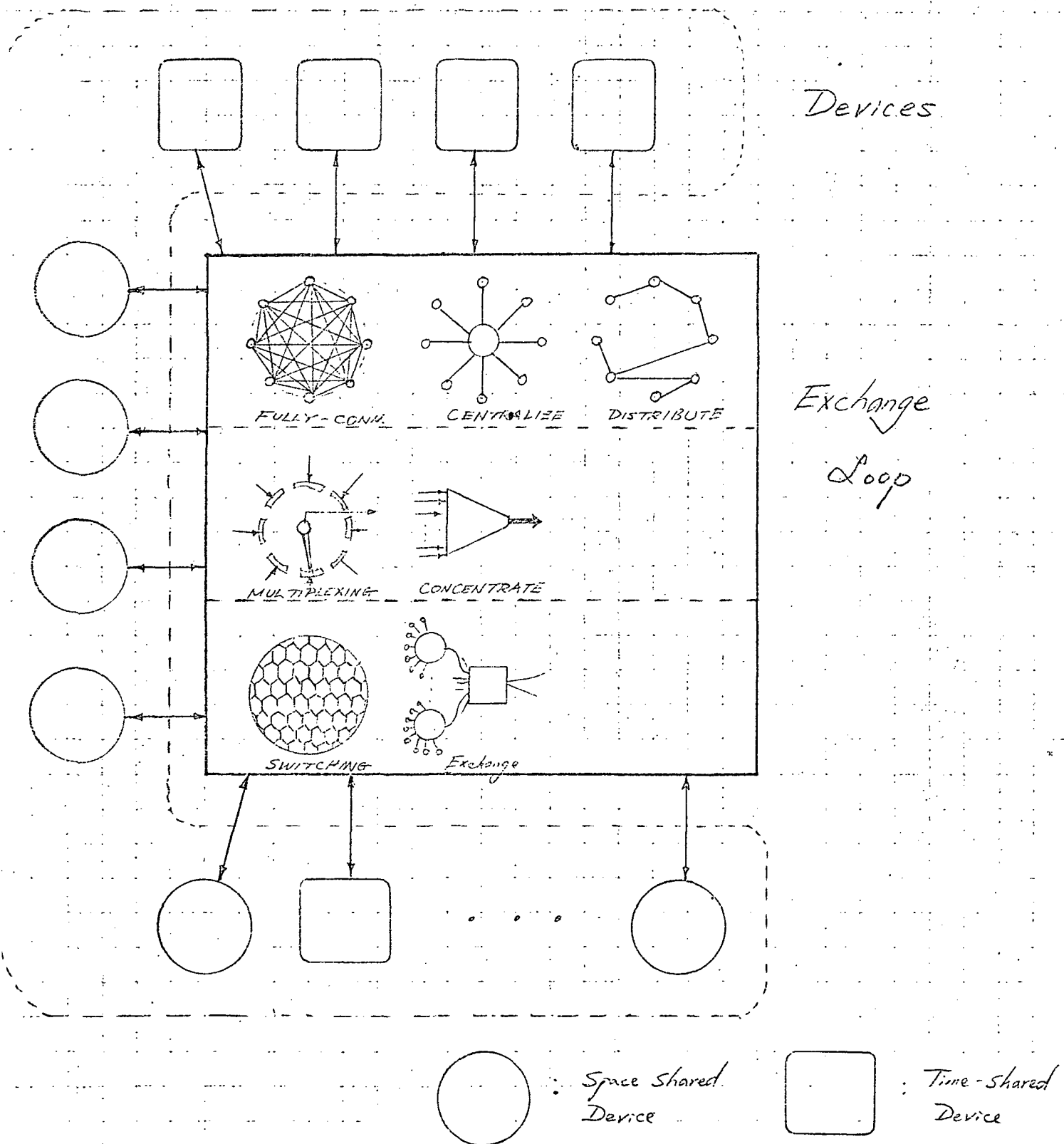


Fig. 2 A Conceptual Model of a General Network

A SIMPLE SWITCHING NETWORK HAS A TOPOLOGICAL STRUCTURE AS SHOWN IN FIG. 3(A), AND CAN BE VIEWED AS A TWO LEVEL PROCESSING TASKS (SEE FIG. 3 (A)):

1. COMMUNICATION - SWITCHING CENTER
2. PROCESSOR - TERMINAL

A MORE COMPLECATE NETWORK AS SHOWN IN FIG. 3 (B), CAN BE VIEWED AS A NESTING OF TWO NETWORKS, EACH (NETWORK) HAS TWO LEVELS OF PROCESSING TASKS AS DESCRIBED IN THE ABOVE EXAMPLE, NAMELY COMMUNICATION AND PROCESSING. THAT IS (SEE FIG. 3 (B)).

- 1.1. INTERCENTER COMMUNICATIONS
- 1.2. HIGH LEVEL PROCESSOR - SWITCHING CENTER
- 2.1. COMMUNICATIONS - SWITCHING CENTER
- 2.2. PROCESSOR - TERMINAL

IN SOME COMPUTERIZED NETWORK SYSTEMS, A SPECIAL COMPUTER IS DESIGNATED TO SERVE ALL INTERCENTER COMMUNICATIONS, AN EXAMPLE OF THIS KIND OF NETWORKS IS SHOWN IN FIG. 3 (C), AND ITS PROCESSING IS SHOWN IN FIG. 3 (C').

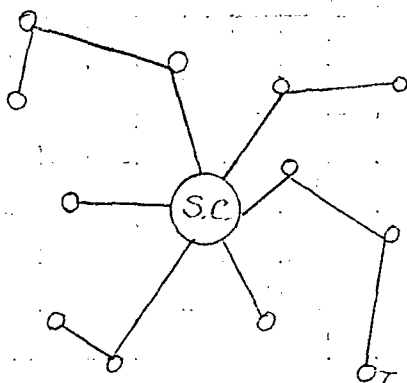
NETWORK PROBLEMS CAN ALSO BE CLASSIFIED INTO TWO CATEGORIES: SWITCHING (OR FLOW) ORIENTED PROBLEMS AND PROCESSOR (OR DEVICE) ORIENTED PROBLEMS.

SWITCHING ORIENTED PROBLEMS INVOLVE :

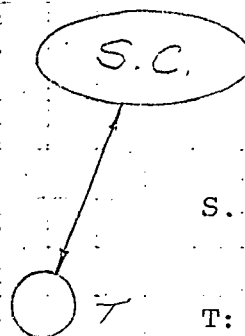
- . THE STRUCTURE OF THE NETWORK,
- . THE COMMUNICATION STRATEGY, AND
- . THE SWITCHING AND EXCHANGE MECHANISM.

PROCESSOR ORIENTED PROBLEMS INVOLVE :

Topological Structure



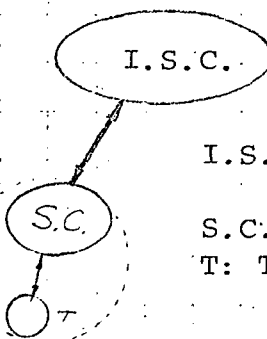
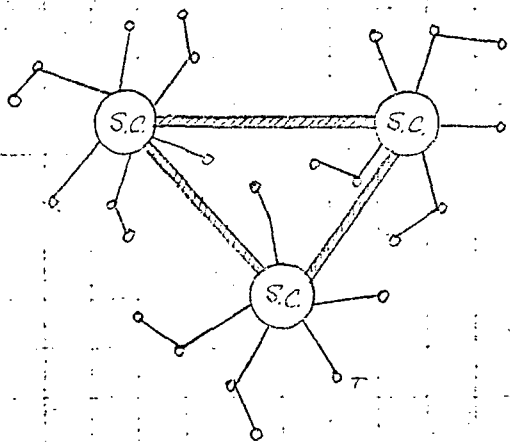
Two - level Processing Tasks



S. C.: Switching Center

T: Terminal

Fig. 3 (a) A Simple Switching Network

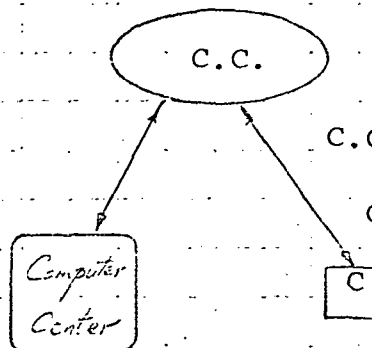
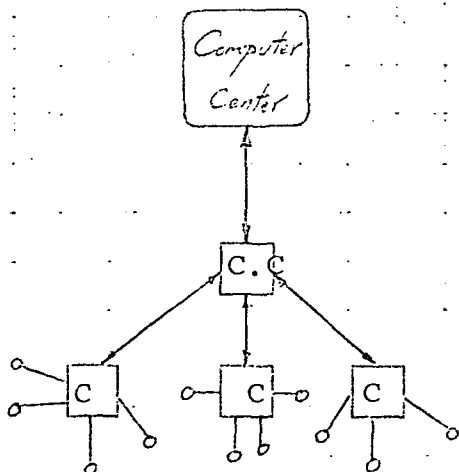


I.S.C.: Inter Center Switching Center

S.C.: Switching Center

T: Terminal

Fig. 3 (b) A General Switching Network



C.C.: Communication Controller

C: Channel

Fig. 3 (c) A Computerized Network

- . THE PROCESSING TIME AND RESPONSE TIME,
- . THE PROCESSOR THROUGHPUT, RELIABILITY AND UTILIZATION,
AND
- . THE RESOURCE ALLOCATION STRATEGY.

FROM THE GLOBAL OR SWITCHING POINT OF VIEW, THE FIRST CONSIDERATION IS THE 'NETWORK CONFIGURATION'. FOR A GIVEN SET OF NODES, THERE ARE MANY POSSIBLE CONFIGURATIONS. AS NOTED BY FRANKEL, THE DIRECT ENUMERATION OF ALL POSSIBLE CONFIGURATIONS FOR A TWENTY-NODE NETWORK IS BEYOND THE CAPABILITIES OF THE MOST POWERFUL PRESENT-DAY COMPUTER

BECAUSE OF THE ENORMOUS NUMBER OF COMBINATIONS OF LINKS THAT CAN BE USED TO CONNECT A RELATIVELY SMALL NUMBER OF NODES, FRANKEL ESTIMATES THAT FOR AS FEW AS A FIVE NODES NETWORK, THERE MAY BE AS MANY AS 1,500 DIFFERENT CONFIGURATIONS OF THE NETWORKS. THIS LEAVES THE PROBLEM OF DETERMINING WHICH IS THE MOST ECONOMICAL NETWORK SUBJECT TO A SET OF CONSTRAINTS. IT IS NOT POSSIBLE TO EXAMINE EVEN A SMALL FRACTION OF THE POSSIBLE NETWORK CONFIGURATIONS THAT MIGHT LEAD TO ECONOMICAL DESIGNS. FOR THIS REASON, SOME APPROXIMATION STRATEGIES AND HEURISTIC METHODS HAVE RECENTLY BEEN DEVELOPED FOR SOLVING THE ABOVE PROBLEM. A CONSIDERABLE AMOUNT OF WORK IN THIS AREA IS STILL UNDER DEVELOPMENT BY A GROUP OF RESEARCHERS, SUPPORTED BY THE ADVANCED RESEARCH PROJECT AGENCY OF THE DEPARTMENT OF DEFENSE (KNOWN AS THE ARPA NETWORK RESEARCH). FURTHERMORE, EVEN IF A CONFIGURATION OF A NETWORK IS FIXED, THE 'NETWORK FLOWS' BETWEEN NODES ARE STILL

NOT CONSTANT OR PRECISELY PREDICATABLE. THIS INVOLVES THE PROBLEM OF 'FLOW TRANSMISSION'. FLOWS (OR MESSAGES) WILL REACH A NETWORK AT RANDOM, THE (MESSAGE) LOAD ON A NETWORK WILL VARY SECOND BY SECOND. DIFFERENT FLOWS HAVE DIFFERENT SOURCES AND SINKS, AND THE TRANSMISSION NOT ONLY DEPENDS ON ITS SOURCE AND SINK BUT ALSO DEPENDS ON THE TRAFFIC PATTERNS AT THAT PARTICULAR MOMENT. THERE ARE MANY TECHNIQUES THAT HAVE BEEN DEVELOPED TO ACHIEVE THE EFFICIENCY OF FLOW TRANSMISSION. THIS IS ONE OF THE MOST ACTIVE AREAS OF TELECOMMUNICATION NETWORK RESEARCH.

WHENEVER ECONOMIC CONSIDERATIONS ARE INVOLVED IN NETWORK DESIGN AND EVALUATION, A MAJOR OBJECTIVE IS THAT OF REDUCING THE COST OF TRANSMISSION AND INSTALLATION. THE STRATEGIES USED IN THIS AREA ARE : MULTIPLEXING, CONCENTRATING, AND FACILITY SHARING. A COMBINATION OF THESE TECHNIQUES IS USUALLY CALLED 'EXCHANGE AND SWITCHING' MECHANISMS. IN AN EXCHANGE AND SWITCHING NETWORK, THE SPECIAL NODES, NAMED SWITCHING CENTERS, ARE ADDED INTO A NETWORK SYSTEM. THE ORIGINAL NODES BECOME THE SUBSCRIBERS OF THESE SWITCHING CENTERS. THERE ARE NO DIRECT CONNECTIONS BETWEEN SUBSCRIBERS, BUT ANY SUBSCRIBER CAN REQUEST THE SWITCHING CENTER TO CONNECT ANY OTHER SUBSCRIBER AS DESIRED. THE SWITCHING CENTERS WILL ESTABLISH A CONNECTION AND MAINTAIN THIS CONNECTION FOR THE DURATION OF THE TRANSMISSION AS THE SUBSCRIBER REQUESTED. THE TRANSMISSION FACILITY IS SHARED BY ALL SUBSCRIBERS. THIS TECHNIQUE HAS BEEN USED WIDELY IN THE FIELD OF ELECTRONIC DATA COMMUNICATION SUCH AS TELEPHONE, TELEGRAMS, AND TELETYPE

COMMUNICATIONS. TO ACHIEVE A WIDE-RANGE OF SWITCHING FUNCTIONS, THIS THEN INVOLVES COMBINATORIAL PROBLEMS, SUCH AS OPTIMAL ROUTE, EFFICIENT DIALING PROCEDURES, ETC.

NOW WE TURN OUR ATTENTION TO EACH INDIVIDUAL PROCESSOR WHICH MAY BE A SPACE SHARED DEVICE OR A TIME SHARED DEVICE.

TO ACHIEVE 'GOOD PERFORMANCE' FOR EACH PROCESSOR IS THE OBJECTIVE OF NETWORK DESIGNERS OR ANALYSTS. THE TERM 'GOOD PERFORMANCE' CAN BE INTERPRETED IN SEVERAL DIFFERENT WAYS DEPENDING ON THE INTERESTS OF THE USER OF THE SIMULATION PACKAGE. FOR THE USER OF THE NETWORK SYSTEM, 'GOOD PERFORMANCE' MAY MEAN FAST PROCESSING TIME AND FAST RESPONSE TIME. FOR A NETWORK ENGINEER, MEAN-TIME BETWEEN-FAILURE, THROUGHPUT, AND PROCESSOR RELIABILITY ARE ESSENTIAL INGREDIENTS OF THE PERFORMANCE. ON THE OTHER HAND, THE NETWORK DESIGNER AND ANALYST SEES PERFORMANCE IN TERMS OF DEGREE OF UTILIZATION OF VARIOUS COMPONENTS, AND SIMULTANEOUSLY MUST BE CONCERNED WITH PERFORMANCE FOR THE USER'S AND ENGINEER'S POINTS OF VIEW.

OVER A GIVEN PERIOD OF OPERATION, SAY 10 SECONDS, THERE ARE PRECISELY 10,000,000 MICROSECONDS OF PROCESSING TIME AVAILABLE. DURING THIS PERIOD OF OPERATION, THESE 10,000,000 MICROSECONDS WILL BE DISTRIBUTED AMONG THE ACTUAL MESSAGE PROCESSING TIME, THE SYSTEM OVERHEAD AND THE SYSTEM IDLE TIME. THESE THREE EVENTS CANNOT OCCUR AT THE SAME TIME. THEREFORE, WHEN NO MESSAGES ARE BEING EXECUTED, AND THE SYSTEM IS NOT IDLING, THEN THE SYSTEM OVERHEAD MUST TAKE PLACE. IN GENERAL, AN INCREASE IN THE ACTUAL

PROCESSING TIME CORRESPONDS TO A DECREASE IN IDLE TIME BUT ALSO CORRESPONDS TO AN INCREASE IN OVERHEAD TIME AS WELL. THIS IMPLIES THEN THAT THE BASIC GOAL FOR REDUCING PROCESSING COST IS TO SEEK A WAY TO MINIMIZE THE OVERHEAD TIME WHILE TRYING TO MAXIMIZE THE ACTUAL PROCESSING TIME. THE RESULT OF THIS MIGHT CAUSE AN INCREASE IN THE NUMBER OF CONCURRENT USERS OF THE PROCESSOR'S FACILITIES AND THEREBY CAUSE AN INCREASE IN THE RESPONSE TIME (OR TURN-AROUND TIME) OF INDIVIDUAL MESSAGES.

THE RESPONSE TIME (OR TURN AROUND TIME) IS THE TIME A PROCESSOR TAKES TO RESPOND TO A GIVEN INCOMING MESSAGE. AS MENTIONED ABOVE, A PROCESSOR MAY PROVIDE ITS CURRENT USERS WITH A SATISFACTORY RESPONSE TIME BUT AT A BURDENSOME OVERHEAD COST. IN SOME NETWORK SYSTEMS WHERE RAPID-RESPONSE IS REQUIRED, SUCH AS IN A SO CALLED REAL-TIME NETWORK SYSTEM, THE TRADE-OFF BETWEEN PROCESSING COST AND THE RESPONSE TIME BECOMES A MAJOR TASK FOR DESIGN AND EVALUATION. ANOTHER IMPORTANT CONSIDERATION IN THE SYSTEM PERFORMANCE IS THE 'RELIABILITY'. THE SERIOUSNESS OF A PROCESSOR BREAK-DOWN IS OFTEN RELATED TO THE RESPONSE-TIME REQUIRED. FOR EXAMPLE TWO HOURS INTERRUPTION MAY NOT BE TOO SERIOUS IF THE PROCESSOR HAS ONE HOUR OF RESPONSE TIME, BUT IT WILL BE DISRUPTED IF THE PROCESSOR REQUIRES SECONDS OF RESPONSE TIME. DIFFERENT PROCESSORS OFTEN HAVE DIFFERENT RELIABILITY REQUIREMENTS, AND THEN HAVE DIFFERENT WAYS TO OVERCOME FAILURES. PROVIDING AS FAIL-SAFE AS POSSIBLE A SYSTEM WILL GENERALLY DEGRADE THE SERVICE OF THE PROCESSOR. IN OTHER WORDS, IT MAY DECREASE THE

'THROUGHPUT (ANOTHER PERFORMANCE CRITERION)' OF A PROCESSOR.

THE TOTAL NUMBER OF ACTUAL PROCESSING TIME AVAILABLE IN A PERIOD OF OPERATION IS REFERRED TO AS THE 'THROUGHPUT' FOR THAT PERIOD. IN GENERAL, THE MAXIMIZATION OF DEVICE THROUGHPUT, AND MAXIMIZATION OF THE SIMULTANEITY OF DEVICE USE MAY BE AN IMPORTANT CONSIDERATION FOR A NETWORK DESIGN AND EVALUATION. THE DIFFICULTY IN DOING SO IS TO ASSIGN EACH REQUIREMENT WITH A PROPER WEIGHT, AND TO SEEK FOR A PROPER BALANCE BETWEEN THESE INTERACTIVE REQUIREMENTS.

A SECOND WAY OF VIEWING PROCESSOR PERFORMANCE IS TO CONSIDER THE RESOURCE ALLOCATION STRATEGIES USED IN THE PROCESSOR.

A PRIMARY TASK OF ANY SYSTEM IS TO TRANSFORM THE CAPABILITIES OF THE HARDWARE COMPONENTS INTO RESOURCES THAT CAN BE USED TO PERFORM DESIRED FUNCTIONS FOR USERS OF THE SYSTEM. IN A MULTIUSER ENVIRONMENT, SUCH AS A NETWORK SYSTEM, PROCESSES (E.G. JOBS) COMPETE FOR THE USE OF RESOURCES. THE MANAGEMENT OF THESE RESOURCES MUST THEN INCLUDE A SYSTEMATIC MECHANISM FOR ALLOCATING AND RELEASING RESOURCES. MOREOVER, THE ALLOCATION OF RESOURCES MAY TAKE ACCOUNT OF THE RELATIVE IMPORTANCE OF JOBS, THAT IS, THE HIGHER PRIORITY (MOST IMPORTANT) JOB SHOULD HAVE CONTROL OF A RESOURCE BEFORE A LESS IMPORTANT JOB. THE PRIORITY MAY CHANGE DURING THE COURSE OF OPERATIONS. A WELL-KNOWN PROBLEM IN THE DESIGN OF A MULTIUSER SYSTEM IS THE SELECTION OF A RESOURCE ALLOCATION STRATEGY THAT WILL PREVENT DEADLOCK. DEADLOCK IS THE SITUATION IN WHICH RESOURCES HAVE BEEN ALLOCATED TO VARIOUS JOBS

IN SUCH A WAY THAT NONE OF THE JOBS CAN CONTINUE PROCESS. FOR EXAMPLE, EACH OF TWO JOBS 'A' AND 'B' NEEDS THE RESOURCES 'X' AND 'Y' AT THE SAME TIME, I.E. WHEN EITHER 'X' OR 'Y' HAS BEEN ALLOCATED TO IT. 'A' WILL CERTAINLY NOT RELEASE THE ALLOCATED RESOURCE BEFORE THE OTHER ONE HAS ALSO BEEN ALLOCATED TO IT (LIKEWISE 'B'). SUPPOSE THE STRATEGY IS SUCH THAT ALLOCATION WILL FOLLOW ON REQUEST IF THE RESOURCE IS FREE. THEN THE SITUATION MAY ARISE THAT 'A' HAS SEIZED RESOURCE 'X' AND 'B' RESOURCE 'Y'. FROM THEN ON, 'A' AND 'B' WILL WAIT FOR EACH OTHER INDEFINITELY, SINCE 'A' CERTAINLY DOES NOT RELEASE 'X' UNTIL IT HAS SEIZED 'Y', I.E. NOT UNTIL 'B' HAS RELEASED 'Y', WHILE 'B' WILL NOT RELEASE 'Y' UNTIL IT HAS SEIZED 'X'. THE DEADLOCK PREVENTION PROBLEMS ARE ONLY A PART OF A RESOURCE ALLOCATION STRATEGY. THE ALLOCATION METHOD SHOULD ALSO DISTRIBUTE RESOURCES EQUITABLY, IN SOME SENSE, AMONG THE USERS AND SHOULD NOT INTRODUCE ANY GROSS INEFFICIENCIES. IN OTHER WORDS, IT SHOULD MINIMIZE THE CHANGE OF JOBS ON PROCESSING AND REDUCE THE SYSTEM OVERHEAD. A MORE DETAILED DISCUSSION FOR SOLVING THESE PROBLEMS WILL BE PRESENTED IN SECTION 2.2.

2.1. SWITCHING ORIENTED TECHNIQUES:

SWITCHING ORIENTED TECHNIQUES MAY BE GROUPED INTO THREE CLASSES:

- (1) THE TECHNIQUES ASSOCIATED WITH THE TOPOLOGICAL STRUCTURE OF THE NETWORK.
- (2) THE TECHNIQUES ASSOCIATED WITH THE TRANSMISSION STRATEGY, AND
- (3) THE TECHNIQUES OF SWITCHING AND EXCHANGING.

2.1.1. NETWORK STRUCTURES:

THERE ARE TWO BASIC STRUCTURES, NAMELY THE CENTRALIZED STRUCTURE AND THE DISTRIBUTED STRUCTURE (FIG. 4-A AND 4-B). BY A CENTRALIZED STRUCTURE, WE MEAN THAT ALL PROCESSING AND ROUTING ACTIVITIES ARE CARRIED OUT AT A DISTINCT CENTRAL NODE (OR MASTER NODE). THIS TYPE OF NETWORK INVOLVES COMMUNICATION TRAFFIC ONLY BETWEEN THE CENTRAL SITE AND THE REMOTE TERMINALS. AN IMMEDIATE CONSEQUENCE IS THAT THE ENTIRE PERFORMANCE FUNCTION OF THE NETWORK IS MAINTAINED AT THE CENTRAL SITE. IN MOST APPLICATIONS, THE CENTRALIZED STRUCTURE DOES OFFER CONSIDERABLE ADVANTAGE IN REDUCING THE MAINTAINENCE COST. A DISTRIBUTED STRUCTURE AS SHOWN IN FIG. 4-B, IS ONE IN WHICH THE NETWORK PROCESSING ACTIVITY IS CARRIED OUT BY EACH NODE. AN ESSENTIAL DIFFERENCE BETWEEN THE ABOVE TWO NETWORK STRUCTURES IS THAT THERE IS NO MASTER-SLAVE TYPE OF OPERATION IN THE DISTRIBUTED STRUCTURE. ONE CAN HAVE A MIXED SYSTEM CONTAINING BOTH STRUCTURES. IN THE DISTRIBUTED STRUCTURE, EACH NODE HAS EQUAL OPPORTUNITY TO PERFORM ITS OWN FUNCTIONS. IN MOST NETWORKS, THE NETWORK STRUCTURE CAN BE SUBDIVIDED INTO TWO

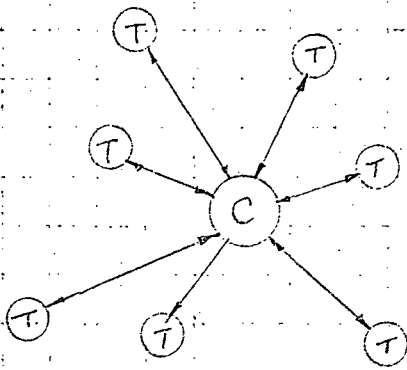


Fig. 4 (a) A Centralized Structure

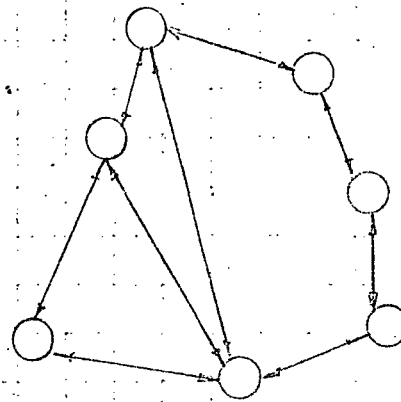


Fig. 4 (b) A Distributed Structure

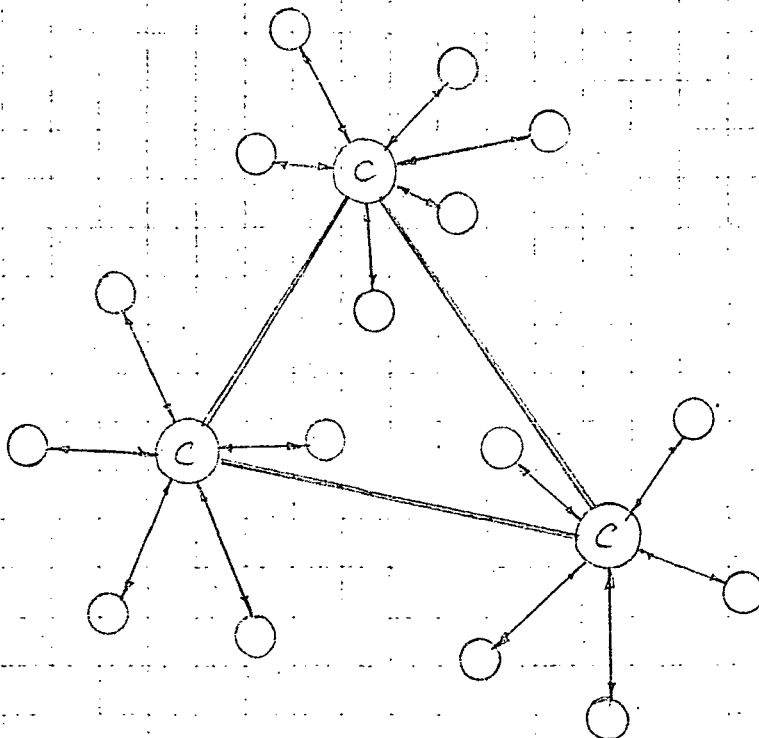
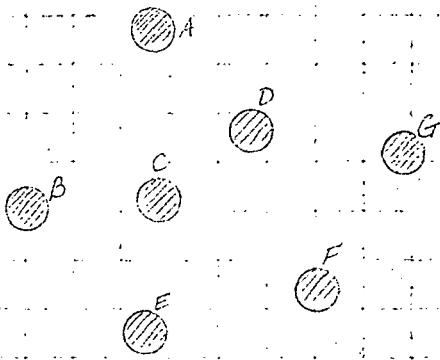


Fig. 4 (c) A Generalize Network Structure

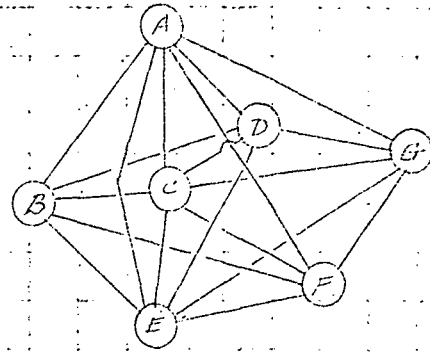
LEVELS AS SHOWN IN FIG. 4-C. THE LOW-LEVEL SUBNETS EMPLOY THE CENTRALIZED STRUCTURE, AND CONSIST OF A CENTRAL (OR MASTER) NODE WHICH CONNECTS A SET OF TERMINAL NODES THROUGH TRANSMISSION LINKS. THE CENTRAL NODE CONTROLS THE LOW-LEVEL SUBNET AND INTERFACES WITH THE HIGHER-LEVEL NETWORK. THE HIGHER-LEVEL NETWORK USUALLY FORMS A DISTRIBUTED STRUCTURE AS SHOWN IN FIG. 4-C. A SUMMARY OF THE ADVANTAGES AND DISADVANTAGES OF A DISTRIBUTED VS. A CENTRALIZED CONFIGURATION IS SHOWN IN THE TABLE 1. BESIDES THE CONSIDERATION OF THE GENERAL STRUCTURE OF A NETWORK, THE LINK CONNECTIONS OF ALL NODES MAY ALSO BE A DIFFICULT PROBLEM. CONSIDER A SYSTEM THAT CONSISTS OF SEVEN NODES AS ILLUSTRATED IN FIG. 5-A. ONE NETWORK CONFIGURATION IS TO PROVIDE COMMUNICATION LINKS BETWEEN ALL NODES SO AS TO HAVE DIRECT LINK BETWEEN EVERY PAIR OF NODES AS IN FIG. 5-B. IN SOME APPLICATIONS, THE COMMUNICATION LINE COST IS OF GREAT SIGNIFICANCE IN DESIGNING OR MAINTAINING THE NETWORK. THEREFORE, REDUCING LINE COSTS BECOMES OF MAJOR IMPORTANCE. A CENTRALIZED STRUCTURE IS ONE SOLUTION TO ACHIEVE THIS GOAL, SINCE FAR FEWER COMMUNICATION LINES ARE REQUIRED TO CONNECT ALL NODES (SEE FIG. 5-C). HERE WE ASSUME THAT NODE 'C' IS CHOSEN AS THE CENTRAL NODE. A FURTHER REDUCTION IN LINE COSTS MAY BE ACHIEVED BY USING A SPECIAL TECHNIQUE CALLED 'MULTIPOINT CONNECTION' OR 'MULTIDROP LINE', IN WHICH ONE LINE CONNECTS SEVERAL NODES (FIG. 5-D). IN GENERAL, THERE ARE TWO TYPES OF MULTIPOINT CONNECTIONS, ONE IS TERMED 'LINEAR MULTIDROP LINE' AND THE OTHER IS CALLED 'LOOP (OR RING) MULTIDROP LINE'. THIS MULTIDROP-LINE

Type	Primary Applications	Major Advantages	Major Disadvantages
Centrolized	Network with a clustering of terminals in the geographic sense but little clustering of the operating functions.	Low cost for maintaining and controlling the network functions without mutual interference problem.	Higher cost and complexity for data communications.
Distributed	Network with many clustering of terminals both in the geographic sense and function of operations.	More reliable and independent. Easier to expand and to reconfigure of the network.	High cost and complexity for interfacing various incompatibilities.

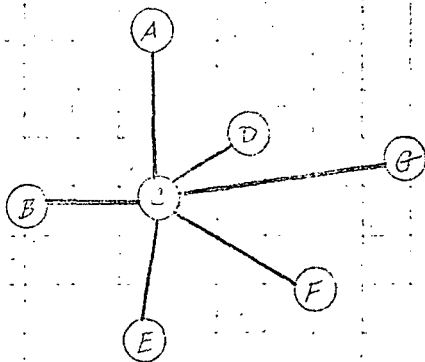
Table 1. A summary of the advantages and disadvantages of a distributed vis a Centrolized configurations.



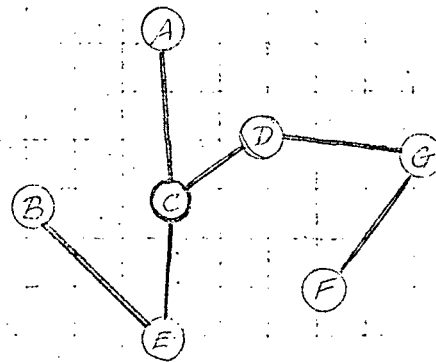
5 (a) Swown Nodes



5 (b) Normalized Structure



5 (c) A Centralized Structure



5 (d) Multidrop Lines

Fig. 5 The Different Structures of the Line Connection

CONFIGURATION REQUIRES THE CENTRAL NODE TO HAVE THE ABILITY TO ADDRESS EACH INDIVIDUAL NODE ON THE LINE, AND ALSO REQUIRES EACH NODE TO BE ABLE TO RECOGNIZE AND TO PROCESS ONLY THOSE MESSAGES ADDRESSED TO IT. THE DIFFERENT TRANSMISSION STRATEGIES ARE DISCUSSED IN THE NEXT SECTION.

2.1.2. TRANSMISSION STRATEGIES

WE DESCRIBE SEVERAL TRANSMISSION STRATEGIES THAT WE EXPECT TO INCORPORATE INTO THE SYSTEM:

1. MULTIPLEXING
2. BUFFERING
3. CONCENTRATING
4. STORE-AND-FORWARDING

2.1.2.1. MULTIPLEXING:

THE MAIN PURPOSE OF USING THE MULTIPLEXING TECHNIQUE IS TO REDUCE TRANSMISSION COSTS. THE CLASSICAL DEFINITION OF MULTIPLEXING IS SHARING THE TRANSMISSION MEDIA BY THE ALLOCATION OF CAPACITY TO SEPERATE CHANNELS THROUGH TIME OR FREQUENCY DIVISION. THE LARGEST NUMBER OF PRACTICAL MULTIPLEXING IS THE TIME-DIVISION TYPE OF MULTIPLEXING. THIS TYPE OF MULTIPLEXING IS CHARACTERIZED BY THE ADDRESSING METHODS FOR TRANSMISSION. THE MAJOR CATEGORIES ARE: CONTENTION, POLLING, AND SWITCHING. BOTH CONTENTION AND POLLING MAKE USE OF MULTIPOINT (OR MULTYDROP) LINE WHERE EACH TERMINAL NODE IS PERMANENTLY CONNECTED, PARTY-LINE

FASHION, TO EACH OTHER TERMINAL OF THE NETWORK. IN A CONTENTION TRANSMISSION, ANY NODE DESIRING TO COMMUNICATE WITH ANOTHER NODE MUST WAIT UNTIL THE LINE IS FREE AND ATTEMPTS TO SEIZE THE LINE FOR ITS OWN USE. A POLLED TRANSMISSION DIFFERS FROM A CONTENTION TRANSMISSION, IN WHICH, A SINGLE MASTER NODE SEQUENTIALLY ADDRESSES EACH SLAVE NODE TO DETERMINE WHETHER IT HAS INFORMATION TO TRANSMIT. THE SWITCHING TRANSMISSIONS ARE SIGNIFICANTLY DIFFERENT FROM BOTH OF THE ABOVE TWO TYPES, IN THAT, THEY ALLOW A COMMUNICATION FACILITY TO BE DEDICATED TO A NODE PAIR (OR A SET OF NODES) FOR TRANSMISSION. SOME MAJOR APPLICATIONS, ADVANTAGES AND DISADVANTAGES OF VARIOUS MULTIPLEXING TECHNIQUES ARE PRESENTED IN THE TABLE 2.

2.1.2.2. BUFFERING

IN MOST APPLICATIONS, THE TRANSMISSION RATE OF A LINE IS USUALLY DIFFERENT FROM THE PROCESSING RATE OF A NODE WHICH IS ATTACHED TO THE LINE.

A WELL KNOWN TECHNIQUE NAMED BUFFING IS USED TO GIVE A BETTER MATCH BETWEEN THE LINE TRANSMISSION SPEEDS AND NODE PROCESSING SPEEDS. DURING THE PROCESSING, THE BUFFERING ROUTINES TRY TO MAINTAIN AN INPUT BUFFER FULL OF INFORMATION SO THAT MINIMIZE THE PROCESSOR WAITING TIME (I.E. WAIT FOR INPUT DATA). MEANWHILE THE BUFFER ROUTINES TRY TO MAINTAIN AN EMPTY OUTPUT BUFFER SO THAT THE PROCESSOR CAN OUTPUT THE INFORMATION TO THE BUFFER AND KEEP EXECUTING. IN GENERAL, THE MULTIPLE BUFFERING IS USED, WHERE THE LINE TRANSMITS THE DATA INTO ONE BUFFER AREA WHILE THE NODE

Type	Primary Application	Major Advantage	Major Disadvantage
Contention	Networks with terminals dispersed over a wide geographic area.	Low cost for dispersed terminal networks.	Possible mutual terminal interference and possible large queuing times.
Polling	Same as Contention type	Low cost in some applications without mutual interference problems.	Possible long queuing times except for wide bandwidth facilities.
Switching	Any multi-terminal network.	Can be configured to maximally utilize trunk capacity.	High cost and complexity for small and medium size networks.

Table 2 Major applications of Various Multiplexing Arrangements.

PROCESSES ON THE OTHER BUFFER AREAS. ON INPUT, WHEN THE BUFFER AREA CURRENTLY IN USE BY NODE IS EMPTY, THE BUFFER ROUTINE SWITCHES IT FOR TRANSMITTING DATA AND SWITCHES THE NEXT FULL BUFFER FOR PROCESSING. THE SIMILAR CONCEPTS APPLIES TO THE OUTPUT PROCESS.

2.1.2.3. CONCENTRATING

CONCENTRATING IS A TECHNIQUE WHICH IS USED PRIMARY TO MATCH THE INPUT LINE TRANSMISSION SPEEDS AND THE OUTPUT LINE TRANSMISSION SPEED. A CONCENTRATOR COLLECTS THE MESSAGES FROM A SET OF LOW-SPEED LINES (USUALLY TRANSMIT DATA IN ASYNCHRONOUS FASHION) THEN PACKS THEM AND TRANSMITS THESE MESSAGES OVER THE HIGH-SPEED LINE (USUALLY USING SYNCHRONOUS TRANSMISSION). REPLIES WILL TRAVEL BACK IN A CONVERSE MANNER.

THE CONCEPT IS ILLUSTRATED IN FIG. 6.

2.1.2.4. STORE AND FORWARDING

THE STORE AND FORWARDING TECHNIQUE IS FREQUENTLY USED IN THE DATA COMMUNICATION NETWORKS. IT HOLDS INCOMING MESSAGES ON A BUFFER AREA UNTIL THEY CAN BE TRANSMITTED FORWARD AT MORE DESIRABLE CONDITIONS. A MESSAGE SWITCHING NETWORK, SUCH AS TELEX NETWORK, WHICH EMPLOIES THIS CONCEPT IS SOMETIMES REFERRED TO AS A 'STOREAND-FORWARD' NETWORK. IN CHAPTER 3 A STORE-AND-FORWARD SWITCHING NETWORK IS DISCUSSED IN DETAIL.

2.1.3. TECHNIQUES OF SWITCHING AND EXCHANGING

AS DESCRIBED EARLIER, IF A NETWORK INVOLVES A LARGE NUMBER OF NODES THEN A DIRECT CONNECTION BETWEEN EVERY TWO NODES MAY NOT BE ECONOMICALLY FEASIBLE. IN THIS CASE THE DESIGNER OF A PRACTICAL SYSTEM ECONOMIZES BY USING THE TECHNIQUES OF SWITCHING AND EXCHANGING. THERE TWO KINDS OF SWITCHING AND EXCHANGING METHODS, NAMELY MESSAGE SWITCHING AND LINE SWITCHING. IN LINE SWITCHING, A COMMUNICATION PATH THROUGH A MESSAGE CENTER IS ESTABLISHED BETWEEN THE SENDING NODE AND THE RECEIVING NODE. THIS PATH IS ASSIGNED PERMANENTLY FOR THE DURATION OF THE TRANSMISSION. IN MESSAGE SWITCHING, ON THE OTHER HAND, NO DIRECT CONNECTION EXISTS BETWEEN THE SENDER AND THE RECIEVER. IN THIS SYSTEM, A MESSAGE IS ROUTED THROUGH THE NETWORK TO ITS DISGNATED NODE IN A STORE-AND-FORWARD FASHION.

IN THIS SECTION WE INTRODUCE SOME TECHNIQUES THAT ARE COMMONLY FOUNDED IN THE ABOVE TWO TYPES OF SWITCHING NETWORKS. AMONG THESE TECHNIQUES ARE:

1. SUBSCRIBER (OR NODE) IDENTIFICATION TECHNIQUE,
2. HIERARCHY STRUCTURE OF SWITCHING CENTERS,
3. DIALING AND ROUTING PROCEDURES, AND
4. MUTUAL CO-OPERATION.

(1) SUBSCRIBER (OR NODE) IDENTIFICATION TECHNIQUE

IT IS CLEAR THAT EACH NODE WITHIN A GIVEN NETWORK HAS TO HAVE AN UNIQUE IDENTIFIER IN ORDER TO HAVE AN UNIQUE REFERENCE. IN MOST APPLICATIONS, A DIGIT CODING SYSTEM IS USED WHICH NOT ONLY PROVIDES AN UNIQUE REPRESENTATION BUT ALSO PROVIDES ROUTING INFORMATION. FOR EXAMPLE, IN THE SEVEN DIGITS CODE WHICH IS USED IN THE UNITED STATES TELEPHONE NETWORK. (SEE FIG. 7).

301	454	4247
AREA	CENTRAL	SUBSCRIBER
CODE	OFFICE	CODE

THE FIRST THREE DIGITS ARE THE AREA CODE, THE NEXT THREE DIGITS REPRESENT THE CENTRAL OFFICE CODE, AND THE LAST FOUR DIGITS ARE THE SUBSCRIBER CODE. DIALING SIGNALS WILL BE ROUTED FIRST ACCORDING THE AREA CODE TO THE DESIGNATING AREA, AND THEN ROUTED TO THE CENTRAL OFFICE AND FINALLY TO THE DESIGNATED USER'S TELEPHONE.

(2) HIERARCHY STRUCTURE OF SWITCHING CENTERS

IN GENERAL, A SWITCHING CENTER CAN ONLY HANDLE A FIXED AMOUNT OF EXCHANGE REQUESTS. IN ORDER TO HANDLE A LARGE AMOUNT OF EXCHANGE REQUESTS, A HIGHER LEVEL SWITCHING CENTER IS ESTABLISHED WHICH HANDLES THE INTERCONNECTION BETWEEN LOWER LEVEL SWITCHING CENTERS. (SEE FIG. 6). A LARGE NETWORK REQUIRES A HIERARCHICAL STRUCTURE OF SWITCHING CENTERS. THIS

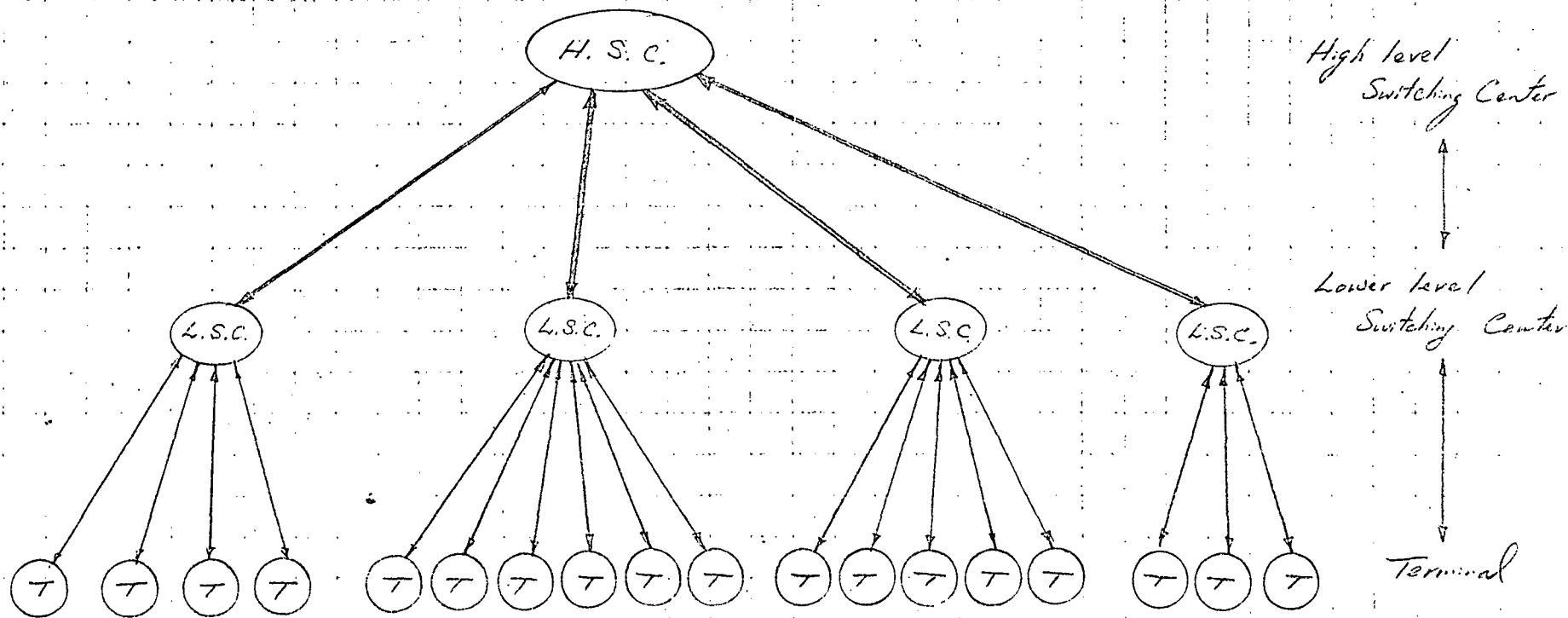


Fig. 6 The Hierarchy Structure of a Switching Center

301 454 4247
Area Code Central office code Subscriber code

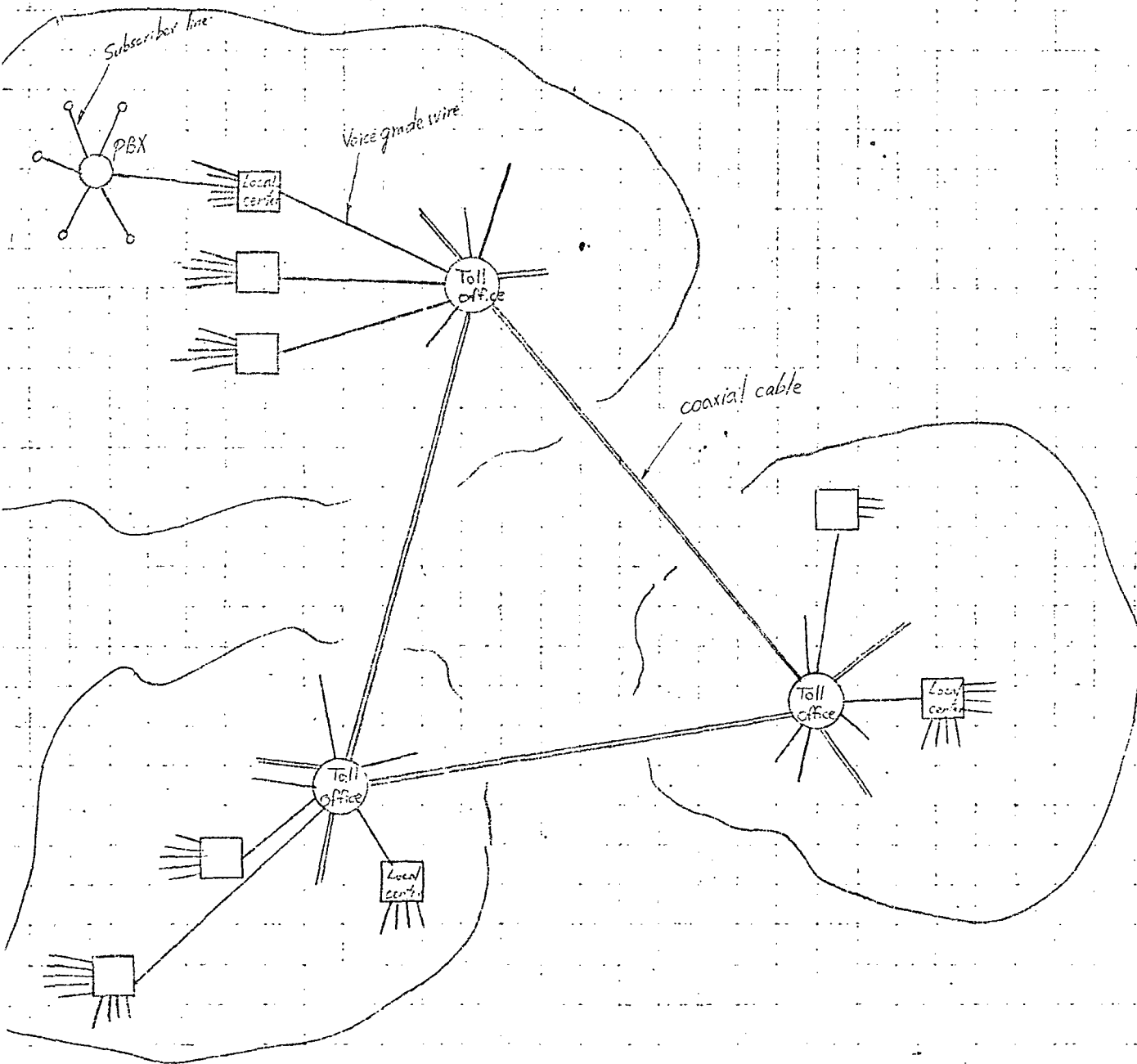


Fig. 7 A Hierarchy Structure of a Telephone System

TECHNIQUE HAS BEEN USED IN THE TELEPHONE SYSTEMS AS SHOWN IN FIG. 7. THE ADVANTAGES OF THIS HIERARCHICALLY STRUCTURED NETWORK, IN ADDITION TO THOSE WE HAVE MENTIONED ABOVE, ARE: (A) BETTER RELIABILITY - IF ONE SWITCHING CENTER IS INOPERATIVE FOR SOME REASON, IT AFFECTS ONLY ITS OWN SUBSCRIBERS, (B) INCREASED LOAD SHARING - EACH CENTER HAS ONLY A LIMITED AMOUNT OF EXCHANGE REQUESTS, (C) EASY EXPANDABILITY - IT CAN BE EXPANDED BY MEANS OF ADDING ONE MORE LEVEL INTO THE HIERARCHICAL STRUCTURE. THE MAJOR DISADVANTAGE IS THE COMPLEXITY OF THE NETWORK.

(3) DIALING AND ROUTING PROCEDURES

THE PRIMARY CONSIDERATION OF DIALING AND ROUTING PROCEDURES IS TO SEEK AN ECONOMIC PATH BETWEEN TWO GIVEN NODES. BECAUSE OF EITHER THE LACK OF ENOUGH INFORMATION, OR THE LIMITED CAPABILITY OF A SWITCHING CENTER, THIS ECONOMIC PATH MAY NOT BE FOUND. THEREFORE, SOME OTHER TECHNIQUES SUCH AS CIRCLE ROUTE DETECTION, MUST BE INCORPORATED INTO THE PATH FINDING PROCEDURE.

IN GENERAL, FOR EVERY POSSIBLE CONNECTING MODE, THE SWITCHING CENTER HAS A LIST OF BEST ROUTES ASSOCIATED WITH IT. THE SWITCHING CENTER WILL TRY TO ESTABLISH A DIAL (OR TO ROUTE THROUGH) THE BEST POSSIBLE ROUTE AT THE TIME A DIALING REQUEST (OR A ROUTING REQUEST) IS BEING PROCESSED. AN EXAMPLE OF THIS DIALING (OR ROUTING) PROCESS IS SHOWN IN FIG. 8.

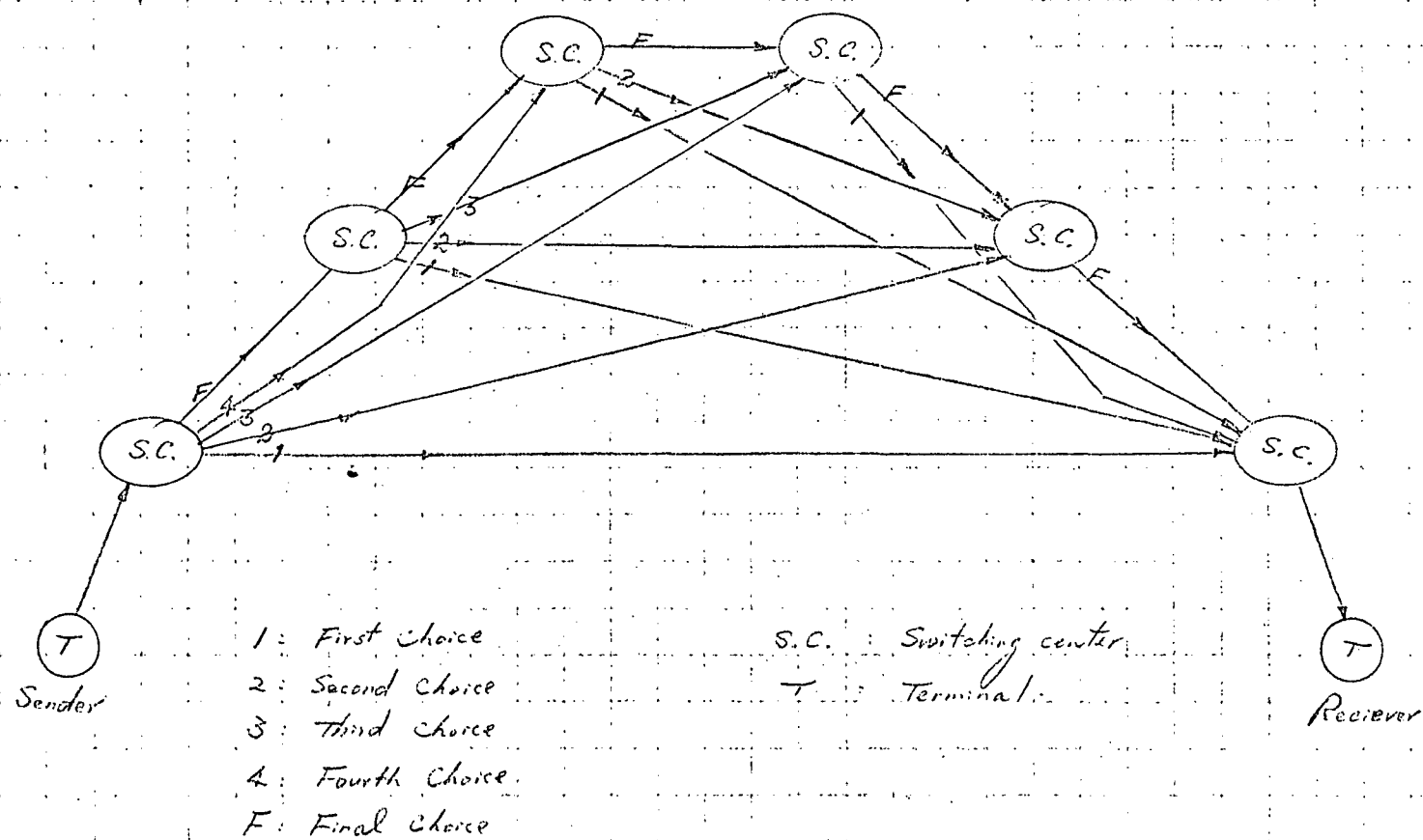


Fig. 8 An Example of Telephone Routing Process

(4) MUTUAL COOPERATION AMONG NODES

WHEN A NODE SENDS A MESSAGE TO ONE ANOTHER NODE, A VARIETY OF CONTROL SIGNALS MUST PASS TO AND FROM BETWEEN THE NODES TO ENSURE THAT THEY ARE WORKING IN STEP WITH EACH OTHER. FOR EXAMPLE, THE SENDING NODE MAKES A REQUEST FOR TRANSMISSION AND THE RECEIVING NODE ACKNOWLEDGE THE REQUEST. IN GENERAL, THERE ARE TWO TYPES OF COOPERATION, NAMELY 'HANDSHAKING' COOPERATION, AND 'MASTER-SLAVE' COOPERATION. 'HANDSHAKING' COOPERATION IS A CONVERSATIONAL TYPE OF OPERATION IN A FLIP-FLOP FASHION BETWEEN REQUEST AND ACKNOWLEDGMENT. THE TRANSMITTER SENDS A MESSAGE AND WHEN COMPLETED, THE RECEIVER SENDS AN ACKNOWLEDGMENT. IF A HALF-DUPLEX LINK (ONE WAY AT A TIME) IS USED BETWEEN TWO NODES THEN THE DELAY OF CHANGING THE LINE TRANSMISSION DIRECTION MUST BE TAKEN INTO ACCOUNT IN HANDSHAKING. AN EXAMPLE OF AN HANDSHAKING COOPERATING PROCEDURE IS ILLUSTRATED IN FIG. 9. IN A 'MASTER-SLAVE' TYPE OF COOPERATION, THE NODE DESIGNATED AS THE MASTER MAY ADDRESS REQUESTS THROUGH LINES WHICH WERE SEIZED FROM OTHER NODES, AND MAY POLL THE MESSAGES FROM THE NODES CONNECTED TO THE LINES IN ITS TERRITORY. A TYPICAL OPERATION IS SHOWN IN THE EXAMPLE 2 (SEE FIG. 10).

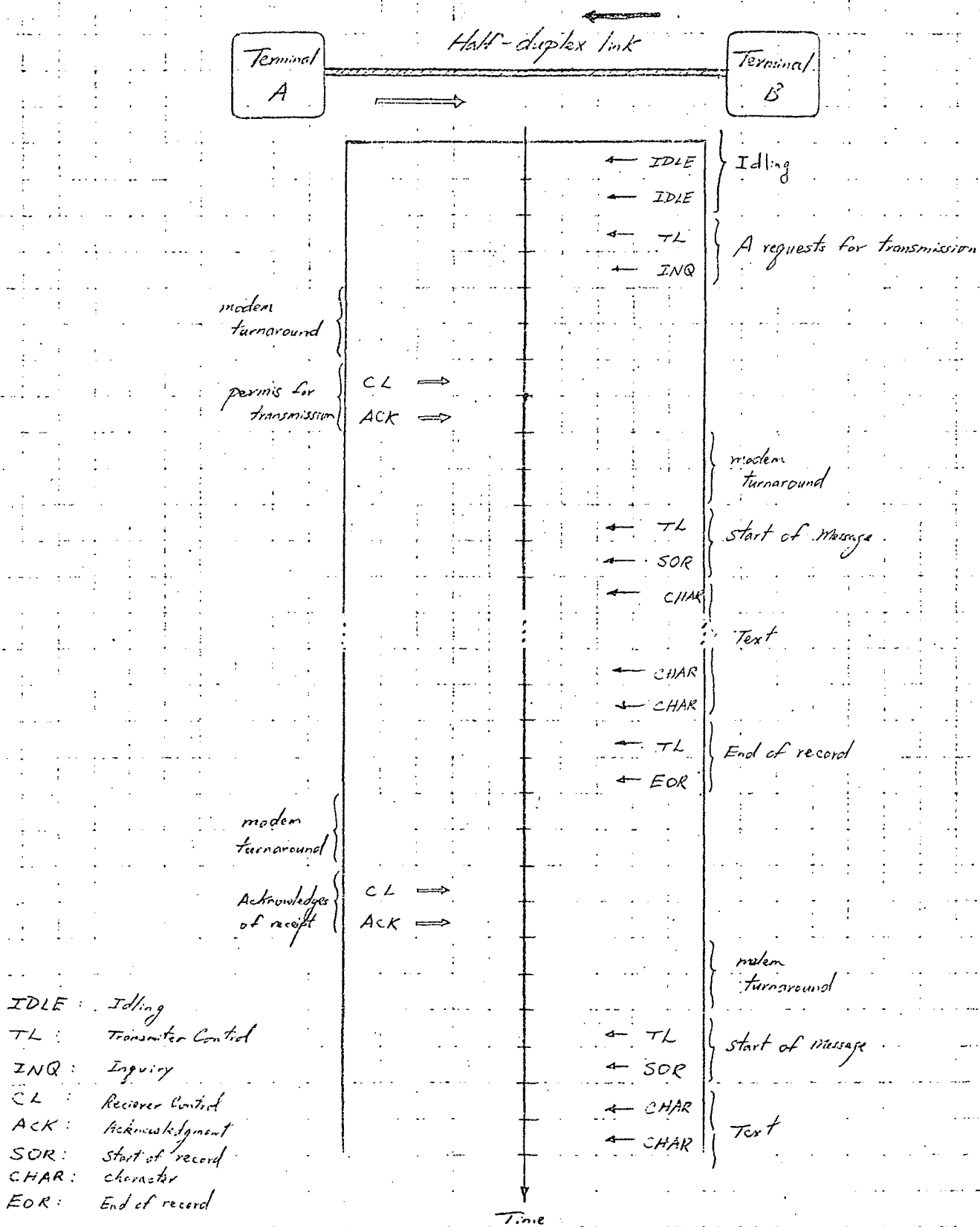


Fig. 9 An Example of Handshaking Cooperating Procedure

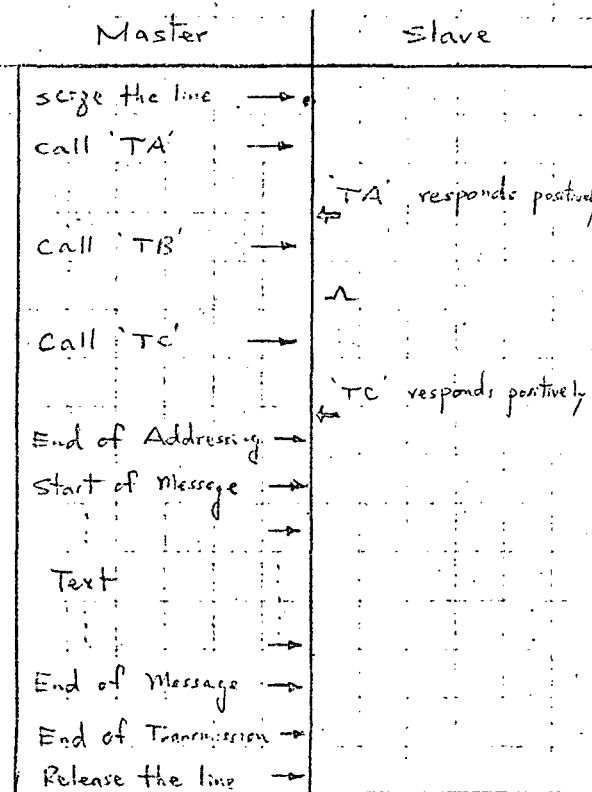
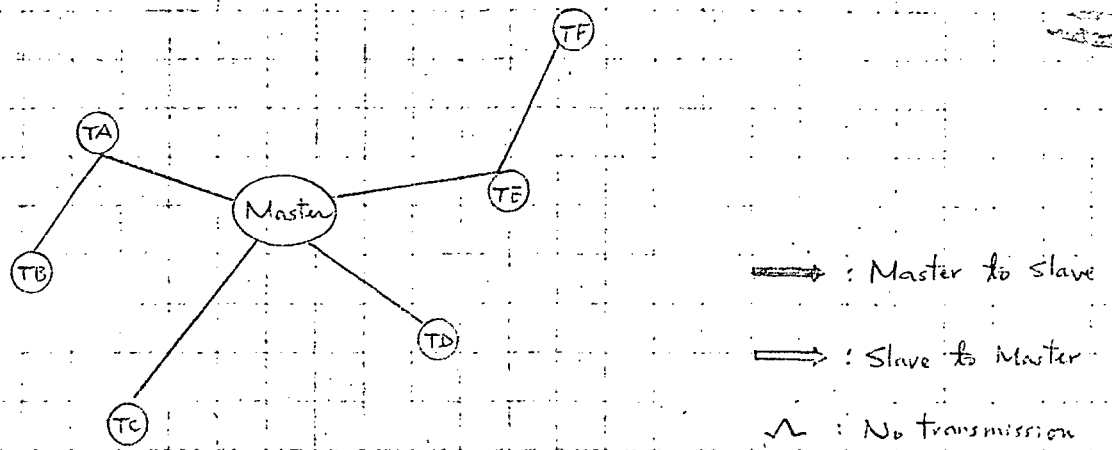


Fig. 10 An Example of 'Master-Slave' Cooperation Procedure

2.2. PROCESSOR ORIENTED TECHNIQUES:

PROCESSOR ORIENTED TECHNIQUES MAY BE GROUPED INTO THREE CLASSES:

- (1) THE TECHNIQUES ASSOCIATED WITH THE PROCESSOR EFFECTIVITY AND EFFICIENCY;
- (2) THE TECHNIQUES ASSOCIATED WITH THE RESOURCE ALLOCATION STRATEGIES;
- (3) THE TECHNIQUES ASSOCIATED WITH THE PROCESSOR FAILURES AND RECOVERY.

2.2.1. PROCESSOR EFFICIENCY AND EFFECTIVITY

2.2.1.1. INTERRUPTS AND TRAPS

INTERRUPT AND TRAPS ARE REQUIRED TO

- . COMMUNICATE AMONG ASYNCHROUS DEVICES, AND FOR
- . COOPERATION WITH THE RESOURCE SCHEDULER

PRIORITY INTERRUPTS ARE AN IMPORTANT FEATURE OF A RESOURCE SHARING SYSTEM, FOR THE VARIOUS PROCESSORS AND DEVICES CAN COMMUNICATE WITH EACH OTHER. THE BASIC CONCEPT OF THE INTERRUPT IS VERY SIMPLE. WHENEVER A PROCESSOR (OR DEVICE) HAS A MESSAGE FOR AN OTHER PROCESSOR, AN INTERRUPT SIGNAL IS SENT THROUGH A PRESPECIFIED INTERRUPT LINE. THE PROCESSOR THAT RECIEVES THE INTERRUPT SIGNAL WILL SUSPEND THE CURRENT JOB AND

PROCESS THE INTERRUPT SIGNAL. AFTER THIS SIGNAL HAS BEEN PROCESSED, THE INTERRUPTED JOB IS THEN RESUMED FROM THE POINT IT SUSPENDED OPERATION. WITH SUCH AN INTERRUPT SYSTEM, A PROCESSOR (SAY 'A') CAN START OR STOP A JOB FOR AN OTHER PROCESSOR (SAY 'B') WITHOUT SPENDING MUCH TIME IN MONITORING THE PROCESSING OF THAT JOB. IT MAY IGNORE ALL PROCESSING DONE BY THE PROCESSOR 'B' UNTIL AN EXPLICIT SIGNAL IS RECEIVED FROM IT. IN GENERAL, FOUR TYPES OF INTERRUPTS EXISTS ON A CONVENTIONAL INTERRUPTABLE PROCESSOR, THEY ARE: SERVICE COMPLETION, INTERVAL TIMER, SYSTEM FAILURE, AND REQUEST FOR SERVICE INTERRUPTS.

A 'TRAP' IS A SELF-INTERRUPT, WHERE THE INTERRUPT SIGNAL GENERATED WITHIN A PROCESSOR. INTERRUPTS SUCH AS INTERVAL TIMER, AND SYSTEM FAILURE CAN BE CALLED TRAPS.

IN MOST INTERRUPTABLE SYSTEMS, THE DEVICE OF HANDLING INTERRUPTS IS A MAJOR DRIVER (OR SUPERVISOR) OF THE RESOURCE-SHARING SYSTEM. FACILITY SCHEDULING AND RESOURCE ALLOCATION ARE STARTED, STOPPED, AND CONDITIONED BY THE VARIOUS INTERRUPTS. ALL INTERRUPTS ARE EXPLICIT CALLS TO THE SUPERVISOR FOR ACTION OR ASSISTANCE.

2.2.1.2. MUTUAL COOPERATION

THERE ARE TWO BASIC SOURCE OF INTERTASK (OR INTERPROCESS) COMMUNICATION. A PRIME SOURCE ARE THE INTERRUPT SIGNALS AS DISCUSSED IN THE PREVIOUS SECTION. THE SECOND SOURCE IS THE

MUTUAL COOPERATION PROCESS INTRODUCED BY DIJKSTRA. IN THIS METHOD, ALL COMMUNICATION INFORMATION IS KEPT IN A SHARED STORAGE KNOWN AS AN 'EVENT CHANNEL'. THERE CAN BE MANY EVENT CHANNELS IN A RESOURCE-SHARING SYSTEM. EVENT CHANNELS CAN BE PROTECTED SUCH THAT ONLY AUTHORIZED TASKS (OR JOBS) CAN COMMUNICATE WITH A GIVEN CHANNEL. WHEN A TASK WISHES TO COMMUNICATE WITH OTHER TASKS, IT SENDS A MESSAGE ADDRESSED TO A GIVEN EVENT CHANNEL OR CHANNELS. WHEN A TASK REACHES A POINT WHERE IT IS EXPECTING COMMUNICATION, IT EXAMINES THE APPROPRIATE CHANNEL. IF THERE IS A MESSAGE, THE MESSAGE MAY THEN BE MOVED FROM THE CHANNEL. IF THERE IS NOT SUCH EXPECTING MESSAGE, THE TASK IS BLOCKED UNTIL AN EXPECTED MESSAGE IS RECEIVED.

2.2.1.3. INTERLOCK AND PROTECTION

WHEN SEVERAL PROCESSORS OR USERS SHARE A COMMON FACILITY, CERTAIN PRECAUTIONS AND PROTECTION ARE REQUIRED. FOR EXAMPLE, SEVERAL USERS MAY BE SHARING A COMMON DATA BASE. WHEN THE DATA BASE IS BEING MODIFIED BY ONE USER, IT IS DANGEROUS TO ALLOW AN OTHER USER TO ACCESS IT. IT IS THEREFORE NECESSARY TO LOCK OUT FURTHER ACCESS TO THE DATA BASE UNTIL THE MODIFICATION IS COMPLETED. ONE OF THE MOST TROUBLESOME AREAS OF THE INTERLOCK MECHANISM IS THE 'SYSTEM DEADLOCK'. THERE ARE TWO TYPES OF SYSTEM DEADLOCK: (A) TASKS WAITING FOR EACH OTHER, AND (B) TASKS COMPETING DEMANDS FOR RESOURCES. DESIGNING FOR INTERLOCK MUST PROVIDE MEANS OF RECOGNIZING POTENTIAL DEADLOCK SITUATIONS.

A RESOURCE CAN BE PROTECTED BY USING INTERLOCIS WHICH LOCK OUT ALL POSSIBILITY OF FURTHER ACCESS. THE OTHER WAY OF PROTECTION IS TO PROTECT THE ACCESS MECHANISM FOR THE RESOURCES. AN EXAMPLE OF THE SECOND TYPE OF PROTECTION IS THE ACCESS CONTROL BY USING A 'PASS WORD'. IN ADDITION TO THESE, A PROTECTION SCHEME IS USUALLY ACCOMPLISHED IN SEVERAL LEVELS. THIS KIND OF MULTIPLE LAYERS OF PROTECTION WILL INCREASE THE REALIABILITY OF PROTECTION.

2.2.2. RESOURCE ALLOCATION STRATEGIES

THE CENTRAL PROBLEM OF A RESOURCE-SHARING SYSTEM IS TO SHARE THE EXISTING RESOURCES AMONG A LARGE NUMBER OF DEMANDS. ONE WAY TO LOOK AT THIS PROBLEM IS TO USE THE 'VIRTUAL RESOURCE' TO MODEL THE ARBITRARY DEMANDS FOR 'ACTUAL RESOURCE'. THE ACTUAL RESOURCES ARE THE PHYSICAL COMPONENTS OR DEVICES OF A NETWORK. THE VIRTUAL RECOURCES ARE PHYSICAL-DEVICES INDEPENDENT IN THE SENSE THAT THE USER DOES NOT HAVE TO BE AWARE OF THE PHSICAL CONFIGURATIONS AND CAPABILITIES OF THE SYSTEM. EACH USER CAN THINK THAT HE IS WORKING WITH A SYSTEM WITH CHARACTERISTICS ORIENTED TOWARD HIS JOB. EACH USER CAN SPECIFY HIS OWN VIRTUAL CONFIGURATION AND CAPABILITIES. THIS CONCEPT OF THE VIRTUAL RESOURCE IS ILLUSLRATED IN FIG. 11.

SINCE A USER'S JOB CAN BE PROCESSED ONLY WHEN THE ACTUAL RESOURCES ARE AVAILABLE TO IT, THE SYSTEM MUST HAVE AN ALLOCATOR WHICH ASSIGNS THE AVAILABLE ACTUAL RESOURCE TO MEET

Virtual Network
(with Respect to User A)

Physical Network

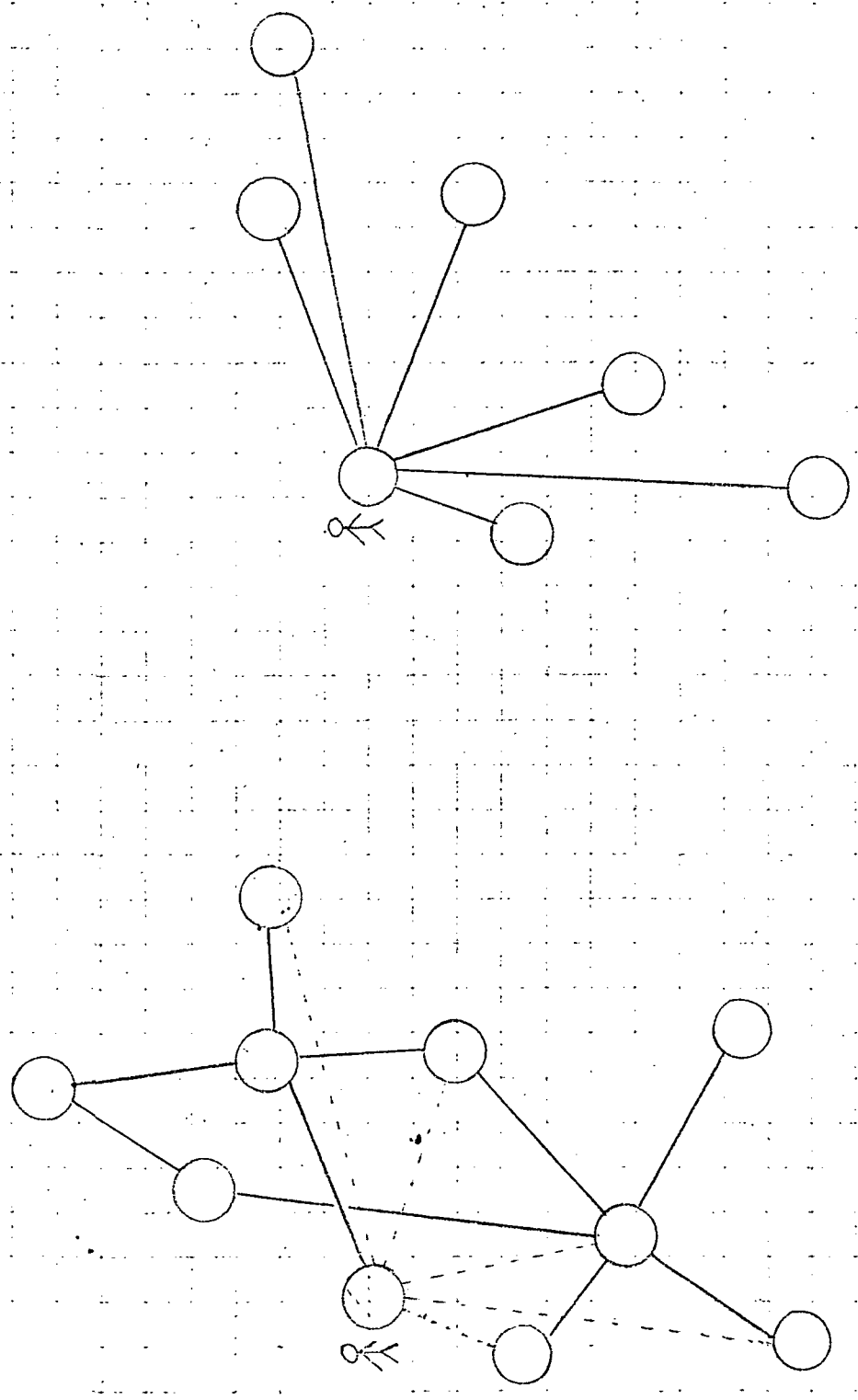


Fig. 11 The Concept of Virtual Resource

THE DEMANDS OF THE VIRTUAL RESOURCES. THE ALLOCATION MUST ALSO 'RELEASE' A PHYSICAL RESOURCE FROM ITS BOUND VIRTUAL RESOURCE SO IT CAN BE USED FOR OTHER DEMANDS. RESOURCE ALLOCATION IS AN INTERFACE BETWEEN ACTUAL AND VIRTUAL RESOURCES, AND IS AIMED AT CONVERTING THE ACTUAL RESOURCES INTO VIRTUAL RESOURCES UNDER CERTAIN REQUIREMENTS, SUCH AS RAPID RESPONSE TO EACH USER, AND MINIMIZED SYSTEM OVERHEAD. IN PARTICULAR, THESE ALLOCATORS INVOLVE 'QUEUEING' AND 'SCHEDULING' PROBLEMS. BY 'SCHEDULING' WE MEAN A PLAN WHICH DETERMINES WHICH DEMAND IS TO BE BOUND NEXT TO AN ACTUAL RESOURCE. 'QUEUEING' TECHNIQUES, IN GENERAL, ARE USED FOR PLANNING SUCH A SCHEDULER.

2.2.3. PROCESSOR FAILURES AND RECOVERY

THE PROBLEMS OF WHAT TO DO ABOUT PROCESSOR FAILURES AND HOW TO RECOVER FROM THEM ARE PARTICULARLY AWKWARD. THIS IS NOT ONLY BECAUSE FAILURES ARISE FROM MANY DIFFERENT SOURCES, BUT ALSO BECAUSE IT IS QUITE IMPOSSIBLE TO PREDICT THE NATURE OF MANY OF THE FAILURES WHICH WILL OCCUR IN PRACTICE. THESE FACTS MEAN THAT THE PROCESSOR FAILURES WILL OCCUR EVEN AFTER CONSIDERABLE DEVELOPMENT AND TESTING. THERE ARE BASICALLY TWO TECHNIQUES FOR PLANNING TO REDUCE SYSTEM INTERRUPTION.

- (1) COMPONENT REDUNDANCY - WHEN ONE COMPONENT FAILS, A SECOND ONE TAKES OVER ITS WORK.
- (2) FALLBACK (OR RECONFIGURATION) PROCEDURES - WHEN ONE

COMPONENT FAILS, THE SYSTEM MODIFIES ITS MODE OF OPERATION (E.G. CONFIGURATION) TO CIRCUMVENT THE ERROR. IN SO DOING IT MAY GIVE A DEGRADED FORM OF SERVICE BUT WILL STILL CARRY OUT THE URGENT PART OF ITS JOB.

THE PROBLEM OF RECOVERY IS DEPENDENT ON THE TYPE OF ERROR. MOST ERRORS ARE RECOVERABLE PROVIDED THAT IT HAS BEEN DETECTED EARLY ENOUGH. IF AN ERROR IS DETERMINED TO BE NOT RECOVERABLE, A FRESH COPY OF THE FAILURE COMPONENT SHOULD BE RESTORED. IN EITHER CASES, THE SYSTEM SHOULD BE ABLE TO BACK TO BE BROUGHT ITS ORIGINAL MODE OF OPERATION.

3. TWO LEVEL VIEWS OF A COMMUNICATION NETWORK

ELECTRICAL DATA COMMUNICATIONS SYSTEMS HAVE BEEN IN SERVICE FOR MORE THAN ONE HUNDRED YEARS. THERE ARE TWO PRINCIPAL TYPES OF COMMUNICATION NETWORKS: 'CIRCUIT SWITCHING' AND 'MESSAGE SWITCHING' NETWORKS. BOTH NETWORKS CONSIST OF ONE OR MORE SWITCHING CENTERS WHICH HAVE THE SAME GENERAL FUNCTION TO COMMUNICATE WITH A NUMBER OF TERMINALS AND TO TRANSMIT MESSAGES AMONG THEM.

IN A CIRCUIT SWITCHING NETWORK, THE ROLE OF THE SWITCHING CENTERS IS TO ESTABLISH A DIRECT CONNECTION FROM ONE TERMINAL TO ANOTHER. AFTER THE CONNECTION IS SET UP, THE TERMINALS CARRY ON THEIR COMMUNICATION, ONE-WAY OR TWO-WAYS. WHEN THE TERMINALS FINISH COMMUNICATING, THE SWITCHING CENTERS DISCONNECT THE CIRCUIT, RESTORING THE SYSTEM TO READINESS FOR OTHER CONNECTIONS. AN EXAMPLE OF THIS TYPE OF NETWORK IS A TELEPHONE NETWORK.

THE DISTINGUISHING CHARACTERISTIC OF A MESSAGES SWITCHING NETWORK IS THAT MESSAGES ARE STORED AND FORWARDED. A TYPICAL EXAMPLE WILL BE TELTGRAPH NETWORK, OR TELETYPE (TELEX) NETWORKS. IN A MESSAGE SWITCHING NETWORK, A MESSAGE IS CREATED AND TRANSMITTED INTO A SWITCHING CENTER FROM THE ORIGINATING TERMINAL, AS SOON AS AN INPUT CHANNEL IS AVAILABLE WITHOUT WAITING FOR A DIRECT CONNECTION BETWEEN ORIGINATING AND DESIGNATING TERMINALS. WHENEVER THIS INPUT TRANSMISSION HAS BEEN COMPLETED, THE

ORIGINATOR IS FREE TO SEND THE REST OF THE MESSAGE OR AN OTHER MESSAGES. MEANWHILE THE NETWORK TAKES RESPONSIBILITY FOR RELAYING THE MESSAGE TO ITS DESIGNATED TERMINALS. IN GENERAL, A MESSAGE SWITCHING NETWORK IS MORE COMPLICATED THAN A CIRCUIT-SWITCHING NETWORK. HERE WE ONLY DESCRIBE THE TWO LEVEL VIEW FOR A MESSAGE SWITCHING NETWORK. FOR A CIRCUIT-SWITCHING NETWORK THE SAME TREATMENT CAN ALSO BE APPLIED

AS MENTIONED IN THE INTRODUCTION, WE ARE ESPECIALLY INTERESTED IN THE OPERATIONS OF NETWORKS. THE DETAILS OF THE COMPLEX OPERATIONS OF A MESSAGE-SWITCHING NETWORK CAN BEST BE STUDIED OR ILLUSTRATED IN TWO WAYS. AGAIN, ONE IS CALLED GLOBAL OR SWITCHING ORIENTED VIEW --WHICH REPRESENTS THE HISTORY OF A MESSAGE AS IT IS PASSED THROUGH THE NETWORK; THE OTHER IS LOCAL OR PROCESSOR ORIENTED VIEW --- WHICH SPECIFIES THE OPERATIONS TO BE CARRIED OUT BY EACH INDIVIDUAL COMPONENT.

AS THE FIRST EXAMPLE (SEE FIG. 12), THIS TWO LEVEL VIEW FOR A MESSAGE SWITCH NETWORK IS ILLUSTRATED IN DETAIL AS FOLLOWS.

3.1. GLOBAL OR SWITCHING ORIENTED OPERATIONS:

THE PRIME MOVER OF THIS LEVEL OF OPERATION IS THE MESSAGE AS IT FLOWS THROUGH THE NETWORK. THE WHOLE PROCESS CAN BE DESCRIBED WITH THE FLOW DIAGRAM AS SHOWN IN FIG.13.

THE PROCESS BEGINS WITH AN APPROPRIATE LINE CONNECTION

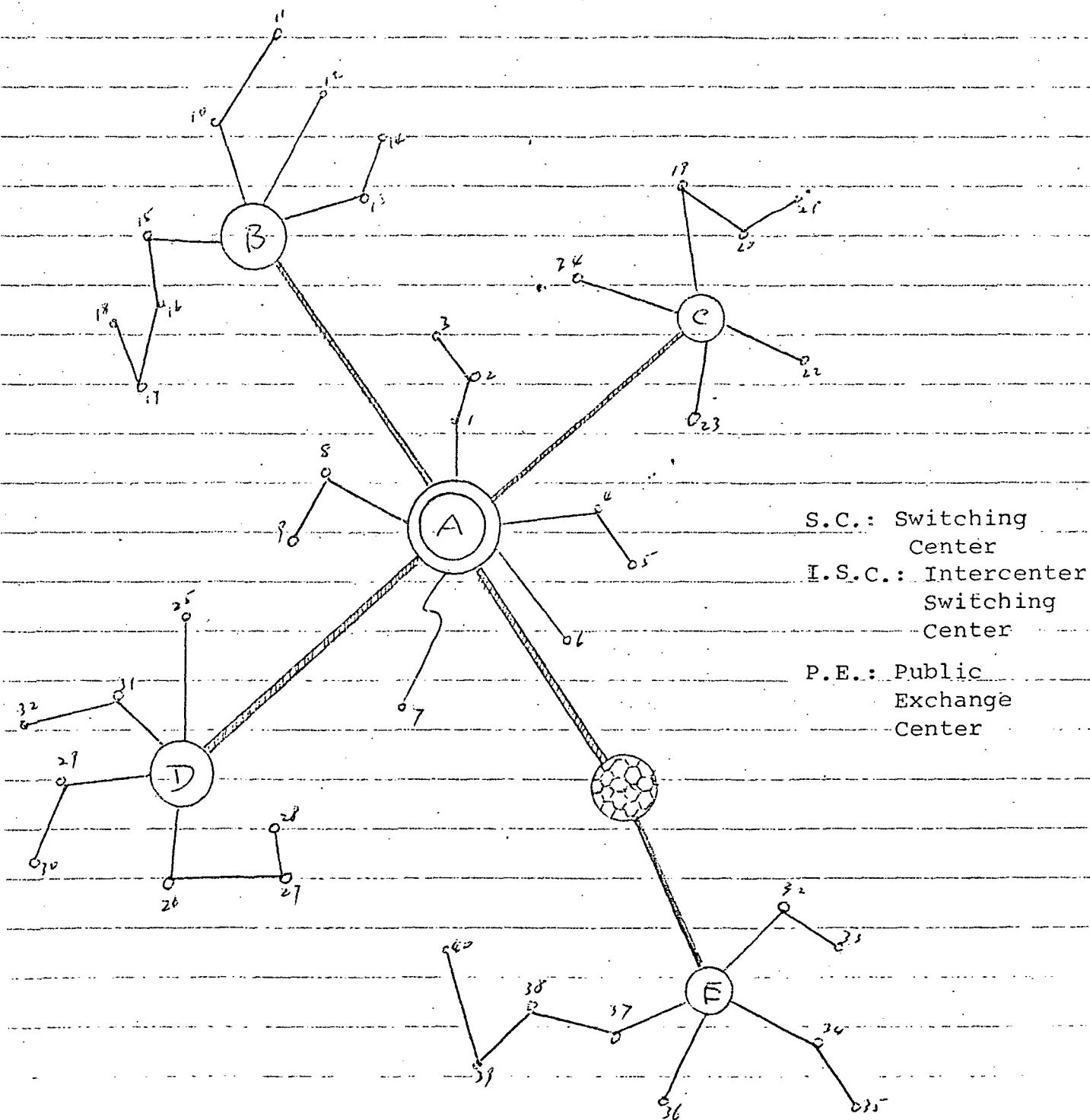
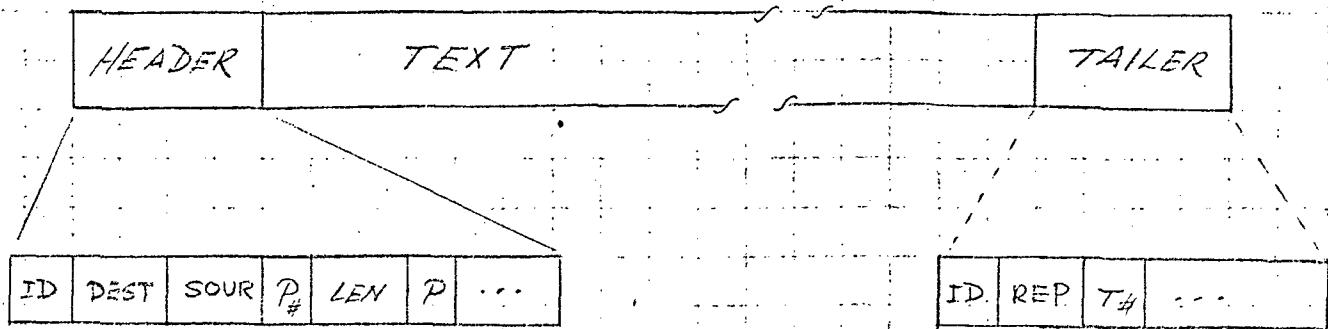


Fig. 12-A Communication Network

PROCEDURE SUCH AS A DIALING PROCEDURE TO CONNECT A MESSAGE WITH A SWITCHING CENTER (STATE1). AS SOON AS THE CONNECTION IS ESTABLISHED, AN INPUT-BUFFER IN THE SWITCHING CENTER IS RESERVED FOR THIS COMMUNICATION (STATE2) AND THE SENDER MAY THEN TRANSMIT A MESSAGE INTO THE MESSAGE SWITCHING CENTER (STATE3). HE USES A FORMAT THAT IS ACCEPTABLE TO THE CENTER. IN GENERAL, IT BEGINS WITH A HEADER AND ENDS WITH A TAILER AS SHOWN IN FIG.14. THE HEADER INCLUDES A LIST OF ADDRESSES AND OTHER PERTINENT INFORMATION SUCH AS PACKAGE NUMBER, MESSAGE LENGTH, AND PRIORITY. THE HEADER IS FOLLOWED BY THE TEXT AND THEN BY A TRAILER. THE TEXT ARE THOSE MESSAGES WHICH WILL TRANSMIT TO THE RECEIVER.

AT THE SWITCHING CENTER, THE INCOMING MESSAGE IS ACCEPTED INTO BUFFER STORAGE, WHERE IT IS COLLECTED INTO BLOCKS OF SOME STANDARD LENGTH (STATE4). THE CENTER SERVES MANY INPUT LINES AND PROCESSES INCOMING MESSAGE BLOCKS BY SOME SCHEDULING SCHEME. UPON RECEIPT OF THE HEADER, THE MESSAGE IS THEN SCHEDULED FOR PROCESSING. THIS PROCESS MAY INVOLVE CODE CONVERSION, HEADER INTERPRETATION AND SO ON (STATE 5). TRANSMISSIONS DO NOT BEGIN IMMEDIATELY UPON RECEIPT OF THE HEADER. THE ENTIRE MESSAGE IS FIRST STORED IN THE SWITCHING CENTER'S MESSAGE STORAGE. IN THE CASE OF MULTIPLE ADDRESSES, THE MESSAGE MAY BE STORED IN DUPLICATE OR SPECIAL BOOKKEEPING IS MAINTAINED TO KEEP TRACK OF ALL ITS TRANSMISSIONS. ONCE A MESSAGE HAS BEEN COMPLETELY STORED IN THE MESSAGE STORAGE, THE INPUT LINE AND BUFFER ARE RELEASED FOR SUBSEQUENT USE (STATES 6 AND 8). THE SENDER IS ALSO FREE TO LEAVE



ID : Message identifier

DEST : Designating Node's ID

SOUR : Originating Node's ID

P# : Package number

LEN : Message length

P : Priority

REP : Reply flag

T# : Total number of packages

Fig. 14 A General Format of a Message

THE TERMINAL OR TO START OTHER COMMUNICATIONS (STATE 7), AND MEANWHILE THE NETWORK CONTINUES TO PROCESS THE MESSAGE. IF THE DESIGNATING TERMINAL (RECEIVER) IS CONNECTED WITH DIFFERENT CENTERS, THE MESSAGE IS THEN ROUTED THROUGH ONE OR MORE CENTERS (STATE 9).

THE TRANSMISSION BETWEEN SWITCHING CENTERS USES THE CONTENTION TRANSMISSION WHERE EACH CENTER HAS EQUAL PRIORITY TO HOLD A COMMUNICATION LINE FOR TRANSMITTING A MESSAGE TO ANOTHER. THE OUTPUT PROCESSING FROM ONE SWITCHING CENTER TO ANOTHER BEGINS WITH A LINE CONTENTION PROCEDURE (STATE 10). WHENEVER A LINE IS SEIZED BY A SWITCHING CENTER (THE SENDER-CENTER), THE INPUT-PROCESSING IS INITIALIZED AT THE RECEIVER-CENTER. THE INPUT-PROCESSING IS ESSENTIALLY THE SAME AS THE INPUT-PROCESSING FOR PROCESSING AN INCOMING MESSAGE FROM AN ORIGINATING TERMINAL (SEE FIG. 13, THE INPUT-PROCESS INCLUDES STATES 2, 4, 6, AND 8). AS SOON AS THE INPUT-PROCESS OF THE RECEIVING CENTER IS INITIALIZED, AN OUTPUT BUFFER IN THE SENDING CENTER IS THEN ALLOCATED TO RETRIEVE THE MESSAGE TEXT FROM THE SENDING CENTER'S MESSAGE STORE (STATE 11). THE OUTPUT PROCESSOR LOADS THE MESSAGE TEXT INTO THE OUTPUT BUFFER AND BEGINS TRANSMISSION THROUGH THE LINE TO THE RECEIVING CENTER (STATE 12). THIS TRANSMISSION CONTINUES TO PROCEED AT THE RATE ADAPTED TO THE RECEIVING RATE OF THE RECEIVING CENTER UNTIL THE ENTIRE MESSAGE HAS BEEN COMPLETELY TRANSMITED. THE OUTPUT PROCESSING IS TERMINATED BY A SIGNAL FROM THE RECEIVING CENTER AND THE OUTPUT BUFFER (OF THE SENDING CENTER)

IS THEN RELEASED FOR SUBSEQUENT USE.

NOTE THAT THE TRANSMISSION BETWEEN SENDING-NODE AND RECEIVING NODE IS A 'HAND SHAKING' TYPE OF MUTUAL OPERATION. EVERY PIECE OF THE MESSAGE IN THE SENDING-NODE BUFFER WILL NOT BE RELEASED UNTIL THAT PIECE OF MESSAGE IS COMPLETELY RECEIVED AND CHECKED WITH NO ERROR BY THE RECEIVING-NODE (OR NODES). (SEE STATES 3, 4, 5, 6, AND 7, OR STATES 12, 4, 5, 6 AND 13.). THIS PREVENTS THE LOSS OF INFORMATION AND PROVIDES A POSSIBILITY OF AN ERROR RECOVERY.

THE MESSAGE WILL THEN BE TRANSMITTED FROM CENTER TO CENTER (AS SHOWN BY THE DOTTED LINE FROM STATE 9 TO STATE 10 IN THE FIG.13), UNTIL IT REACHES A CENTER TO WHICH THE DESIGNATED TERMINAL (I.E. THE RECEIVER) IS CONNECTED.

THE OUTPUT-PROCESS FOR TRANSMITTING A MESSAGE TO ITS RECEIVER IS SLIGHTLY DIFFERENT THAN AS MENTIONED ABOVE FOR TRANSMITTING MESSAGES BETWEEN CENTERS. [SEE FIG.13, THE OUTPUT PROCESS BETWEEN CENTERS (OUTPUT 1) CONTAINS STATES 10, 11, 12 AND 13, WHILE THE OUTPUT PROCESS FOR TRANSMITTING A MESSAGE TO ITS TERMINAL (OUTPUT2) INVOLVES STATES 14, 11, 12, 13, AND 8]. THE TRANSMISSION FROM A CENTER TO ITS TERMINAL IS AN ADDRESSING TRANSMISSION WHERE THE TRANSMISSION IS PROCESSED AS SOON AS THE ADDRESSED TERMINAL IS FREE. THE OUTPUT 2 PROCESS BEGINS WITH A TERMINAL ADDRESSING PROCEDURE (STATE 14) WHICH ESTABLISHES A CONNECTION BETWEEN THE CENTER AND THE ADDRESSED TERMINAL, AND ALSO CALLS THE TERMINAL'S ATTENTION FOR RECEIVING THE MESSAGE

(STATE 15). WHEN THIS PROCEDURE IS FINISHED, AN OUTPUT BUFFER OF THE CENTER IS THEN ALLOCATED (STATE 11), THE MESSAGE IS LOADED INTO THE BUFFER, AND SENT OUT TO THE TERMINAL AS THE SAME OPERATION IN OUTPUT1 PROCESS (STATE 12). UPON RECEIPT OF THE MESSAGE, THE TERMINAL WILL ASSEMBLE THE MESSAGE, TRANSLATE THE CODE, ETC (STATE 16). AT THE END OF TRANSMISSION, THE CENTER RELEASES THE OUTPUT BUFFER (STATE 13) AND THE COMMUNICATION LINE (STATE 8), AND SIGNALS THE TERMINAL TO DISCONNECT FROM THE CENTER (STATE 17).

AS ILLUSTRATED IN THE ABOVE DESCRIPTION, AND IN FIG. 13, A MESSAGE'S LIFE CAN BE REPRESENTED BY A FLOW DIAGRAM THAT CONSISTS OF 17 STATES. WHERE A MESSAGE IS CREATED AT STATE 1 AND IS TERMINATED AT STATE 17, IT MAY BE IN ANY ONE OF THE 17 STATES AT ANY GIVEN TIME.

THIS GLOBAL STUDY OF A NETWORK GIVES AN OVERALL PICTURE OF THE ENTIRE NETWORK. A CLOSER LOOK AT SOME SPECIFIC INTERESTING PARTS OF THE NETWORK WILL BE NECESSARY. THIS IS INCLUDED IN THE STUDY OF THE LOCAL PROCESSOR ORIENTED OPERATIONS.

3.2. LOCAL OR PROCESSOR ORIENTED VIEW

IN THIS VIEW, A COMMUNICATION NETWORK CONSISTS OF A SET OF PROCESSORS WHICH CORRESPOND TO NODES, LINKS, OR EVEN SUBNETS IN THE GRAPH REPRESENTATION OF A NETWORK. A PROCESSOR IS A LOGICAL

UNIT WHICH HAS THREE ASPECTS: (1) IT IS A DATA CARRIER WHICH HOLDS THE DATA (OR MESSAGES) WHILE THE MESSAGE FLOWS THROUGH IT; (2) IT HAS A SPECIFIC PROCESSING FUNCTION AND WILL EXECUTE ACCORDINGLY; (3) IT MAY HAVE ONE OR MORE COMPONENTS, AND THOSE COMPONENTS ARE LOGICALLY CONNECTED THROUGH A SPECIAL MACHINISM. IN THIS SECTION WE ARE GOING TO STUDY THE SAME COMMUNICATION NETWORK, AS PRESENTED IN THE PREVIOUS SECTION, FROM A RATHER DIFFERENT POINT OF VIEW, NAMELY THE LOCAL OR PROCESSOR POINT OF VIEW.

IN THEORY, THE PROCESS OF MOVING INFORMATION FROM ONE POINT TO ANOTHER CAN BE BROKEN DOWN INTO FIVE STAGES, EACH OF WHICH CAN BE REPRESENTED BY A DISCRETE COMPONENT. THESE COMPONENTS ARE: THE 'ENCODER', WHICH PUTS THE INFORMATION INTO A FORM IN WHICH IT CAN BE TRANSMITTED; THE 'TRANSMITTER', WHICH CHANGES THE INFORMATION INTO SIGNALS FOR TRANSMISSION; THE 'MEDIUM', WHICH CONVERTS THE INFORMATION TO SIGNAL FORM; THE 'RECEIVER', WHICH ACCEPTS THE SIGNALS; AND THE 'DECODER', WHICH TRANSFORMS THE RECEIVED SIGNAL BACK INTO AN UNDERSTANDABLE FORM. IN THE ELECTRONIC DATA COMMUNICATION FIELD, THESE FIVE STAGES OF THE COMMUNICATION PROCESS CORRESPOND TO THE TERMINALS OR SWITCHING CENTERS (ENCODERS AND DECODERS), THE 'MODEM' OR 'DATASET' (TRANSMITTERS AND RECEIVERS), AND THE SIMPLEX, OR HALF-DUPLEX, OR FULL-DUPLEX LINK (MEDIUMS). A SIMPLIFIED MODEL CAN BE MADE WHICH COMBINES THE MODEM AND TRANSMISSION LINE TO FORM A COMMUNICATION LINK AS SHOWN IN FIG.15 A MODEM IS A COMPONENT WHICH TAKES THE 'DIGITAL SIGNALS' FROM A TERMINAL AND MODULATES THE CARRIER WAVE TO ACHIEVE AN

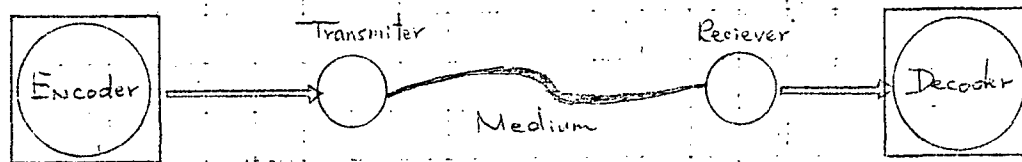


Fig. 15 (a) The Five Stages of a Data Transmission

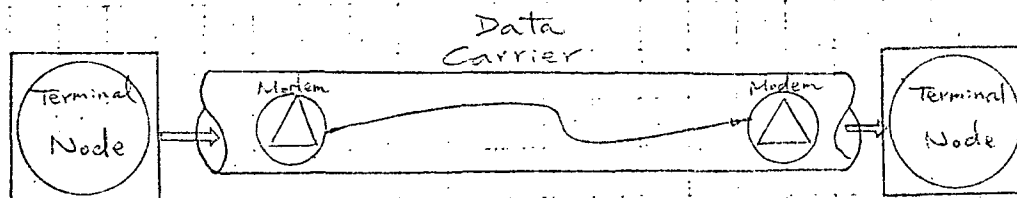


Fig. 15 (b) A Simplified Model of a Data Transmission

'ANALOG SIGNAL' AT THE SENDING END AND, CORRESPONDINGLY DEMODULATES IT AT THE RECEIVING END.

THEREFORE, A COMMUNICATION NETWORK AS PRESENTED IN THE PREVIOUS SECTION CAN BE CONSIDERED AS A SET OF THREE TYPES OF PROCESSORS, NAMELY COMMUNICATION LINKS, SWITCHING CENTERS, AND TERMINAL NODES. EACH OF THESE IS DISCUSSED BELOW.

3.2.1. A COMMUNICATION LINK:

IN GENERAL, COMMUNICATION LINKS ARE CLASSED AS SIMPLEX, HALF DUPLEX, AND FULL DUPLEX. THE 'SIMPLEX' LINKS TRANSMIT IN ONE DIRECTION ONLY. THE 'HALF DUPLEX' LINKS CAN TRANSMIT IN EITHER DIRECTION, BUT ONLY IN ONE DIRECTION AT ONCE. THE 'FULL DUPLEX' LINKS TRANSMIT IN BOTH DIRECTIONS AT THE SAME TIME. TRANSMISSION IN TWO DIRECTIONS CAN BE OBTAINED ON TWO-WIRE OR FOUR-WIRE LINES. A TYPICAL TWO-WIRE TRANSMISSION LINK IS SHOWN IN FIG. 16-A. AS SHOWN, AT ANY GIVEN MOMENT ONE END WILL SERVE AS TRANSMITTER AND THE OTHER AS RECEIVER. THE TRANSMITTER SENDS A MESSAGE TO THE RECEIVER. UPON RECEIPT OF THE MESSAGE, THE RECEIVER MUST ACKNOWLEDGE THE MESSAGE AS ACCEPTABLE OR ERRONEOUS. IN ORDER TO DO THIS, THE NORMAL RECEIVER REVERSES ITS ROLE AND ACTS AS A TRANSMITTER. TO ACCOMPLISH THIS REVERSAL, THE DIRECTION OF THE DATA FLOW ON THE LINK MUST BE REVERSED. A SPECIFIC AMOUNT OF TIME IS CONSUMED AND KNOWN AS 'MODEM TURN AROUND TIME'. AFTER THIS REVERSAL, AN ACKNOWLEDGEMENT IS SENT FROM THE NORMAL RECEIVER TO

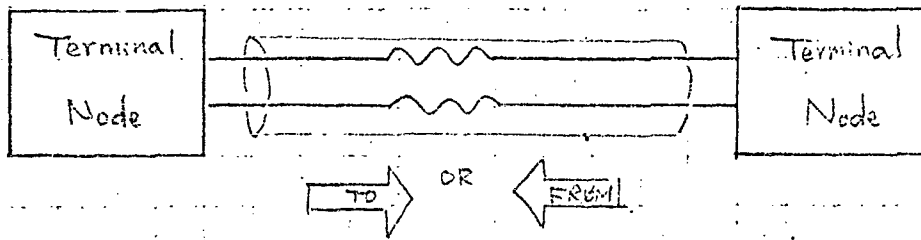


Fig. 16 (a) A Two -Wire Half -Duplex line

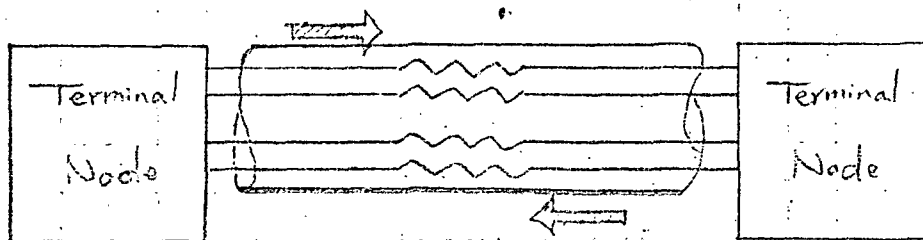


Fig. 16 (b) A Four-Wire Full-Duplex Line

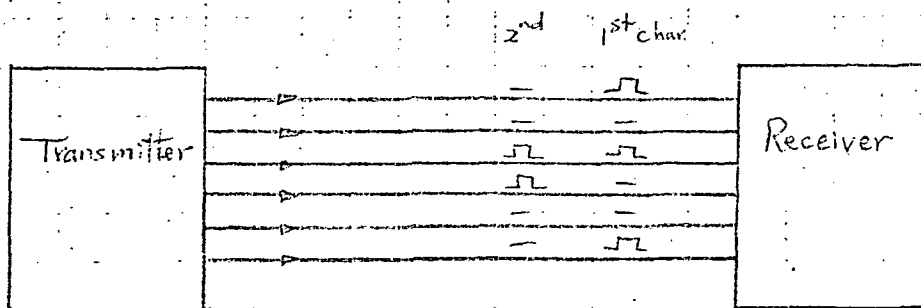


Fig. 17 (a) A Serial Transmission

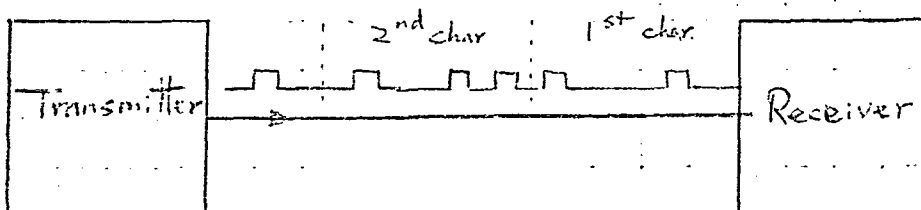


Fig. 17 (b) A Parallel Transmission

THE NORMAL TRANSMITTER. UPON RECEIPT OF THE ACKNOWLEDGMENT, ANOTHER REVERSAL OF THE LINK DIRECTION IS REQUIRED IN ORDER TO TRANSMIT THE NEXT MESSAGE. IT IS APPARENT THAT TWO 'MODEM TURN AROUND TIME' PER MESSAGE TRANSMISSION IS REQUIRED FOR A 'HALF-DUPLEX' LINK. IN A FULL DUPLEX LINK, FOUR WIRES ARE USUALLY USED, AS REPRESENTED IN FIG. 16-B. TWO WIRES ARE USED FOR TRANSMISSION AND THE OTHER TWO WIRES ARE USED TO 'REPLY TO DENOTE ACCEPTANCE. AT THE END OF EACH DATA TRANSMISSION, THE TERMINALS REVERSE THEIR ROLES OF RECEIVER OR TRANSMITTER, BY A SIMPLE SWITCH, BUT THE LINK DOES NOT CHANGE ITS STATUS. THAT IS, THERE IS NO 'MODEM TURN AROUND' DELAY INVOLVED IN THE TRANSMISSION OF A FULL DUPLEX LINK. IN ADDITION TO THE TRANSMISSION DIRECTION OF A LINK, ANOTHER PRIMARY CONSIDERATION OF A LINK IS THE CONNECTIVITY OF A LINK. A LINK CAN BE SWITCHED THROUGH AN EXCHANGE OFFICE, OR PERMANENTLY CONNECTED, OR SHARED WITH SOME OTHER PARTIES. THIS LINK, REFERED TO AS A 'SWITCHED', 'PRIVATE', OR 'PARTY, LINK. THE COST OF A PRIVATE LINE USUALLY IS MUCH HIGHER THAN OTHERS, SO IT IS USED WHEN THE CONSTANT CONNECTION AND FREQUENTLY USE ARE NECESSARY. THE PARTY LINK IS THE NEXT EXPENSIVE LINK BECAUSE THE COST IS SHARED BY PARTIES. IF THE TERMINAL HAS ONLY A LOW USAGE THEN THE SWITCHED LINK WILL BE THE MOST ECONOMIC ONE. THE SWITCHED LINK ALSO PROVIDES THE ABILITY TO DIAL ANY TERMINAL CONNECTED WITH THE SAME SWITCHING SYSTEM AND GIVES GREAT FLEXIBILITY.

THE OTHER CATEGORIZATION OF A LINK TYPE IS THE TRANSMISSION

RATE. TABLE 3 LISTS SEVERAL TYPES OF COMMUNICATION LINKS RELATED TO ITS TRANSMISSION RATE. THE COMMUNICATION LINKS USED IN COMMON CARRIERS FALL INTO THREE CATEGORIES : (A) SUBVOICE GRADE: 45BITS/SEC - 500 BITS/SEC, (B) VOICE GRADE: 600 BITS/SEC - 5000 BITS/SEC, (C) WIDE BAND: MORE THAN 10000 BITS/SEC.

BESIDES THOSE MENTIONED ABOVE, EACH LINK HAS ITS OWN DEGRADING FACTORS WHICH SPECIFY THE CONDITIONS OF A TRANSMISSION LINK SUCH AS NOISE RATE, FAILURE RATE, ETC.

3.2.2. A TERMINAL NODE:

AS DISCUSSED EARLIER, A TEMINAL NODE IS NEEDED TO ENABLE TRANSMISSION AND TO DISPLAY THE MESSAGE BETWEEN THE NETWORK AND THE OUTSIDE WORLD. REGARDLESS OF THE VARIETY OF INPUT /OUTPUT MEDIA EMPLOYED FOR DISPLAYING THE MESSAGE, THE CONCEPT IS ESSENTIALLY THE SAME. IN THIS SECTION, WE ARE CONCERNED WITH THE TRANSMISSION MODE WHICH WAS GENERATED BY A TERMINAL NODE. IN GENERAL, THESE TRANSMISSION MODES CAN BE SUMMARIZED AS FOLLOWS: PARALLEL VS SERIAL; SYNCHRONOUS VS ASYNCHRONOUS; BIT OR CHARACTER VS BLOCK TRANSMISSION.

(A) PARALLEL VS SERIAL TRANSMISSION - DIGITAL DATA CAN BE SENT OVER COMMUNICATION LINKS EITHER IN A SERIAL MODE OR IN A PARALLEL MODE. IN SERIAL TRANSMISSION THE INFORMATION IS HANDLED SEQUENTIALLY AS SHOWN IN FIG. 17-A. IN PARALLEL TRANSMISSION, ON THE OTHER HAND, THE INFORMATION IS DIVIDED

Table 3. ADVANTAGES AND DISADVANTAGES OF THE VARIOUS TRANSMISSION MODES

MODE OF TRANSMISSION	ADVANTAGES AND DISADVANTAGES
Four-wire Two-wire	Permits full-duplex transmission.
Simplex Half duplex Full duplex Data in both directions at once. Data in one direction; control information in the other	Rarely used for data transmission, as there is no return path for control, or error signals. Commonly used for data transmission, though a full-duplex line may cost little more. (Often 10% more in the United States.) System sometimes cannot take advantage of this, as data cannot be made available for transmitting in both directions simultaneously. Can substantially reduce the response time, however, on a conversational multidrop line. Often requires a more expensive terminal. Commonly used on a link between concentrator and computer. A common arrangement, though, as data are still only being sent in one direction at a time, half-duplex transmission may give better value for money at low character rates. With high character rates the line turnaround time may be long compared to the character time and full-duplex operation may eliminate most turnaround delay.

MODE OF TRANSMISSION	ADVANTAGES AND DISADVANTAGES
Serial-by-character Parallel-by-bit Separate wires Separate frequencies	Low transmitter cost, but high line cost. Economical for in-plant use. Line costs too expensive for long distances. Used on voice lines to give a slow but inexpensive terminal. For efficient line utilization, however, data set costs are high, and receiver cost can be high.
Serial-by-character Serial-by-bit The most common system, especially on long lines. Start-stop transmission Synchronous transmission High-speed pulse train	Inexpensive terminal, e.g., telegraph machines. Only one character lost if synchronization fails. Not too resilient to distortion at high speeds. More expensive terminal. Block lost if synchronization fails. Efficient line utilization. High ratio of data to control bits. More resilient to noise and jitter than start-stop transmission, especially at high transmission speeds. The most common system on lines of 600 bits per second and faster. In-plant or private wiring only at present. Low wiring cost with low terminal cost. High accuracy.

INTO CHARACTERS (OR BITS) WHICH ARE TRANSMITTED SIMULTANEOUSLY. (SEE FIG. 17-B). THE STREAM OF DATA IS OFTEN DIVIDED INTO CHARACTERS (OR BITS) AND SENT EITHER SERIAL-BY-CHARACTER, SERIAL-BY-BIT; OR SERIAL-BY CHARACTER, PARALLEL-BY-BIT. IF THE CHARACTERS ARE COMPOSED OF SIX BITS EACH, THEN SIX LINES WOULD BE NEEDED FOR TRANSMISSION IN A SERIAL-BY-CHARACTER, PARALLEL-BY-BIT SYSTEM. IN SPITE OF THE OBVIOUS COST DISADVANTAGES OF MAINTAINING SIX LINES OVER A LONG DISTANCE INSTEAD OF ONE, THERE IS THE ADVANTAGE THAT ALL SIX BITS (I.E. ONE CHARACTER) WILL REACH THE RECIVER AT THE SAME TIME

(B) SYNCHRONOUS VS ASYNCHRONOUS TRANSMISSION - WITH SYNCHRONOUS TRANSMISSION, A MESSAGE IS SENT IN A CONTINUOUS CHARACTER (OR BIT) STREAM. WITH ASYNCHRONOUS TRANSMISSION, SOMETIMES REFERRED TO AS 'START-STOP' TRANSMISSION, A MESSAGE IS DIVIDED INTO SEGMENTS (CHARACTERS, OR BITS) AND ONE SEGMENT IS SENT AT A TIME. THE SEGMENT IS INITIALIZED BY A 'START' SIGNAL AND TERMINATED BY A 'STOP' SIGNAL. IN A SYNCHRONOUS TRANSMISSION, A SYNCHRONIZING SIGNAL IS SENT AT SPECIFIED TIMES TO ENSURE THE SYNCHRONIZATION BETWEEN TWO TERMINAL NODES. WHEN TERMINALS TRANSMIT TO EACH OTHER CONTINUOUSLY WITH REGULAR TIMING, SYNCHRONOUS TRANSMISSION CAN GIVE THE MOST EFFICIENT LINE UTILIZATION (I.E. FASTER, MORE ACCURATE, MORE COMPACT.) HOWEVER, START-STOP TERMINALS ARE GENERALLY LESS EXPENSIVE THAN SYNCHRONOUS TERMINALS.

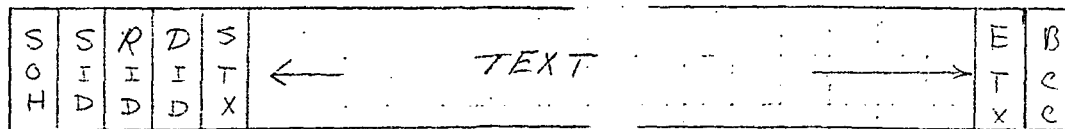
(C) BIT OR CHARACTER VS BLOCK TRANSMISSION -

THE TRANSMISSION METHODS DESCRIBED ABOVE ARE USED PRIMARY FOR TRANSMITTING SINGLE ITEMS (E.G. BITS) OR SMALL GROUPS OF ITEMS (E.G. CHARACTERS, OR WORDS). MUCH OF TRANSMISSION THAT TAKES PLACE TO AND FROM SWITCHING CENTERS IS OF LARGE BATCHES OF ITEMS (E.G. MESSAGES). IN FIG. 18, WE SEE THAT TWO CONTROL CHARACTERS 'STX' (START OF TEXT) AND 'ETX' (END OF TEXT) ENCLOSE A SEQUENCE OF CHARACTERS THAT IS TO BE TREATED AS AN ENTITY AND IS REFERRED TO AS THE 'TEXT'. IN THIS MODE OF TRANSMISSION, A MESSAGE HEADER IS ACCOMPLISHED WITH THE TEXT. IN GENERAL, THE HEADER PRECEDES THE TEXT AND CONTAINS THE ROUTING INFORMATION AS SHOWN FIG. 18.

3.2.3. A SWITCHING CENTER

AS DISCUSSED IN SECTION -- A MESSAGE SWITCHING CENTER STANDS AS A DECISION MAKER FOR THE ENTIRE COMMUNICATION FLOW. WE SUMMARIZE THE OPERATIONS PERFORMED BY THE SWITCHING CENTER BELOW:

1. THE CENTER ACCEPTS MESSAGES FROM REMOTE TERMINALS.
2. THE CENTER DETECTS ANY ERROR IN TRANSMISSION AND REQUESTS A RETRANSMISSION OF FAULTY MESSAGES.
3. ON RECEIPT OF A MESSAGE, IT ANALYZES THE MESSAGE'S HEADER TO DETERMINE THE DESTINATION OR DESTINATIONS TO WHICH THE MESSAGE MUST BE SENT.



- start of text
- Current device identifier
- Receiver's identifier
- sender's identifier
- start of header

- Block check character
- end of Text

Fig. 18 A Format of Block Transmission

4. THE CENTER MAY ANALYZE THE HEADER FOR A PRIORITY INDICATION OR SOME NECESSARY PROCESSING INDICATION, AND THEN STORES ALL MESSAGES.
5. THE CENTER REDIRECTS MESSAGES FROM THE STORE AND SENDS THEM TO THE DESIGNATED TERMINALS.
6. IF MESSAGES ARE SENT TO A DESTINATION AT WHICH THE TERMINAL IS TEMPORARILLY INOPERATIVE, THE CENTER INTERCEPTS THESE MESSAGES. IT MAY REROUTE THEM TO ALTERNATIVE TERMINALS OR IT MAY STORE THEM UNTIL THE INOPERATIVE TERMINAL IS WORKING AGAIN.
7. THE CENTER MAINTAINS AN AWARENESS OF THE STATUS OF LINKS AND TERMINALS WHICH ARE CONNECTED TO IT.
8. THE CENTER MAY CONDUCT A STATISTICAL ANALYSIS OF THE TRAFFIC THAT IT IS HANDLING.
9. THE CENTER MAY MAINTAIN A LOG FILE AND AN ACCOUNT SYSTEM, WHICH PERIODICALLY PRODUCES REPORTS OF ITS OPERATION AND BILLS FOR USERS.

4. A TWO LEVEL VIEW OF A COMPUTER NETWORK

DATA COMMUNICATIONS AND COMPUTER NETWORKS HAVE RECENTLY BECOME A SUBJECT OF CONSIDERABLE INTEREST IN THE FIELD OF NETWORK RESEARCH. IN THE PRECEDING SECTIONS, WE HAVE DISCUSSED SOME MAJOR CHARACTERISTICS IN TERMS OF GLOBAL AND LOCAL POINTS OF VIEW. IN THIS SECTION AND IN THE FOLLOWING SECTION, A BRIEF DISCUSSION OF THE COMPUTER NETWORK WILL BE PRESENTED. BY THE TERM 'COMPUTER NETWORK' WE MEAN THE DEFINITION AS DEFINED BY THE 1968 NETWORK OF COMPUTER CONFERENCE¹. THAT IS,

'COMPUTER NETWORK': A SINGLE COMPUTER CENTER HAVING A MULTIPLICITY OF REMOTE TERMINALS.

'NETWORK OF COMPUTERS': TWO OR MORE COMPUTER SYSTEMS WHICH COMMUNICATE WITH ONE ANOTHER, AND

(1) MAY HAVE THEIR OWN FAMILY OF REMOTE TERMINALS, WHERE A TERMINAL IS DEFINED AS THE FIRST ECHELON HARDWARE BEYOND THE COMPUTER INTERFACE; AND

(2) MAY BE, BUT NOT NECESSARILY MUST BE, GEOGRAPHICALLY SEPARATED.

A TIME-SHARED COMPUTER SYSTEM IS ESSENTIALLY A COMPUTER NETWORK BY THE ABOVE DEFINITION. TWO OR MORE COMPUTER SYSTEMS SEPARATED EITHER PHYSICALLY OR LOGICALLY, YET CONNECTED, CONSTITUTE A NETWORK OF COMPUTERS. SOME EXAMPLES OF NETWORKS OF COMPUTERS SUCH AS THE ARPA NETWORK², AND THE OCTOPUS NETWORK³

ARE BRIEFLY PRESENTED IN THE NEXT CHAPTER. IN THIS CHAPTER, A GENERAL TIME SHARING SYSTEM IS PRESENTED FROM THE VIEW OF GLOBAL AND LOCAL STUDIES.

4.1. GLOBAL VIEW OF A COMPUTER NETWORK

TIME-SHARED COMPUTER SYSTEMS WERE DESIGNED TO OVERCOME THE SHORTCOMINGS OF THE TRADITIONAL BATCH OPERATING SYSTEM. THESE SHORTCOMINGS ARE : (1) USERS MUST WAIT AN HOUR OR MORE (EVEN THOUGH A MINIMUM AMOUNT OF SERVICE MAY BE REQUIRED) ; (2) MANY APPLICATIONS, SUCH AS REALTIME INTERACTION, ARE IMPOSSIBLE TO CARRY OUT. IN A TYPICAL TIME-SHARING SYSTEM, THE USER COMMUNICATES WITH A SMALL INTERMEDIATE COMPUTER WHICH HAS SIMULTANEOUS CONVERSATIONS WITH MANY DIFFERENT USERS. IT INTERRUPTS A LARGER CENTRAL PROCESSOR ONLY WHEN A USER NEEDS COMPUTING SERVICE, CUSTOMARILY FOR A VERY BRIEF PERIOD OF TIME. THE CENTRAL PROCESSOR'S TIME IS DIVIDED INTO SMALL TIME SLICE (SEGMENTS), AND A USER CAN OBTAIN A QUICK SHOT OF PROCESSING ON DEMAND. IN A WELL-ORGANIZED SYSTEM, THE AVERAGE USER CAN EXPECT RESPONSE TIMES WITHIN TEN SECONDS AND, AS MANY AS A DOZEN SERVICE REQUESTS PERFORMED WITHIN THE SPAN OF FIFTEEN MINUTES. THUS, A TIME-SHARED SYSTEM ALLOW THE USER TO INTERACT EFFECTIVELY WITH HIS PROGRAM.

THE TIME-SHARING USER SITS AT A TERMINAL DEVICE SUCH AS A

TYPEWRITER, TELETYPEWRITER, OR CATHODE-RAY DISPLAY HAVING BOTH INPUT AND OUTPUT FACILITIES. THE USER TYPES HIS PROGRAM INTO THE SYSTEM IN A NATURAL MANNER AND RECEIVES ERROR MESSAGES AND ANSWERS. THE TERMINAL DEVICE ACTS AS IF IT WERE DIRECTLY ATTACHED TO THE COMPUTER. IN ESSENCE THEN, A PORTION OF COMPUTER MEMORY, INPUT/OUTPUT FACILITIES, AND ALL ASSOCIATED FACILITIES ARE PROVIDED AT EACH REMOTE TERMINAL SITE.

THE COMPLEX OF THESE ACTIONS CAN BE STUDIED BY TRACING THE VARIOUS STATES THROUGH WHICH A PROGRAM PASSES DURING THE TIME IT IS ACTIVE. THE FOLLOWING IS AN EXAMPLE WHICH ILLUSTRATES A TYPICAL FLOW THROUGH A TIME-SHARED COMPUTER SYSTEM AS SHOWN IN FIG. 19.

1. A USER SITS DOWN AT HIS TERMINAL AND TURNS IT ON. IF IT IS DIRECTLY CONNECTED, OR DIALS THE COMPUTER, IF IT IS CONNECTED BY SWITCHED TELEPHONE LINE, THE COMMUNICATION UNIT (CU) RECEIVES THE CALL.
2. THE CU 'INTERRUPTS' THE CENTRAL PROCESS UNIT (CPU). A 'PRIORITY ROUTINE' DETECTS THAT A NEW JOB IS REQUIRED TO BE ESTABLISHED. IT ALLOCATES AND INITIALIZES CERTAIN TABLES, ASSIGNS A JOB IDENTIFIER, AND ACQUIRES A BLOCK OF CORE FOR ACCEPTING THE INPUT FORM, AND COMMUNICATES WITH THE TERMINAL. CONTROL THEN RETURNS TO THE INTERRUPTED PROGRAM.
3. A SYSTEM SIGN-ON MESSAGE IS SENT TO THE TERMINAL TO INDICATE THAT THE SYSTEM IS READY TO ACCEPT HIS COMMAND. THE JOB IS NOW IN THE 'COMMAND STATE', TO ACCEPT INPUT COMMANDS TO THE

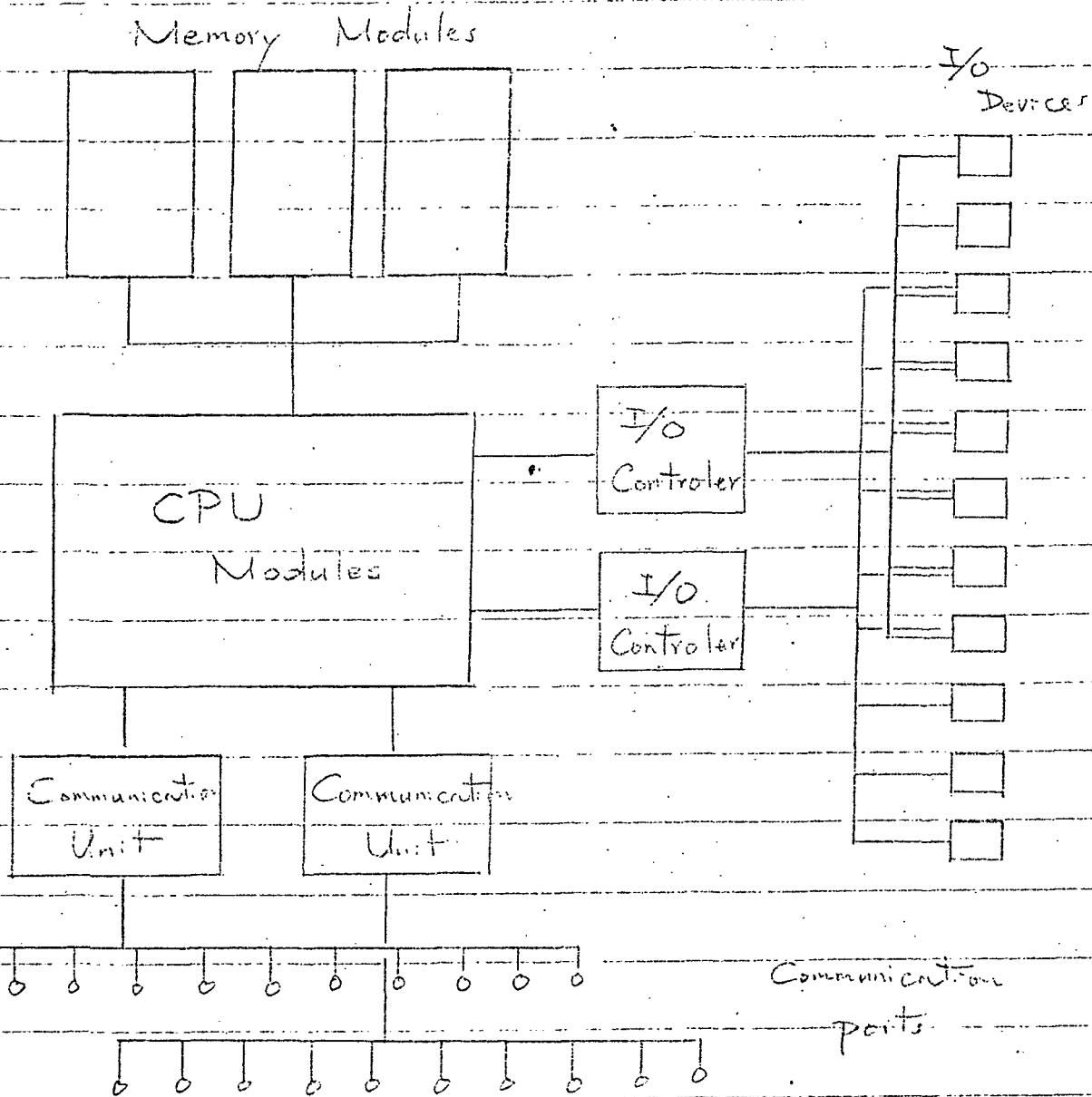


Fig 1.9 An Example of Computer Network

SYSTEM. NOTE THEN AT THIS STATE, THE SYSTEM WILL INTERPRET ANY SENTENCE THAT THE USER TYPES AS A COMMAND AND WILL SEARCH FOR THE CORRESPONDING INTERPRETATION.

4. THE CU CONTINUES TO READ COMMANDS FROM THE COMMUNICATION LINES INTO THE BUFFER STORE, AT THE SAME TIME AS THE COMPUTER IS PROCESSING OTHER TASKS.
5. AT EVERY FIXED TIME PERIOD, THE CPU POLLS THE CHARACTERS FROM THE CU'S BUFFER ONE CHARACTER AT A TIME. IF THE CHARACTER JUST POLLED IS NOT A CARRIAGE RETURN INDICATOR, IT WILL BE ADDED TO THE BUFFER; OTHERWISE THE 'SYSTEM COMMAND INTERPRETER' WILL BE CALLED, AND A SEARCH FOR THE CORRESPONDING INTERPRETATION PERFORMED. THE JOB IS NOW IN THE 'READY FOR PROCESSING' STATE, AND REQUIRES ATTENTION FROM THE APPROPRIATE SCHEDULING ALGORITHMS.
6. ONCE THIS PROGRAM HAS BEEN SCHEDULED FOR EXECUTION, IT IS IN THE 'PROCESSING' STATE. NOTE THEN AT THIS STATE ANY NONCOMMAND STATEMENTS WHICH THE USER TYPES IN WILL BE TREATED AS INPUT DATA AND STORED IN THE INPUT BUFFER. WHENEVER THE INPUT BUFFER BECOMES IN DANGER OF OVERFLOWING, THE CPU STOPS POLLING CHARACTERS FROM THE CU FOR THAT BUFFER. THIS MAY THEN CAUSE THE INPUT BUFFER OF THE CU TO BECOME IN DANGER OF OVERFLOWING. IF OVERFLOW OCCURS THE CU WILL THEN LOCK AND INFORM THE USER BY SENDING A 'WAIT' MESSAGE TO THE TERMINAL.
7. WHENEVER THE USER'S PROGRAM REQUESTS INPUT DATA FROM THE

TERMINAL, THE SYSTEM EXAMINES THE INPUT BUFFER BELONGING TO THAT USER. IF THERE IS SUFFICIENT DATA IN THE BUFFER, DATA IS TRANSFERRED TO THE USER'S PROGRAM, WHICH CONTINUES TO RUN. IF THERE IS NOT SUFFICIENT DATA IN THE BUFFER, THE SYSTEM WILL PLACE THE PROGRAM IN THE 'INPUT WAIT' STATE. IT IS THEN TEMPORARILY IGNORED BY THE SCHEDULING MECHANISM UNTIL THE USER HAS INPUT ENOUGH DATA. NOTE THAT WHEN THE DATA IS MOVED FROM THE INPUT BUFFER AND THE OVERFLOW CONDITION NO LONGER EXISTS, THE SYSTEM WILL PUT THAT BUFFER INTO THE POLLING LIST. AT THE NEXT POLL TIME, THE CU WILL UNLOCK THE TERMINAL AND WILL SEND A 'READY' MESSAGE TO INFORM THE USER THAT THE SYSTEM IS READY TO ACCEPT INPUTS.

8. A PROGRAM MAY GENERATE OUTPUTS TO THE TERMINAL. THESE OUTPUTS ARE FIRST STORED IN THE OUTPUT BUFFER AND THEN SENT THROUGH THE CU TO THE TERMINAL. IF THE PROGRAM GENERATES SO MUCH OUTPUT THAT THE OUTPUT BUFFER BECOMES IN DANGER OF OVERFLOWING, THE SYSTEM WILL PLACE THE PROGRAM INTO THE 'OUTPUT WAIT' STATE.
9. A PROGRAM MAY REFER TO A FILE IN AUXILIARY STORAGE. IN THIS CASE, A 'FILE READ' OR 'FILE WRITE' REQUEST WILL BE SENT TO I/O CHANNEL. IF THE CHANNEL OR DEVICE IS BUSY OR THERE ARE EARLIER REQUESTS FOR THAT FILE, THE PROGRAM IS THEN PUT IN THE 'FILE WAIT' STATE.
10. WHEN A PROGRAM IS IN ONE OF THE WAITING STATES, IT WILL CAUSE CONTROL TO BE RETURNED TO THE SCHEDULING ROUTINE, AND

THIS WILL IN TURN GIVE CONTROL TO ANOTHER JOB. THIS INSURES THAT THE COMPUTER WILL PERFORM OTHER WORK WHILE THE ABOVE PROGRAM WAITS.

11. AT SOME LATER TIME, SOME OTHER JOB WILL BE INTERRUPTED BECAUSE THE WAIT CONDITION WHICH CAUSED THE DEDICATED JOB TO BE HELD UP HAS CHANGED. IN SOME CASES, THE PROGRAM IS PLACED INTO 'READY FOR PROCESSING' STATE. THE ENTIRE PROCESS FORMS A LOOP FROM STEP 5 THROUGH 11, UNTIL THE PROGRAM FINALLY TERMINATES.

THIS COMPLETES THE LIFE OF A JOB IN THE SYSTEM. THE USER MAY SEND AN 'END OF TRANSMISSION' SIGNAL WHICH CAUSES THE 'CU' RELEASE THE COMMUNICATION LINE AND BUFFER.

4.2. LOCAL OR PROCESSOR VIEW

THERE ARE THREE BASIC COMPONENTS IN A COMPUTER NETWORK :
(A) COMMUNICATIONS FACILITIES AND THEIR INTERFACES TO DIGITAL EQUIPMENTS, (B) COMPUTER HARDWARE AND SOFTWARE, AND (C), REMOTE USER'S TERMINALS.

4.2.1. COMMUNICATION FACILITIES

THREE MAJOR COMMUNICATION FACILITIES HAVE BEEN USED IN THIS EXAMPLE: LINKS, SWITCHING CENTERS, AND COMMUNICATION CONTROL UNIT.

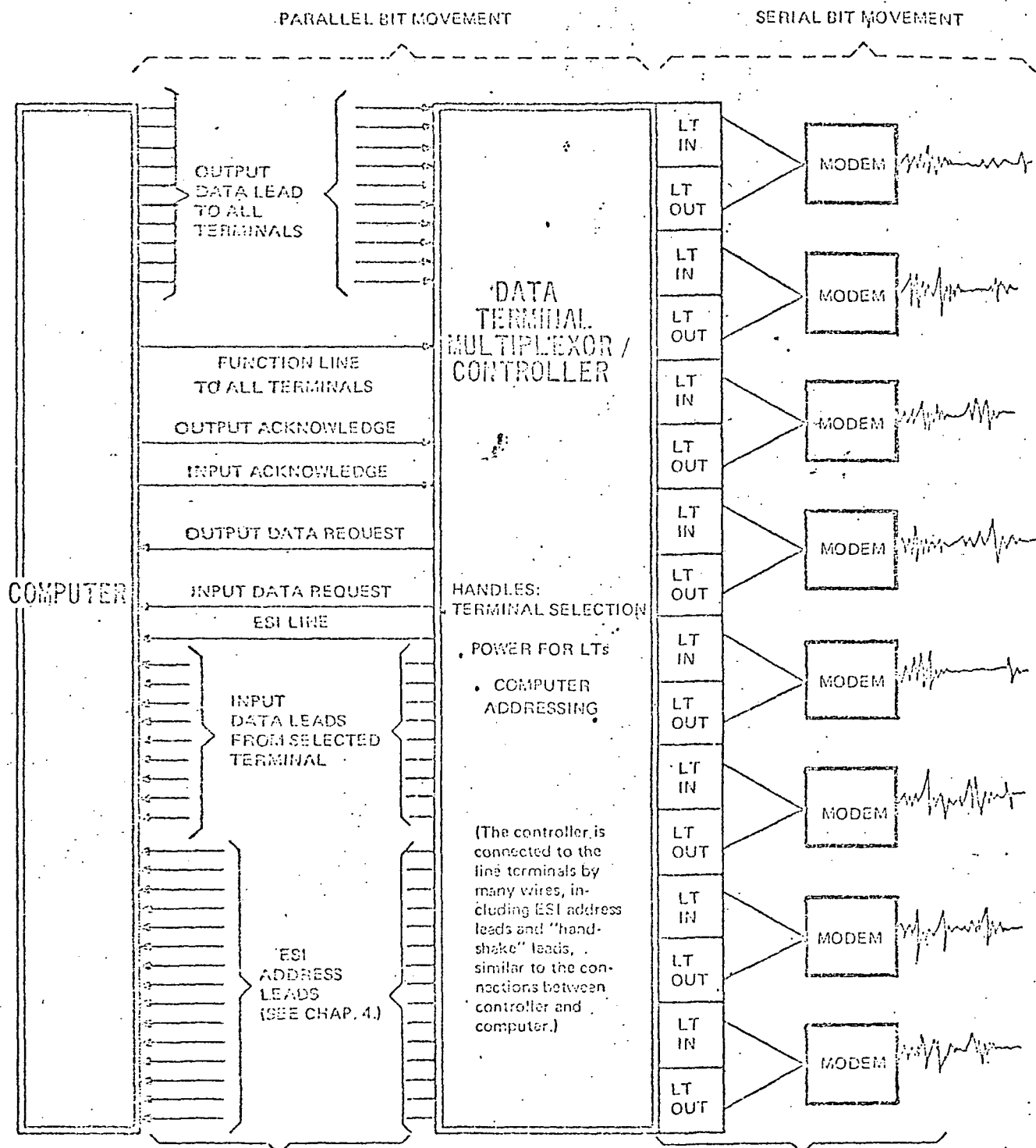
MOST OF THE FUNCTIONS HAVE BEEN DISCUSSED IN SECTION ***, A FUNCTION WHICH SHOULD STAND OUT, HOWEVER, IS THE COMMUNICATION CONTROL UNIT. A TYPICAL COMMUNICATION CONTROL UNIT IS SHOWN IN FIG. 20. AS SHOWN, THERE ARE TWO LINE CONTROLLERS PER CHANNEL (OR LINK), ONE FOR THE INPUT AND ONE FOR THE OUTPUT. THIS IS THE CASE IN ALL COMMUNICATION CONTROL UNITS EXCEPT THOSE OPERATING ON THE SIMPLEX PRINCIPLE (I.E. ONLY ONE FIXED DIRECTION). THE MAJOR FUNCTIONS OF A COMMUNICATION CONTROL UNIT ARE LISTED AS FOLLOWS:

(A) INPUT

- (1) RECEIVE AN INPUT REQUEST FROM ONE OF THE LINE CONTROLLERS. AN INPUT FLAG OF THAT CONTROLLER IS SET TO PREVENT THE INPUT/OUTPUT CONFLICT.
- (2) THE COMMUNICATION CONTROLLER EXAMINES THE LINE CONTROLLERS SEQUENTIALLY. WHEN IT FINDS ONE WHICH HAS RAISED ITS INPUT FLAG, IT STOPS AND ASSEMBLES ON THE INCOMING CHARACTER IN THE WORD BUFFER.
- (3) WHEN THE WORD BUFFER IS FULL, THE COMMUNICATION CONTROLLER GENERATES AN INTERRUPT SIGNAL TO THE CPU. THIS WILL CAUSE THE CPU TO FETCH THE ASSEMBLED WORD IN MEMORY.

(B) OUTPUT:

- (1) WHEN THE OUTPUT BUFFER HAS COMPLETED OUTPUTTING ALL CHARACTERS, IT RAISE AN OUTPUT-COMPLETED FLAG.
- (2) THE COMMUNICATION CONTROLLER STOPS ITS SCAN AT THIS LINE WHEN THE OUTPUT-COMPLETION FLAG IS SENSED AND SENDS AN INTERRUPT TO THE CPU.



MULTIPLEXING THEORY: ONE HIGH SPEED (BIT-PARALLEL) CHANNEL CONSTANTLY SERVES EACH OF MANY SLOWER (BIT-SERIAL) CHANNELS.

Computer data terminals are supplied with varying numbers of line terminals. When employed at the central site, the configuration generally appears as shown above. When computers communicate with each other, the "remote" computer would need only one line terminal module (one input, one output function) and the controller with its housing, power supply and indexing capability, etc. (Not all computer data terminals have all of the features shown above. See Appendix B.)

Fig. 20 Typical Communication Control Unit

- (3) THE CPU CHECKS TO SEE IF ADDITIONAL MESSAGES ARE TO BE OUTPUT. IF SO, THE CPU SEND A WORD TO THE COMMUNICATION CONTROLLER.
- (4) THE COMMUNICATION CONTROLLER DEPOSITE THE WORD IN A APPROPRIATE OUTPUT BUFFER AND CONTINUES ITS SCAN.

4.2.2. COMPUTER

A COMPUTER CONSISTS OF AT LEAST THE FOLLOWING COMPONENTS: MEMORIES, PROCESSORS, PERIPHERALS, AND CHANNELS. THE COMMUNICATION BETWEEN ANY PAIR OF COMPONENTS IS VIA CHANNELS WHICH PROVIDE BOTH 'DATA AND CONTROL' INFORMATION PATHS. HERE WE DISCUSS BRIEFLY, SOME PRIMARY FUNCTIONS OF EVERY COMPONENT. FOR MORE DETAILED INFORMATION, REFER TO [3].

(A) MEMORY COMPONENTS:

ALL MEMORY COMPONENTS ARE FUNCTIONALLY SIMILAR BECAUSE THEY STORE PROGRAMS WHILE THEY ARE BEING INTERPRETED BY A PROCESSOR; STORE DATA FOR PROGRAMS; AND STORE OTHER STATE INFORMATION AS REQUIRED BY THE PROCESSORS. A MEMORY COMPONENT MAY BE DESCRIBED BY: (1) THE NUMBER OF INDEPENDENT MEMORY MODULES,

(2) THE PROPERTIES OF EACH MEMORY MODULE

- . THE DATA WIDTH (I.E. WORD LENGTH) OF INFORMATION ACCESSED AT ONE TIME,
- . THE QUANTITY OF INFORMATION STORED,

- . THE ACCESS TIME (I.E. THE TIME THE MODULE REQUIRES TO OBTAIN DATA, GIVEN THAT THE MODULE IS FREE, FROM THE TIME AN ACCESS REQUEST HAS BEEN MADE).
 - . THE CYCLE TIME - THE TIME THE MODULE REQUIRES TO COMPLETELY ACKNOWLEDGE A REQUEST, AND BECOME FREE FOR THE NEXT REQUEST.
 - . MEMORY FAILURE PROBABILITY (INCLUDES DETECTED FAILURES AND UNDETECTED FAILURES).
- (3) ADDRESS SCHEME - THE METHOD USED TO ASSIGN PHYSICAL ADDRESS.

(B) PROCESSOR COMPONENTS:

A SINGLE COMPUTER MAY HAVE ONLY ONE PROCESSOR, WHILE A MULTI-PROCESSOR COMPUTER HAS MORE THAN ONE PROCESSOR. PROCESSORS CONNECT WITH MEMORY COMPONENTS AND ENACT USER COMPUTATIONAL PROCESSES. A PROCESSOR CAN BE SPECIFIED BY THE FOLLOWING PARAMETERS:

- (1) INSTRUCTION SET ABILITY
- . PROCESSING TIME REQUIRED FOR A GIVEN INSTRUCTION OR ALGORITHM.
 - . MEMORY SPACE REQUIRED FOR A GIVEN INSTRUCTION OR ALGORITHM.
- (2) THE NUMBER OF PROGRAMS WHICH ARE RECOGNIZED AS INDEPENDENT PROCESSES.
- (3) PROGRAM SWITCHING (OR SWAPPING) TIME.
- (4) THE NUMBER OF REGISTERS ASSOCIATED WITH A PROCESS WHICH

RESIDE IN THE PROCESSOR AND MUST SWAPPED WHEN A NEW PROCESS IS SELECTED.

(C) PERIPHERAL COMPONENTS:

THE PERIPHERAL COMPONENTS ARE THOSE DEVICES WHICH ARE PHYSICAL AND LOGICALLY PERIPHERY OF A COMPUTER, E.G. I/O DEVICES, TERMINALS, FILE SYSTEMS. THE FOLLOWING PARAMETERS, IN GENERAL, ARE USED IN DESCRIBING A PERIPHERAL COMPONENT:

(1) CAPACITY OF THE COMPONENT.

(2) ACCESS TIME - INFORMATION SELECTION OR ACCESS TIME MAY BE EXPRESSED IN TERM OF THE FOLLOWING OPERATORS:

- . RANDOM - DATA SELECTION IS A CONSTANT AND INDEPENDENT OF THE ADDRESS.
- . LINEAR - DATA SELECTION TIME VARIES PROPORTIONATELY WITH THE ADDRESS REQUIRED.
- . CYCLIC LINEAR - DATA SELECTION TIME VARIES PROPORTIONALLY WITH THE ADDRESS. ADDRESSES ARE BEING CHANGED AUTOMATICALLY, AND TAKE ON CYCLIC VALUES AT SOME RATE.

(3) ADDRESSABILITY OF INFORMATION.

(4) REPLACEABILITY OF INFORMATION.

(5) REMOVEABILITY OR PORTABILITY OF INFORMATION.

(D) CHANNEL COMPONENTS:

A CHANNEL PROVIDES A COMMUNICATION PATH BETWEEN TWO DIFFERENT COMPONENT TYPES. THE FUNCTION OF A CHANNEL IS NETWORK. THE

NETWORK. IN GENERAL, THEY ARE PHYSICALLY IDENTICAL. THE FUNCTION OF LINKS IN A COMMUNICATION NETWORK WE HAVE BEEN DISCUSSED IN SECTION *-*.

4.2.3. TERMINALS:

IN GENERAL, A DATA TERMINAL INCLUDES THREE MAJOR PARTS : THE LINE TERMINALS, THE LINE TERMINAL CONTROLLERS, THE INPUT/OUTPUT DEVICES. A DATA TERMINAL MAY OPERATE ON THE SIMPLEX PRINCIPLE, USING EITHER AN INPUT OR AN OUTPUT FUNCTION, IN WHICH CASE ONLY ONE LINE TERMINAL WOULD BE NEEDED. A TYPICAL DATA TERMINAL IS SHOWN IN FIG. 21. MOST OF THE FUNCTIONS MAY BE RECOGNIZED FROM THE DISCUSSION OF COMMUNICATION LINE TERMINALS,

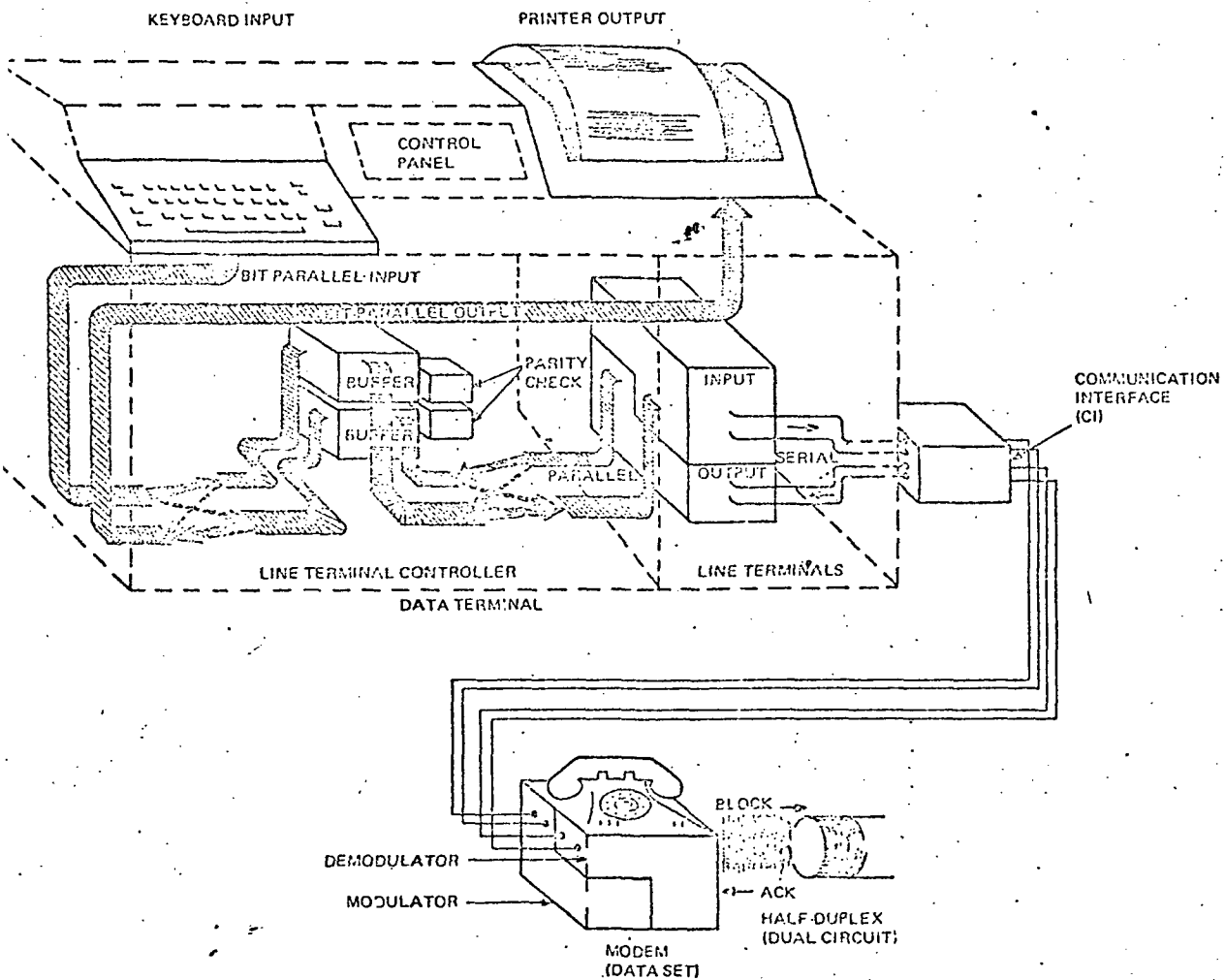


Figure 21. A Typical Remote Data Terminal (idealized)

5. TWO LEVEL VIEW OF A NETWORK OF COMPUTERS

TO LOOK BEYOND THE PREVIOUS TWO SECTIONS, NAMELY COMMUNICATION NETWORKS AND COMPUTER NETWORKS, WE COME TO THE NETWORK OF COMPUTERS, WHICH ARE COMPUTER NETWORKS CONNECTED TOGETHER. IT WOULD, PERHAPS, BE BETTER TO TALK OF A COMMUNICATION NETWORK WITH A SET OF COMPUTER NETWORKS CONNECTED TO IT.

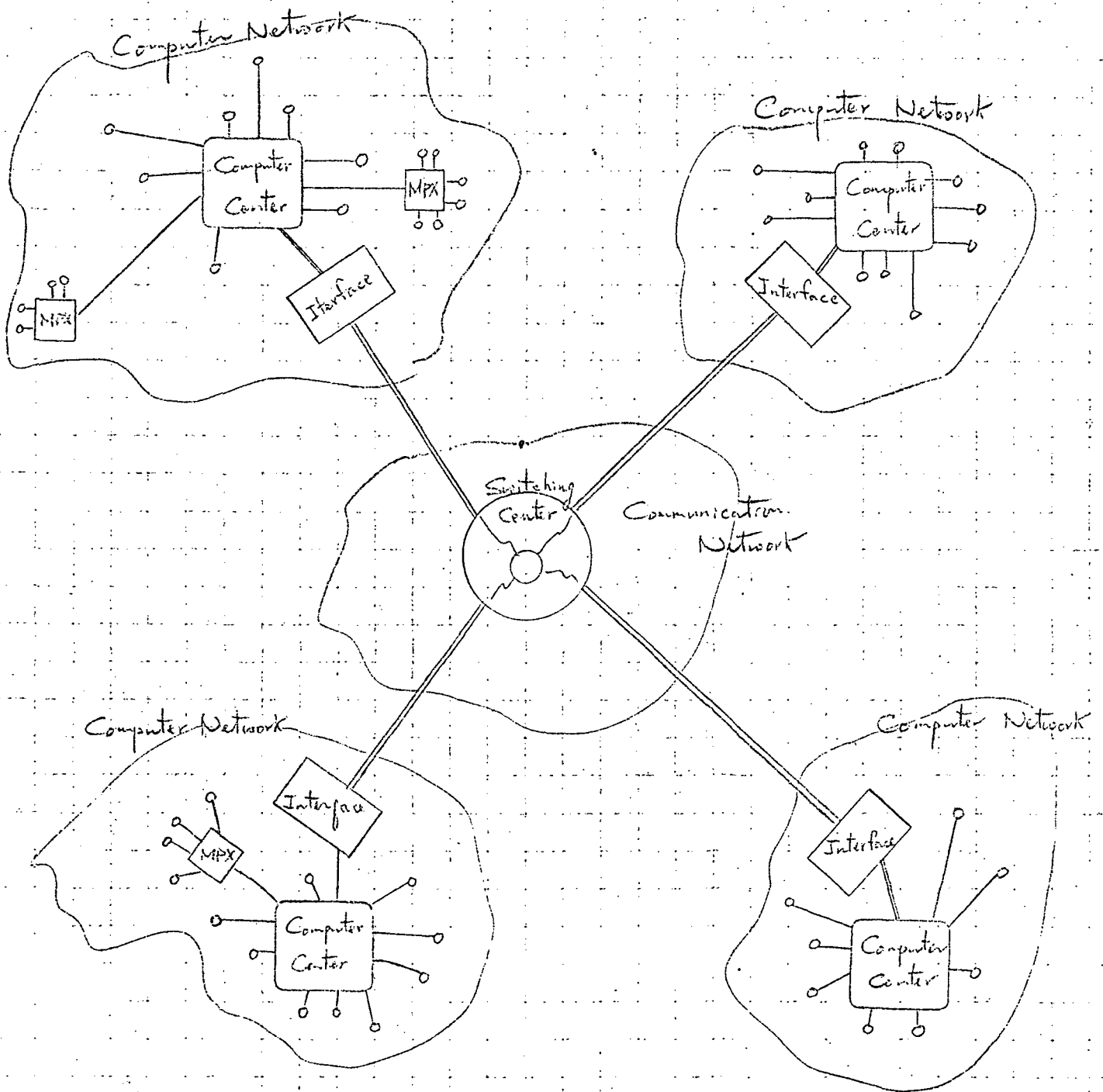
THE PAST FEW YEARS HAVE SEEN THE DEVELOPMENT OF SEVERAL NETWORKS OF COMPUTERS. MOST OF THESE ARE RELATIVELY MODEST ARRANGEMENTS FOR REASONABLY HIGH SPEED DATA LINKS BETWEEN TWO OR THREE COMPUTERS PHYSICALLY LOCATED REASONABLY CLOSELY TO ONE ANOTHER, OR BETWEEN A LARGE COMPUTER AND ONE OR MORE 'REMOTE-JOB-ENTRY' STATIONS, USUALLY SMALL COMPUTERS THEMSELVES. HOWEVER, ONE NETWORK, NOW IN THE EARLY STAGES OF ACTUAL OPERATION, IS CONSIDERABLY MORE SOPHISTICATED. THIS IS THE ARPA NETWORK. CURRENTLY THE ARPA NETWORK HAS OVER A SCORE OF NODES. PHYSICALLY DISPERSED FROM CALIFORNIA TO MASSACHUSETTS (AND SOON TO INCLUDE ENGLAND AND NORWAY). EACH NODE CONSISTS OF AN IMP (INTERFACE MESSAGE PROCESSOR) TO WHICH IS CONNECTED ONE OR MORE HOST COMPUTERS (RANGING FROM THE PDP-11S TO THE ILLIAC-IV IN SIZE); THE IMPS ARE INTER-CONNECTED VIA HIGH BANDWIDTH TELEPHONE LINES. THE DATA RATES AVAILABLE FOR DATA (STREAMS OF BITS) ARE OF THE ORDER OF 50,000 BITS PER SECOND AND THE DELAY IN ROUTING A MESSAGE BETWEEN THE SENDER AND THE RECEIVER IS MEASURED IN TENS OF

MILLISECONDS. THE COST OF SENDING DATA IS CONSIDERABLY LESS THAN A DOLLAR PER MEGABIT AND WITHIN THE NEXT YEAR OR SO THE NETWORK WILL HAVE LARGE CAPACITY STORAGE DEVICES WHICH WILL PERMIT INDEFINITE STORAGE OF INFORMATION AT A COST OF ABOUT ONE DOLLAR PER MEGABIT. ALTHOUGH THE ARPA NETWORK IS STILL IN THE ADVANCED DEVELOPMENT STAGE ITS FEASIBILITY HAS BEEN PROVED; IT IS QUITE CLEAR AT THIS POINT THAT SUCH NETWORKS ARE TECHNICALLY FEASIBLE AND THERE SEEMS NO QUESTION BUT THAT THEY WILL PLAY AN EXTREMELY IMPORTANT ROLE OVER THE NEXT DECADE.

SEVERAL BRIEF EXAMPLES OF NETWORKS ARE DESCRIBED TO PROVIDE ILLUSTRATIONS OF NETWORKS OF COMPUTERS. THE MORE INTERESTING EXAMPLES ARE STILL IN THE PLANNING STAGE; THOSE THAT EXIST CURRENTLY ARE HIGHLY SPECIALIZED.

5.1. GLOBAL OR SWITCHING ORIENTED VIEW :

AS MENTIONED ABOVE, A NETWORK OF COMPUTERS IS A COLLECTION OF COMPUTER NETWORKS CONNECTED TOGETHER BY A COMMUNICATION NETWORK (AS SHOWN IN FIG. 22). THE COMMUNICATION NETWORK CARRIES MESSAGES IN THE 'STORE AND FORWARD' MANNER. EACH MESSAGE ENTERS THE COMMUNICATION NETWORK IN A WELL-ARRANGED FORMAT REQUIRED BY THE COMMUNICATION NETWORK. THE RESPONSIBILITY FOR PUTTING MESSAGES INTO THIS FORMAT BELONGS TO A SPECIAL PURPOSE INTERFACE MESSAGE PROCESSOR. THIS INTERFACE PROCESSOR CONNECTS A COMPUTER NETWORK



MPX: Multiplexer

Fig. 22 An Example of a Network of Computers

TO THE COMMUNICATION NETWORK, AND MAKES THE COMPUTER NETWORK BEHAVE AS A NODE IN THE COMMUNICATION NETWORK. FIGURE 23 ILLUSTRATES THE FORM OF THE NETWORK OF COMPUTERS. TO THE USER OF THE NETWORK, THE STORE-AND-FORWARD NATURE OF THE NETWORK MIGHT IN SOME INSTANCES (E.G. RAPID-RESPONSE) BE HIDDEN. EACH NODE OF THE NETWORK IS OF MANY KINDS, AND IN GENERAL MAY HAVE A DIFFERENT INTERFACE PROCESSOR.

IN THIS SECTION WE PRESENT AN EXAMPLE OF A NETWORK PROGRAM WHICH IS WRITTEN ON A BLOCK STRUCTURED TYPE OF 'NETWORK JOB-CONTROL-LANGUAGE'. IN THIS EXAMPLE WE ASSUME THAT A NETWORK-RELATED SOFTWARE, CALLED NETWORK-CONTROL SUBSYSTEM (NCS), HAS BEEN IMPLEMENTED IN EACH COMPUTER CENTER. THE NCS WILL ALLOW USERS AT THE TERMINAL OF A HOST NODE TO CONNECT TO OTHER HOST NODES, AND TO APPEAR AS REGULAR TERMINAL USER OF FOREIGN HOST NODES.

A USER AT THE HOST NODE Z IS SITTING AT A TELETYPE DIALED INTO ITS HOST COMPUTER. HE WISHES TO PROCESS SOME INFORMATION ON THE HOST X AND THE HOST Y COMPUTERS. A TYPICAL DIALOGUE IS ILLUSTRATED IN FIG. 24. THE MEANING OF EACH LINE OF THE DIALOG IS DISCUSSED HERE.

- (1) THE USER SIGNS ON THE HOST Z.
- (2) A SEQUENCE OF HOST Z'S RUN COMMANDS.
- (3) THE USER STARTS UP A NETWORK JOB BY SPECIFYING THE COMMAND SIGN ON THE NETWORK CONTROL SUBSYSTEM (NCS), AND SPECIFIES ALL NECESSARY INFORMATION, SUCH AS NETWORK ACCESS,

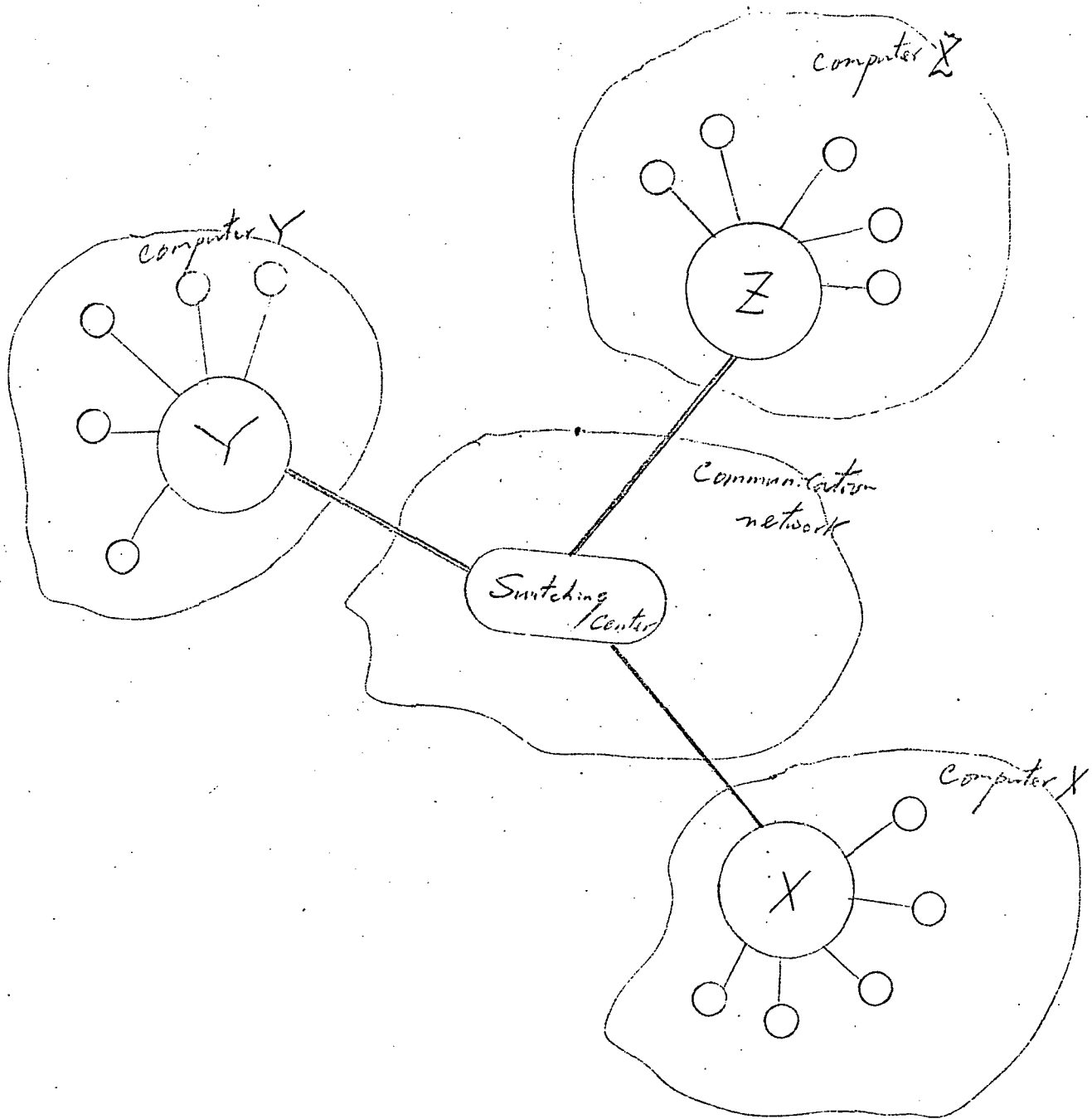


Fig. 23 An Example of a network of computers

AUTHORIZED IDENTIFICATION, BREAK KEY, ETC. A BREAK KEY IS USED TO IDENTIFY ANY MESSAGE FOLLOWING THE BREAK KEY TO BE INTERPRETED LOCALLY RATHER THAN BEING SENT ON TO THE FOREIGN HOST.

- (4) THE USER REQUESTS THE NCS TO ESTABLISH A CONNECTION TO THE HOST X. THE NCS WILL MAKE THE APPROPRIATE CONNECTION REQUEST THROUGH THE COMMUNICATION NETWORK (HIGHT LEVEL NETWORK) TO CONNECT WITH THE HOST X. THE CONNECTIONS WILL BE ESTABLISHED ONLY IF THE HOST X ACCEPTS THIS FOREIGN USER.

THE USER IS NOW IN THE PRE-LOGGED-IN STAGE FOR THE HOST X. THIS IS ANALOGOUS TO THE STANDARD TERMINAL USER'S STATE AFTER DIALING INTO A COMPUTER AND MAKING A CONNECTION BUT BEFORE THE RESPONSE BY THE COMPUTER.

- (5) THE HOST X RESPONDS TO THE USER'S REQUEST BY A STANDARD MESSAGE. FROM NOW UNTIL A BREAK KEY IS PRESSED, ALL CHARACTERS TYPED ON THE USER'S TERMINAL ARE TRANSMITTED UNALTERED THROUGH THE USER'S HOST (I.E. HOST Z), THE COMMUNICATION NETWORK, AND THEN ON THE HOST X. THE USER APPEARS AS A STANDARD TELETYPE USER OF THE HOST X COMPUTER. A SEQUENCE OF HOST X'S RUN COMMANDS CAN BE TYPED IN AS HE WISHES.
- (6) A BREAK KEY IS PRESSED. THIS WILL THEN SWITCH THE USER'S STATE BACK FROM THE HOST X'S TERMINAL-USER TO THE HOST Z'S TERMINAL-USER. THE CONNECTION BETWEEN HOST Z AND HOST X IS

RETAINED UNTIL THE NETWORK JOB IS TERMINATED OR A DISCONNECT COMMAND IS ISSUED.

- (7) THE NCS IS CALLED AGAIN TO ESTABLISH ANOTHER CONNECTION BETWEEN THE HOST Z AND THE HOST Y. THE USER IS NOW IN THE PRE-LOGGED-IN STATE OF THE HOST Y. WHEN THE CONNECTION IS ESTABLISHED, THERE WILL BE TWO VIRTUAL LINKS WHICH CONNECT HOST X AND HOST Y, RESPECTIVELY.
- (8) A RESPONSE MESSAGE FROM HOST Y INDICATES THAT THE USER IS IN THE STATE OF HOST Y'S TERMINAL-USER. CHARACTERS TYPED ON THE USER'S TERMINAL WILL BE TRANSMITTED INTO THE HOST Y JUST THE SAME AS THE STANDARD HOST Y'S TERMINAL'S DID. A SEQUENCE OF HOST Y'S RUN COMMANDS CAN THEN BE TYPED IN AND PROCESSED AT THE HOST Y.
- (9) THE HOST Y'S NCS IS CALLED BY THE USER. SIMILARLY FOR LINE (3), A BREAK KEY IS SPECIFIED AND A CONNECTION TO HOST X IS REQUESTED. NOTE THAT THIS CONNECTION MAY BE ESTABLISHED BY HOST Y THROUGH THE COMMUNICATION NETWORK TO HOST X.
- (10) THE RESPONSE MESSAGE OF HOST X IS ROUTED THROUGH THE HOST Y TO THE USER'S TERMINAL. THE USER IS SAID TO BE IN THE STATE OF HOST X'S TERMINAL-USER. THE USER CAN TYPE IN ANY HOST X COMMAND HE WANTS AND PROCESSING IS PERFORMED AT HOST X. ALTHOUGH, THE USER ENTERS THE SAME STATE AS IN LINE (5), THE MESSAGE ROUTING HAS A SIGNIFICANT DIFFERENCE. IN LINE (5), THE MESSAGES ARE ROUTED FROM HOST Z THROUGH THE VIRTUAL LINK ZX (MESSAGE SWITCHING PATH ESTABLISHED BY THE

COMMUNICATION NETWORK) TO HOST X. HERE, ALL MESSAGES ARE ROUTED THROUGH VIRTUAL LINKS ZY, AND YX, TO HOST X. NOTE THAT THE MESSAGES BETWEEN THE USER AND HOST X MAY TRAVEL A LONGER DISTANCE THAN IT DOES IN LINE (5). BUT THERE IS A VIRTUAL LINK BETWEEN HOST Y AND HOST X, WHICH ALLOWS THE INFORMATION TO MOVE AMONG THESE HOSTS X, Y, AND Z.

- (11) A BREAK KEY \$ IS PRESSED TO INDICATE THAT THE USER WANTS TO RETURN BACK TO HIS PREVIOUS STATE, NAMELY 'A_c A TERMINAL USE HOST Y'.
- (12) THIS BREAK KEY ENDS THE STATE AS A TERMINAL-USER OF HOST Y, AND ALSO RELEASES ALL CONNECTION RELATIONSHIPS WHICH WERE ESTABLISHED BY THE NCS OF THE HOST Y. AS SHOWN IN FIG. 24., THE VIRTUAL CONNECTION BETWEEN THESE THREE HOSTS IS NOW BACK TO THE CONDITION AS SHOWN IN (8). NOTE THAT THE USER BECOMES A TERMINAL-USER OF HOST Z (ITS LOCAL HOST).
- (13) THE NCS OF THE HOST Y IS CALLED AGAIN TO DISCONNECT THE VIRTUAL LINKS ZX AND ZY.
- (14) FINALLY, A BREAK KEY # TERMINATES THE NETWORK JOB. THE USER IS NOW RETURNED TO THE STATE OF THE STANDARD TERMINAL-USER OF ITS HOST. THIS ALLOWSTHE USER TO CREATE AS MANY NETWORK JOBS HE WANTS WITHIN ONE STANDARD JOB.
- (15) THE USER TERMINATES HIS JOB BY A STANDARD TERMINATION PROCEDURE.

* EACH OF THE ABOVE STATES CAN BE SUBSTITUTED BY THE ENTIRE

OPERATIONS AS DESCRIBED IN EITHER CHAPTERS 3 OR 4.

5.2. LOCAL VIEW OF A NETWORK OF COMPUTERS

A NETWORK OF COMPUTERS CAN BE DIVIDED INTO TWO GROUPS, NAMELY HIGH LEVEL COMMUNICATION NETS AND LOCAL NETS (SEE THE ILLUSTRATION IN FIG. 25). THE HIGH LEVEL COMMUNICATION NET CONSISTS OF COMMUNICATION NODES CONNECTED BY LINKS. THE LOCAL NETS, ON THE OTHER HAND, CONSIST OF COMPUTERS AND TERMINALS, WHICH ARE CONNECTED BY LINKS. BETWEEN THE HIGH LEVEL NETWORK AND THE LOCAL NETS, THERE ARE 'INTERFACES' EACH HANDLING A MIXED COLLECTION OF SUBSCRIBERS WITHIN A LOCAL NET.

(A) HIGH LEVEL NET - A COMMUNICATION NET

THE HIGH LEVEL NET CARRIES MESSAGES IN THE 'STORE-AND-FORWARD' MANNER. THESE MESSAGES HAVE A WELL-FORMED FORMAT, AN EXAMPLE OF THIS FORMAT IS SHOWN IN FIG. 26. IN ORDER TO DISTINGUISH THE FIXED FORMATED MESSAGES BETWEEN THOSE MESSAGES THAT APPEAR IN THE LOWER LEVEL NET, WE CALLED THEM 'PACKETS'. THE LENGTH OF A PACKET IS FIXED AND CAN BE EQUALLY DIVIDED INTO SEVERAL UNITS. THESE UNITS ARE SOMETIMES CALLED 'SEGMENTS'. IN GENERAL, THE FORMAT OF THE FIRST SEGMENT OF A PACKET DIFFERS FROM THE REST SINCE IT CONTAINS THE TRANSMISSION INFORMATION (CALLED 'ENVELOPE') OF THE PACKET. A TYPICAL EXAMPLE IS SHOWN IN FIG. 27. THE FIRST FIELD OF THE FIRST

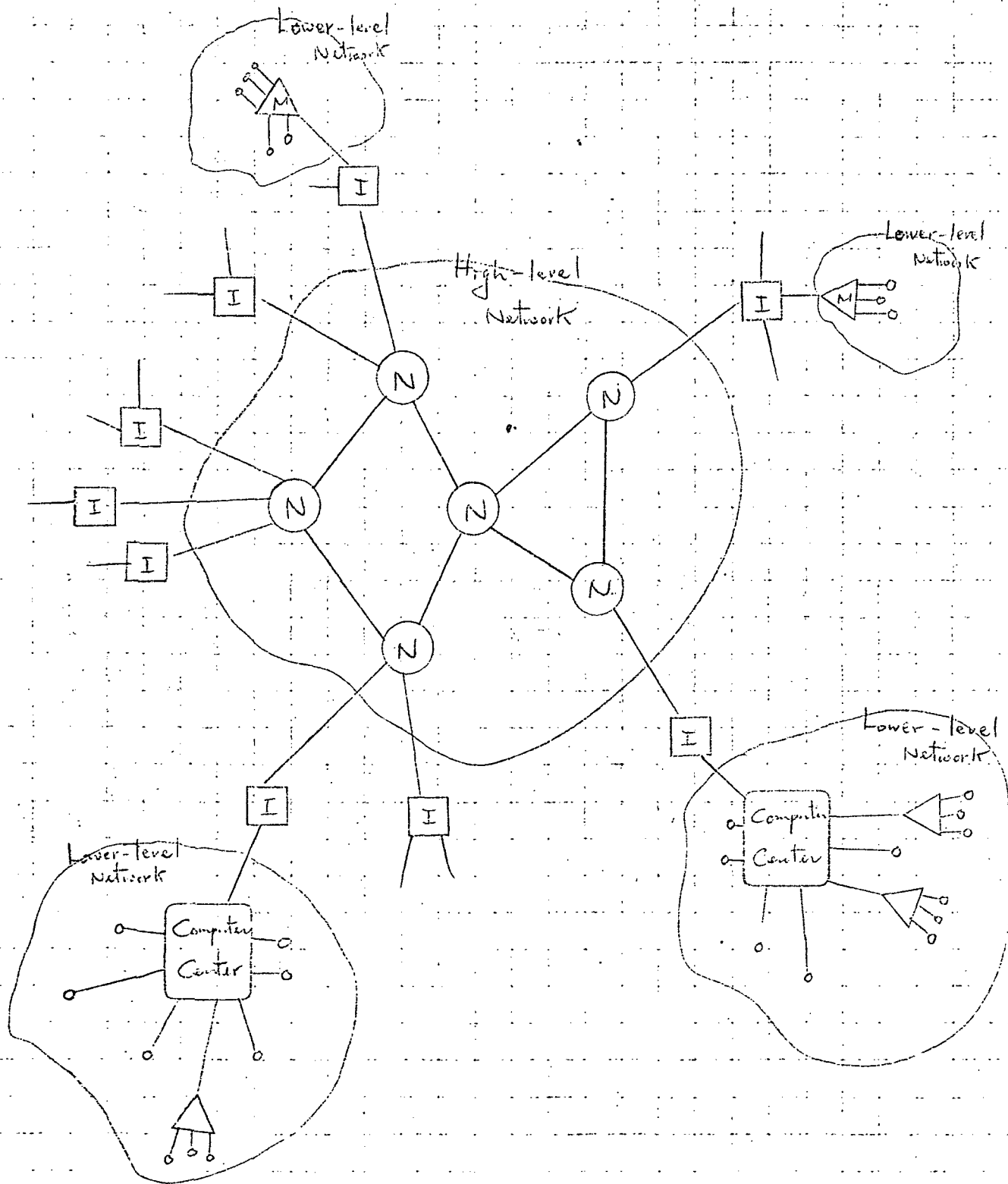


Fig. 25 Two-Level Viewed of a Network of Computers

ST	ID	DE	OR	HO	Message Text	check
Message Text						check
Message Text						
						check
end of message	blank filled					check

ST: Start of packet

ID: Indicator

DE: Destination Node

OR: Origination Node

HO: Hand over

Fig. 26 An Format of a communication Message

Start of packet	Indicator	Destination Node	Origination Node	Hand-Over	
-----------------	-----------	------------------	------------------	-----------	--

Fig. 27 A Typical Example of a Message Header

SEGMENT DISTINGUISHES STANDARD PACKETS FROM LINK MESSAGES AND SERVES TO IDENTIFY THE START OF A PACKET. THE 'INDICATOR' (2ND FIELD) IS A TAG ALLOCATED TO PACKING DURING ITS STAY IN A COMMUNICATION NODE AND REMAINS AS ITS IDENTIFICATION UNTIL THE PACKET HAS BEEN ACCEPTED BY THE NEXT COMMUNICATION NODE. IN ORDER TO MINIMIZE THE PROCESSING TIME, THE PACKET IS ALWAYS LEFT IN ITS ORIGINAL STORE LOCATION AND IS REPRESENTED IN THE QUEUING PROCESS INDICATOR. THE INDICATOR IS ALSO USED TO ACCESS THE STORAGE AREA AT OUTPUT WHEN THE CONTENTS OF THE PACKET ARE TRANSMITTED FORWARDS. FOLLOWING THE DESTINATION AND ORIGINATION ADDRESSES MAY BE A 'HANDOVER NUMBER'. WHEN A NUMBER REACHES A CERTAIN VALUE, THE PACKET WILL EITHER RETURN TO ITS ORIGINATING NODE OR DROP OUT FROM THE NETWORK. SINCE THE OUTPUT LINK TO BE USED IS DETERMINED BY EACH NODE IN TURN BY REFERENCE TO THE DESTINATION. BECAUSE OF THE ADAPTIVE ROUTING TECHNIQUE IT IS POSSIBLE UNDER HEAVY LOAD CONDITIONS THAT A PACKET MAY BE CAUSED TO CIRCLE AROUND ITS REQUIRED DESTINATION NODE. THIS 'HANDOVER NUMBER' IS INCREASED BY ONE AT EVERY NODE TO PREVENT A PACKET REMAIN IN ORBIT FOR EVER. FOLLOWING THE ABOVE INFORMATION, THE FIRST SEGMENT MAY CONTAIN SOME MESSAGE CONTENT PROVIDED THAT THERE IS SOME MORE SPACE AVAILABLE. EVERY SEGMENT IS THE LAST IN A PACKET. EVERY SEGMENT ALSO CARRIES A 'CHECK SUM' USED TO DETECT ERRORS AND NOISES.

CHARACTERISTICS OF THE COMMUNICATION NODE:

THE HARDWARE OF A COMMUNICATION NODE CONSISTS OF A GENERAL

PROPOSE COMPUTER AND SPECIAL UNITS DEALING WITH THE INPUT AND OUTPUT OF EACH LINK. THE CONTROL PROGRAMS OF A COMMUNICATION NODE HANDLE THE QUEUING AND ROUTING OF PACKETS, KEEP A CHECK ON THE STATE OF ALL NEIGHBORING NODES AND LINKS AND PERFORM ALL OTHER NECESSARY 'HOUSE KEEPING' OPERATIONS. A FIXED AREA IN ALL MANIPULATIONS ARE PERFORMED ON ITS STORAGE ADDRESS, WHICH MAY BE THE INDICATOR OF THE PACKET. IN GENERAL, THERE ARE THREE TASKS OPERATING AT A PRIORITY INTERRUPT FASHION. THE THREE TASKS ARE THE 'MAIN PROCESSOR', THE 'INPUT PROCESSOR' AND THE 'OUTPUT PROCESSOR'.

THE INPUT PROCESSOR PERFORMS THE IMMEDIATE SERVICE OF INPUT PACKETS AND SCHEDULING THE INPUT PACKETS FOR MAIN PROCESSOR. THE MAIN PROCESSOR IS THE EXECUTIVE WHICH HANDLES THE QUEUING AND ROUTING OF PACKETS. THE OUTPUT PROCESSOR SENDS THE PACKET THROUGH A FREE LINK TO OTHER NODES.

(B) THE INTERFACE:

IN PRACTICE THE COMMUNICATION NODE OF THE HIGH LEVEL NET MAY CARRY OUT SOME OF THE INTERFACING FUNCTIONS. FOR SIMPLICITY, HOWEVER, WE WILL REGARD THESE FUNCTIONS TO BE CARRIED OUT BY A SEPARATE INTERFACE NODE (OR COMPUTER). THE COMMON FUNCTIONS IT PROVIDES ARE:

- (1) DIVIDING MESSAGES INTO PACKETS AND RE-ASSEMBLING WHERE NECESSARY.
- (2) ADDING THE 'ENVELOPE' (THE FIRST SEGMENT) TO THE PACKET

IN FIXED FORMAT,

(3) ACCOUNTING,

(4) INTERPRETING COMMANDS AND MAINTAINING THE STATUS
INFORMATION FOR EACH USER.

IN ADDITION TO THESE FUNCTIONS IT CARRIES OUT THE ASSEMBLY
OF BITS OR CHARACTERS INTO MESSAGES AND THE CORRESPONDING
DISTRIBUTION OF BITS OR CHARACTERS FOR APPROPRIATE PERIPHERALS.

(C) THE LOCAL NET:

SUBSCRIBING NODES OF A LOCAL NET CAN BE DIVIDED INTO TWO
MAIN CATEGORIES:

- (1) THOSE NODES HAVING SUFFICIENT INTELLIGENCE AND COMPUTING
FACILITIES, E.G. COMPUTER CENTER.
- (2) LESS COMPLICATED NODES WHICH MAY NOT HAVE SUFFICIENT
COMPUTING CAPACITY, E.G. DATA TERMINAL, MINICOMPUTER.

THE PRIMARY CHARACTERISTICS OF THESE TWO CATEGORIES OF
NODES HAVE BEEN DISCUSSED IN THE PREVIOUS SECTIONS. FOR MORE
DETAILED INFORMATION REFER TO [].

5.3. EXAMPLES:

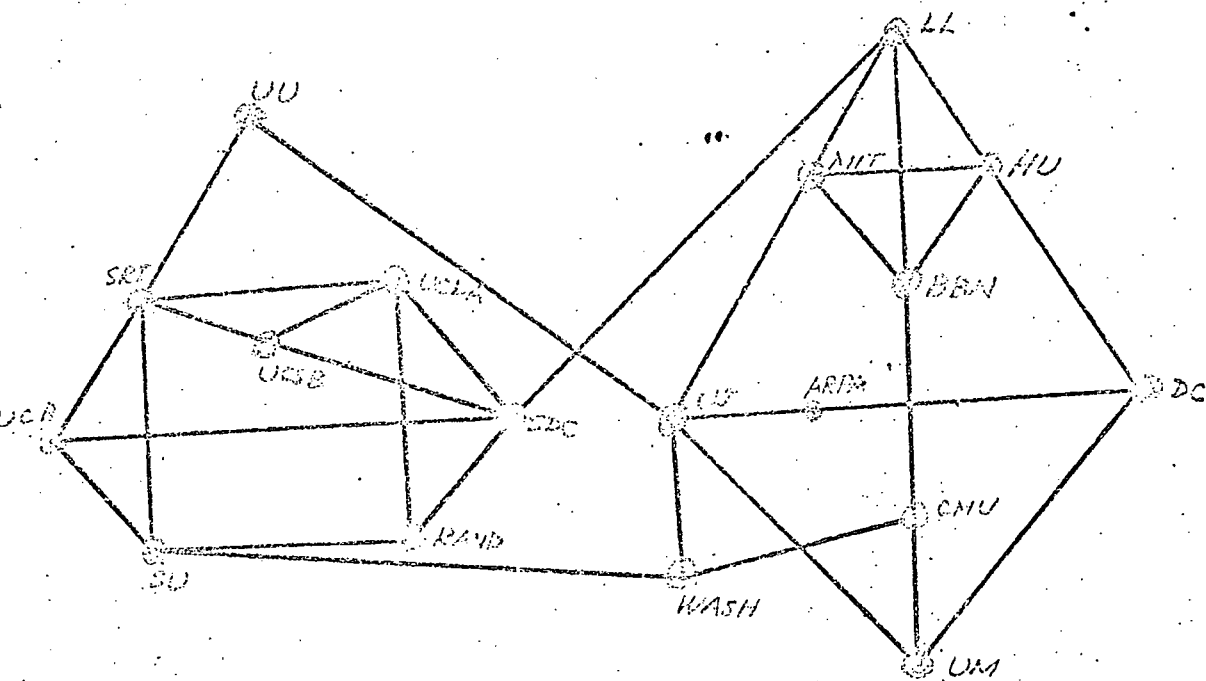
WITH THIS GENERAL VIEW OF A NETWORK OF COMPUTERS, LET US
CONSIDER SEVERAL EXAMPLES.

5.3.1. ARPA NETWORK

FIGURE 28 SHOWS AN INITIAL CONFIGURATION OF THE ARPA NETWORK.

THIS NETWORK PROVIDES STORE-AND-FORWARD COMMUNICATION PATHS BETWEEN A SET OF 19 NODES IN THE UNITED STATES. THE COMPUTERS LOCATED AT EACH OF THE NODES ARE HIGHLY INCOMPATIBLE (E.G. , S.D.S. 940, DEC PDP-10, IBM 360/67, UNIVAC 1108, GE 635, ILLIAC IV, TX-2, ETC.). THIS NETWORK IS DESIGNED TO ALLOW THESE VARIOUS HARDWARE AND SOFTWARE SYSTEMS TO COMMUNICATE AND COOPERATE WITH ONE ANOTHER. THE PRINCIPLE MOTIVATION FOR CREATING THIS NETWORK IS TO PROVIDE EACH OF THE COMPUTER RESEARCH CENTERS THOSE SPECIAL RESOURCES WHICH HAVE BEEN CREATED AT THE OTHER CENTERS. FOR EXAMPLE, THE UNIVERSITY OF ILLINOIS WILL ALLOW ACCESS TO THE EXTREMELY HIGH PARALLEL PROCESSING SPEEDS OF ITS ILLIAC IV; THE UNIVERSITY OF UTAH WILL SERVE AS A MAJOR GRAPHIC CENTER FOR PICTURE PROCESSING.

IN ORDER TO INTERFERE LEAST WITH THE EXISTING OPERATION OF THESE VARIOUS FACILITIES, THE MESSAGE HANDLING TASKS (DELAY, ACKNOWLEDGMENT, ROUTING, BUFFERING, ETC.) ARE CARRIED OUT IN A SPECIAL PURPOSE INTERFACE MESSAGE PROCESSOR ('IMP') COLLOCATED WITH THE PRINCIPLE COMPUTER (DENOTED 'HOST' COMPUTER) AT EACH OF THE COMPUTER CENTERS. THE COMMUNICATION CHANNELS WILL (IN MOST CASES) BE 50 KILOBIT/SEC FULLY DUPLEX TELEPHONE LINE, AND ONLY THE 'IMP'S (NOT THE 'HOST') WILL BE CONNECTED (THROUGH TYPE 303 DATA SETS) TO THESE LINES. THIS COMMUNICATION NET, CONSISTING OF THE



UCB : U.C. Berkeley

SRI : Stanford Research Inst.

SU : Stanford U.

UU : U. Utah

UCSB : U.C. Santa Barbara

UCLA : U.C. Los Angeles

SDC : System Development Co.

RAND : The Rand Co.

DC : Dartmouth College

UI : U. Illinois

WASH : Washington U.

(ARPA : Pentagon)

MIT : Mass Inst. of Tech.

LL : Lincoln Lab. of M.I.T.

BBN : B.B. and N.

CMU : Carnegie Mellon U.

UM : U. of Michigan

HU : Harvard U.

Fig. 28 ARPANET

LINES, 'IMP'S AND DATA SETS, SERVES AS THE STORE-AND FORWARD SYSTEM FOR THE 'HOST' COMPUTER NET. THUS, FOR TRANSMISSION BETWEEN UCLA AND UTAH UNIVERSITY(UU), THE DIRECT PATH OF STORE-ANDFORWARD TRANSMISSION WOULD PASS THROUGH THE 'UCLA HOST' TO 'UCLA IMP' TO THE 'SRI IMP' TO THE 'UU IMP' AND THEN FINALLY TO THE 'UU HOST', AS SHOWN IN THE FIG. 29. WHEN THE 'HOST' HAS A MESSAGE READY FOR TRANSMISSION, IT WILL BE BROKEN INTO A SET OF SMALLER PACKET (EACH SIZE APPROXIMATELY 1024 BITS, OR LESS) WITH APPROPRIATE HEADER INFORMATION (AS SHOWN IN FIG. 30). THE 'IMP' WILL ACCEPT UP TO EIGHT OF THESE (AN ASSEMBLY SET) AT ONE TIME. THE PACKETS THEN INDIVIDUALLY MAKE THEIR WAY THROUGH THE 'IMP' NETWORK WHERE THE APPROPRIATE ROUTING PROCEDURE DIRECTS THE TRAFFIC FLOW. FROM EACH 'IMP' TO 'IMP' PACKET TRANSMISSION, A POSITIVE ACKNOWLEDGMENT IS EXPECTED WITHIN A GIVEN TIME ; ABSENCE OF AN ACKNOWLEDGMENT (CAUSED PERHAPS BY CHANNEL NOISE, OR BY LACK OF BUFFER SPACE, ECT.) WILL FORCE THE TRANSMITTING 'IMP' TO TRY THE SAME OR SOME DIFFERENT CHANNEL FOR RETRANSMISSION. ONE OF THE DESIGN GOALS IS TO ACHIEVE A RESPONSE TIME LESS THEN 1/2 SECOND (ROUND-TRIP) FOR SHORT MESSAGES.

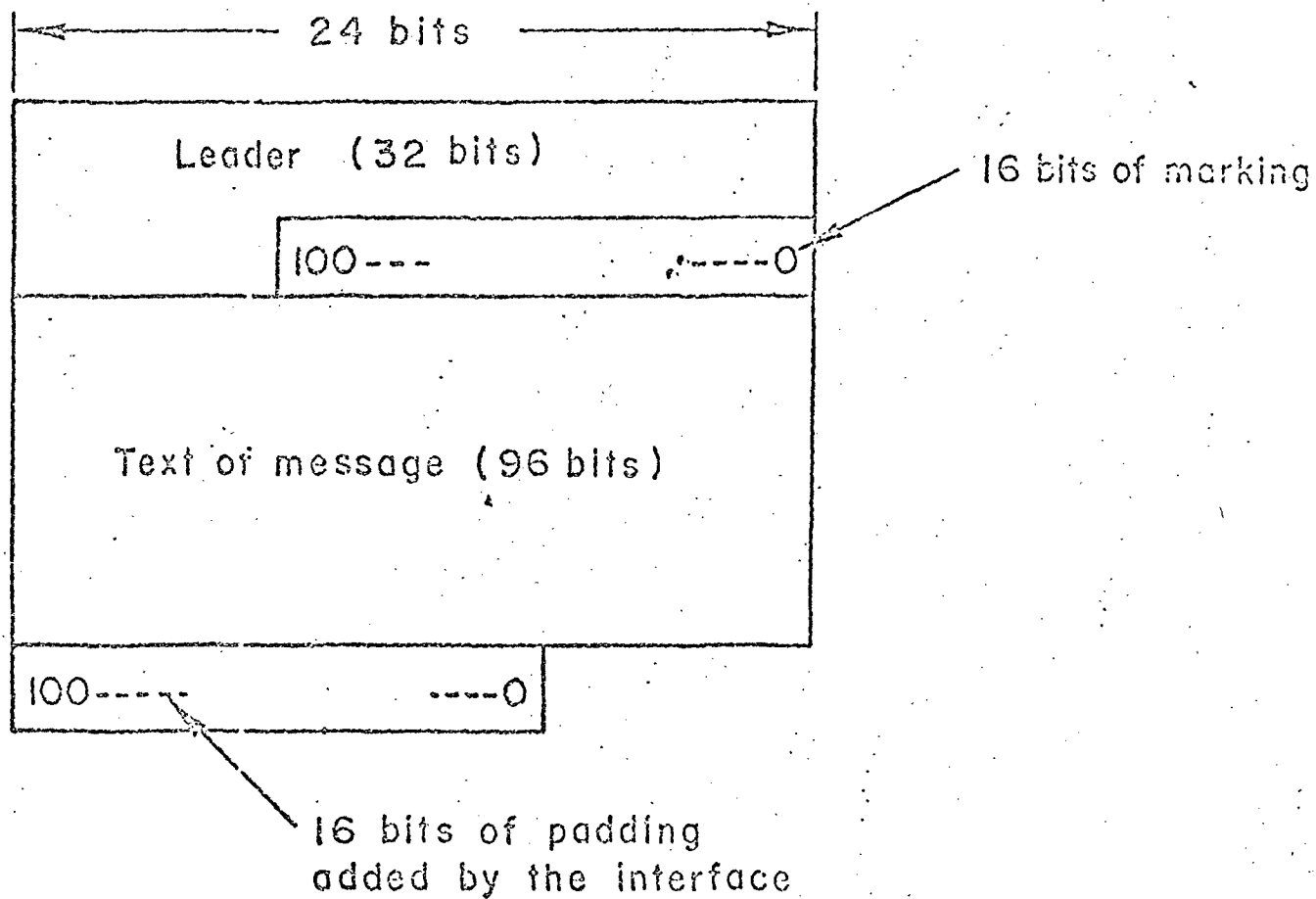


Figure 29 A typical message from a 24-bit machine

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