Interconnecting

Heterogeneous Computer Systems

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1.1 Abstract

The rise in mini and micro computers led to proliferation of computer systems. With these inexpensive computer systems each work group, and often person, could afford his own computational facility. This proliferation of computer systems also increased the need for exchange of data between computers, and the sharing of expensive resources. To address this need computer vendors produced their own proprietary computer networking capability. Examples of this are HP's DS network which pioneered distributed processing, and IBM's Binary Synchronous network, which was primarily hierarchical.

This approach worked well up to a point. It, however, had three limitations:

1) Proprietary networks did not communicate to other proprietary networks. Thus if users bought computers from more than one vendor, inter-vendor communication was difficult at best.

2) Once the network was implemented, it was expensive to rewire it as the computational need of the user changed.

3) The proprietary nature of the networks precluded incorporation of new networking technology.

To ameliorate this problem HP has adopted the International Standards Organization (ISO) Open Systems Interconnect (OSI) model which allowed customers to get the benefit from their network. In contrast IBM adopted its System Network Architecture (SNA), a closed architecture which obsoleted its older BSC network.

This paper outlines a method of designing computer networks based on the ISO OSI model. It explains the ISO model and develops criteria for selecting different hardware and software components from the model to implement an efficient, flexible, and cost effective network based on computational and data traffic needs. The paper shows how a network designed with such principles can allow heterogeneous communications, changes in topology, and upgrading to newer technologies.

1.2 Organization of Paper

This paper addesses the need for developing networks which provide the benefits stated above. Section one briefly explains the International Standard Organization Open Systems Interconnect model. Section two examines the architecture of the OSI model, and the benefits of layering in providing modularity, and expandability. In section three the advantages of using standard communication protocols are explained, and this is expanded in section four which develops a model for selecting different communications protocols. Sections five and six sum up with a case study of networking a multinational company, and a summary of the paper.

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With the advent of mini and personal computers, came lower prices and the proliferation of computers. These computers were distributed in many sites, and a need arose to connect the computers together. The International Standards Organization (ISO) developed the Open Systems Interconnect (OSI) model for connecting computers to provide four services. They are:

- Share information. Computer networks allows companies to share and distribute information over the entire company, even if the company is geographically dispersed

- High Reliability. Computer networks allow higher reliability by providing back up data and processing power. If a disc drive or processor fails others are available to allow computation.

- Load Sharing. Computer networks allow computation to occur at the site of the data, thus allowing only pertinent transactions to be transmitted, and lowering communications cost.

- Communications Network. Computer networks allow electronic mail between members of the company.

This section examines the International System Organization (ISO) Open Systems Interconnect (OSI) model for implementing computer networks which provide the above mentioned functionality. The objectives of the layered model, and the functions of each layer are explained.
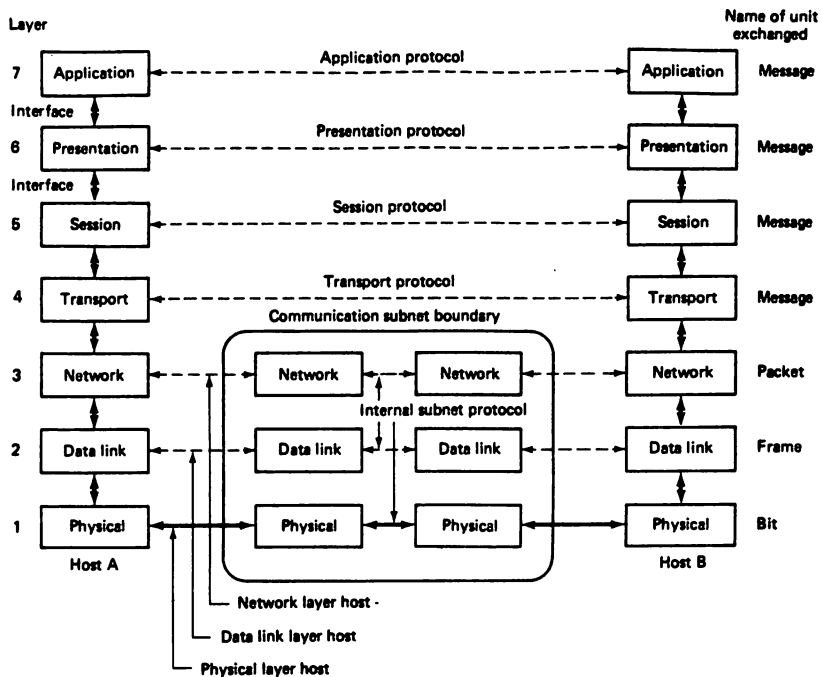
2.1 OSI Model

The ISO committee designed the OSI model in seven layers. With each layer the committee intended :

- Clearly defined layers.

- Each layer has a specific distinct task.

- Modularity in decomposing the network.

The OSI model above has seven layers. Each layer communicates with the layer above and below. The functions of the layers are:

- Layer 1: The Physical Layer. The bottom layer is the physical layer which transmits raw bits over a communications channel. The layer defines the medium, the voltage, the length of electrical signal. The layer defines mechanical, electrical, and procedural interfaces.

- Layer 2: The Data Link Layer. The data link interprets the signals transmitted on the physical link, and ensures accurate transmission and receipt of data through error correction or retransmission. For instance a noise burst can destroy data. The data link protocol requests retransmission and acknowledges the data received.

Layer							Name of unit exchanged
7	Application	Application protocol				Application	Message
Interface							
6	Presentation	Presentation protocol				Presentation	Message
Interface							
5	Session	Session protocol				Session	Message
4	Transport	Transport protocol				Transport	Message
		Communication subnet boundary					
3	Network	Network	Network			Network	Packet
		Internal subnet protocol					
2	Data link	Data link	Data link			Data link	Frame
1	Physical	Physical	Physical			Physical	Bit
	Host A					Host B	

Network layer host -

Data link layer host

Physical layer host

OSI Model

- Layer 3: The Network Layer. The network layer controls the routing of data. It accepts the data from a source converts them into packets and directs them to the right destination.

- Layer 4: The Transport Layer. The transport layer accepts data from the session layer and ensures the data arrives at the destination in the correct sequence. This is specially important in a host computer which establishes multiple sessions with other computers.

- Layer 5: The Session Layer. The session layer provides the user an interface into the network. It establishes a connection between a user on one computer with a user or service on another computer. This connection is known as the session. The session layer handles authentication, and communication protocols employed in the lower layers.

- <u>Layer 6: Presentation Layer.</u> The presentation layer presents the data transfered by the network in an understandable format. This is specially important when the two computers involved employ different internal data representations (eg 7 bit and 8 bit characters). The layers also handle data compression and encryption for speed and security.

- <u>Layer 7: The Application Layer</u> The application layer defines the topmost layer of the OSI model. This layer is defined by the users of the computers. The actual format of the layers depend on the application of the network, and the people implementing them. For instance, electronic mail may use message passing, while distributed data bases may use remote data base access, and distributed processing may use inter-process communication.

This layering allows building of modular networks, which the user can modify easily to adapt to new computational needs and technology.

Advantage of Layering

3.1 Modularity

Since the layers in the OSI model pass well defined messages to the ones above and below, the OSI model allows for modular decomposition of computer network commnunications. This modular decomposability allows for individual, or group, of layers to be replaced easily by other layers providing the same functionality of the layers replaced. This ability to replace layers makes changing of network topology, communications protocol, and technology with minimum effect to other parts of the network and the computer system. This section describes how modification of networks can be effected.

3.2 Changing Your Network

Firstly, modularity is useful in changing computer networks. For instance, suppose a user connects two computer system using point to point synchronous connection on HDLC protocol. This line communicates at 56KBPS, and adequately supports the communications need for the customer. As the users computational needs grow, he purchases another computer and connects this to one of the other computers This creates a problem since the user has to use one of his computers as an intermediate node between the other two. This puts an extra communication burden on the intermediate computer. This is further complicated because the users' communication needs increase.

To resolve this problem, the user switches from a point to point network to a 802.3 local area network. With this the user replaces the binary sychronous cable with a coaxial cable, and the HDLC protocol with the 802.3 protocol.

3.3 Expanding the Network

Let us examine the case if the customer needs to expand his network. Suppose the user wishes to add a computer to another site at a different location. The user then needs to exchange data between his current computer facility and the new computer facility. The user can designate a computer at each site to act as a communications gateway and use an dial up line to connect the two computer sites on an "as required" basis.

To connect these two sites the user adds lower level HDLC communication protocol over a twisted pair. This protocol works in conjunction with the existing upper layers or networking software, allowing the user to utilize existing network software over both the local area and the wide area network. In this manner, from the user's point of view, the local and the wide area computers reside on the same network, the only difference being the speed of the line.

3.4 Adopting New Technology

While the above examples illustrate addition, modification and substitution of the lower layers of the network, network users can modify other layer with a similar approach. The user can expand this approach to encompass new network technologies. For instance if the computer user decides to adopt a mail network based on X.400, he can simply pass messages through the existing lower six layers to implement a new mail system. Similarly if the user increases his data traffic between his remote computer sites, and a new technology, such as optical fiber, offers him a higher data throughput, he can replace his twisted pair copper line with an optical fiber line.

3.5 Advantages of Layering

Thus a layered networking protocol provides a number of advantages:.

1) Easy modification of network to suit actual data communications needs. Since the network is layered, each layer can be replaced without major impact to the other layers.

2) Easy addition to exiting network to expand coverage. Additional links or services can be added to the exiting network, thus providing more functionality when it is needed.

3) Easy incorporation of new networking technology. As new software and hardware technologies become available, they can be added to the network without losing the existing investment in the network.

4) Protection of investment. Because the network can be modified incrementally, existing investment in software and hardware need not be scrapped to either change the network, or adopt newer technology. This reduction of switching cost ensures networks can be cost effectively developed for customer needs.

International Standards

Once the user adopts the OSI layered communication protocol for networking, the user needs to decide which specific protocol to implement. Many vendors offer their own protocol; some of the vendors implement an OSI like layered communication protocol for their network. This approach allows users to connect, to a large degree, computers manufactured by the same computer vendor. However, many users apply computers manufactured by different computer vendor for different task. If the user should wish to connect these computers from multiple vendors in a homogeneous information management system, he will often find the different vendors do not provide the ability to connect to computers manufactured by another vendor. The user then is left to his own resources to pass information between these various computers.

4.1 Advantage of Standards

Adopting networking standards relieves this problem in three way, firstly, through a standard set of protocols, computers manufactured by different vendors can communicate with each other. Secondly, economies of scale ensure cheaper and more reliable networks, and thirdly, international standards tend to exist longer than single vendor protocol, and thereby offer protection to the users investment.

4.2 Mulitivendor Connectivity

Adoption of international standards for all communication provides the user with one immediate benefit – computers purchased from different vendors can communicate using the same protocol. While a vendor proprietary protocol may allow more efficient communication between some of the machines of a given vendor, communications between different vendors, and even different product lines of the same vendor (IBM series 36 and Series 38) are more difficult. Adoption of internationally agreed upon protocol standards (such as GM's MAP) allow users with more connectivity between heterogeneous computers.

4.3 Product Longevity

Another benefit of adopting standard communication protocol is that, the communication protocol tends to exist longer than a protocol supported by one vendor. This is because typically many vendors will support an international standard, and products communicating via the protocol will exist for a time longer than products supported by a single vendor. This is important from a user's financial point of view, as he can purchase communication products to supporting his existing application programs for a longer time than application products using vendor proprietary products.

4.4 Lower Cost

Because multiple vendors support international standards, products supporting these standard protocols are developed by a relatively large group of companies. This results in competition between the suppliers and a lower cost product for the user. Also, because standard communication protocols are supported by

multiple vendors, the number of products available increases, the number of units in use increases, resulting in more variety and lower cost due to economies of scale.

4.5 Tradeoff for Standards

While following a standard provides many benefits for the computer user, typically the standard lag the leading edge technology by a few years. This implies that customers needing to use the latest technology cannot be guaranteed of an international standard with the above mentioned benefits. For instance, fiber optic communication has no established protocol which looks like becoming an international standard.

Similarly, if a user wishes to provide the fastest communication between two specific systems, he may wish to bypass a standard protocol and develop a protocol which he can fine tune to provide the best performance for his specific application.

The user has to evaluate whether these advantages outweigh the benefits of standardization and low cost. In systems like real time fire control on military aircraft, the user may indeed decide a high performance proprietary protocol provides the technological edge to ensure survival of the aircraft. However, the user should realize, that developing proprietary protocol will be more expensive and more time consuming than using standard protocol. In the majority of the cases the user will opt for standard protocols.

Picking A Standard

Once the user commits to the OSI model for his computer communication, the question of what standards to use for his application arises. HP aggregates the OSI model into three layers, and picks standard based on these three layer. This makes choosing standards much simpler with three layers, and the network does not lose much flexibility.

Starting from the bottom the layers are the link, incorporating layers 1 and 2 of the OSI model, the transport, incorporating layers three and four of the OSI model, and the application incorporating layers 5 through 7 of the OSI model.

5.1 Linking the Systems

To establish the computer network, the user must first connect the two systems together. This is the link between the computer systems. It incorporates the lower two level of the OSI model. The user needs to ask himself a number of questions when deciding the type of link over which he will connect his computers.

1) Where does he plan to place his computers. The geography of his computer network determines some of the options he has for connecting his computers. If all his computers are in the same building within 1.5 KM of each other, he can use IEEE 802.3 local area network. If they are in separate nearby building he can use IEEE 802.4 broadband LAN. The user can also use point to point connections, phone switches, and X.25 based data switches for local connections. If distances are larger telephone lines, leased lines, public X.25 networks, and satellites may provide the appropriate connections.

2) What are the performance requirements of the network. In other words what applications does the user expect to run over the network. If the applications require high data transfer, LANS would be appropriate for local connection, and fiber optic and satellite for remote connection. If the user expects rapid response, a satellite connection would cause too much delay.

3) How many systems does the user intend to connect in the network. If the user intends to connect few systems, point to point connections may be the most effective method of connecting the systems. If he wishes to connect many systems, LANs, X.25 switches, and PBX switches (for local connections) may be necessary. LANs, X.25, and PBX switches allow multiple systems to coexist on the same network.

4) Price. How much is the user willing to pay for the network. The higher the performance and functionality, typically, the higher the price.

The user needs to carefully analyze his current and future data communications requirements to develop cost effective connections between his computer systems using the above mentioned guidelines.

5.2 Transporting the Data

After the user establishes a connection between his computer systems, he needs to transport his data between the systems so that the receiving computer can meaningfully interpret the data sent by the transmitting computer.

Luckily the choices here are less. The user needs to determine reliability of the link he has chosen and adopt a transport protocol which provides the most throughput. For instance an 802.3 LAN provides more reliable data than a disc drive. Unfortunately there is only one major standard available today – Transport Control Protocol/Internet Protocol (TCP/IP). TCP/IP was designed for relatively unreliable communications links, and thus provides much higher error checking and correction than is necessary with some of the modern links.

However, many vendors have adopted TCP/IP and it is key in connecting multi-vendor computer. Thus till a better standard is designed by ISO (eg TP4), TCP/IP is the transport protocol of choice.

5.3 Network Applications

After the user develops a method for transferring data reliably from one computer to another, the next task is to pick a set of applications which provide high degree of functionality. This layer covers layers 5, 6 and 7 of the OSI model. This layer provides the functionality of communicating between the computer systems. Functions provided include:

- Inter Process Communication

- Network File Transfer

- Remote Terminal Capability

- Remote Process Management

- Remote Data Base Access

- Network Management

Many implementations of the application layer offer variations of these services. This layer is offered both in vendor developed packages, and in packages based on internationally developed standards. In picking the set of protocols in this layer the user has to keep two thing is mind:

1) Are the protocol based on ISO. That is can the protocols communicate using layers 1–4 of standard international protocols such as TCP/IP X.25, 802.3 etc. If this is not true then the protocols cannot provide communications between multiple vendors. If the protocol is based on international standard, the user can either buy implementations of the protocols on different vendors or, in the case of computer vendor developed protocols, implement these protocols on machines of another vendor.

2) Do these protocols allow modular decomposition. In other works can these protocols allow applications developed on one machine to be distributed over multiple machines. Global address spaces and interprocess communication protocols allow for this expansion capability. Inter-process communication tends to be easier to implement than global address spaces. With

IPC, the user can develop his application program in modules. As the user needs more computation power, he can easily move modules to other computers on the same network, and thereby increase his computational capability by utilizing multiple processors.

A number of international protocols are being developed for different application. They include the MAP protocol for manufacturing environment, the TOP protocol for the engineering environment, and the X. 400 protocol for the electronic mail environment. In addition vendors such as HP, DEC have developed application protocols based on the OSI model.

Designing a System

The previous sections described the OSI model, the advantanges of designing a network based on this model, and some guidelines for selecting layers of these models. This section integrates the previous sections by applying the principles developed before to a hypothetical company which needs distributed computation. The section describes the company's computational needs, its geography, and then designs a network to serve the company

6.1 Company Computing Need

Let us assume we are dealing with a company named ABC. ABC designs, manufactures and sells state-of-the-art widgits. To operate efficiently ABC divides its operations into four functional area, Engineering, Manufacturing, Marketing and Sales, and Administration. Below are described the operations and computational needs of each functional area.

- Engineering. The engineering organization designs the widgits with powerful Computer Aided Design (CAD) workstations. These engineers need to share design between themselves to efficiently design the widgits. They also need access to expensive plotters and disc drives to plot and store the designs. The engineers also need input from the marketing organization for new designs. They also would like to send the designs to the manufacturing operation quickly so that designs can be manufactured and sold before the competition's widgits.

- Manufacturing. To keep costs down ABC company manufactures its widgits in a totally automated factory. The orders are received from the sales force to a materials management computer. This computer automatically plans production based on demand, and orders raw materials and manages inventory. The orders are passed on to factory floor computers which run the production process. Typically one production line is operated by multiple computers. These computers build products based on designs sent to them by the CAD computers in the engineering operation.

- Marketing and Sales. Marketing and sales are two different functions in ABC's marketing organization. The marketing organization performs traditional marketing function of merchandising, forecasting, and product management. To accomplish this efficiently ABC has provided its marketing staff with personal computers which support forecasting, data base management, word processing and graphics. The marketing staff shares common data among its staff. The sales organization was provided with portable computers. The sales force determines price quotes with these computers and enters orders to the factory by these computers.

- Administration ABC employs a relatively small administrative staff. Their main functions consists of accounting, personnel, and report generation. They use a minicomputer, and need data from all other operations on revenues, expenses, personnel, and capital outlays.

6.2 Company Geography

ABC is arranged in three groups. The Engineering organization and manufacturing organization are situated in adjacent buildings in one locations. Marketing and administration are located in another two adjacent buildings in another city, and the sales offices are spread all over the continent.

- Engineering and Manufacturing. ABC's engineering and manufacturing facilities are located in an adjacent building. The engineers each have design workstations, and share a number of high speed disk drives, printers, and plotters. The manufacturing floor is organized around production lines. Each line is controlled by computers operating a number of PLCs. The production line computers themselves are scheduled by a production planning computer.

- Marketing and Administration.. The Marketing and administration groups are situated in one building. The marketing organization is grouped into 4 to 6 man units. Each person in the unit works on PC and needs to share his information with others in his workgroup. Occasionally a person in one group needs to share information with people in other groups. The administrative organization employs a central computer to manage corporate wide data bases. The people in administrative organization use intelligent terminals to establish sessions on the computer. The computer is maintained in a central computer room.

- Sales Office. ABCs sales offices are scattered all over the continent. Each sales office has a small computer with a group of PCs. The main function of the computers is to generate quotes, log orders, and keep track of customers. The sales office receives new parts lists every week, and transmits orders every hour on an as-needed basis.

6.3 Picking The Network

Given ABC's computational needs, communications traffic, and geography, the next task is to pick the application software, the transport protocol, the connection technology. The application software is determined by the functionality required from the network, the transport is determined by performance and error recovery concerns, and link technology is determined by the geography of the systems.

6.3.1 Application Software

ABC needs to perform a number of functions over the network. In the engineering environment it needs to pass files between the engineers and access data bases remotely. In the manufacturing environment the different computers need to pass information to each other in real time to inform the other computers on process control. In the marketing organization, the PC users need terminal access to the mini computers, and file transfer capability. The sales office needs batch file transfer capability, to HQ to receive updates and send orders. All functional groups need a mail capability to pass messages. Below are a list of standard protocols and services ABC implemented on its network.

- MAP. For the manufacturing operation the protocol to follow the Manufacturing Automation Protocol (MAP) being developed. This protocol is being developed for real time computer networks on the factory floor. This provides remote terminal and file transfer capability.

- X.400. For the corporate wide mail network, X.400 is the networking protocol being developed by the CCITT for electronic mail. This packages the messages from any computer and routes it to another computer.

- Network File Transfer. This function is needed to transfer files and share information between users on different computers.

- Remote Data Base Access. This function provides access to data on remote computers.

- Virtual Terminal. This allows users of one system to initiate sessions on a remote computer.

6.3.2 Transport Protocol

The standard industry transport protocol is TCP/IP. Company ABC picks TCP/IP since this allows them the most flexibility in choosing the upper level application software, and lower level network link.

6.3.3 Link Technology

ABC needs a number of communication links. Each of these links is for a different communication need.

- Broadband LAN. The manufacturing environment needs a deterministic real time network which allows high speed communication between production line computers. for this purpose a broad band 802.4 LAN is appropriate. This LAN is extended to connect the manufacturing planning computer to the production computers. The 802.4 LAN also reaches the next building where the CAD computer reside. It connects to the engineering computer network via a gateway.

- Baseband LAN. For the engineering CAD stations a 802.3 baseband LAN provides the same high performance at a lower price than the broadband LAN. The workstations connect over this 10 MBPS LAN to each other and a dedicated server which supports high speed disc drives, printers, and plotters.

- Work Group Thin Lan. For the marketing organization, a local high speed network is necessary. The network implemented by ABC supports workgroups of four to six people. The network uses a small minicomputer which double as a file, print, and plot server. Eighty per cent of group communication is among themselves. Twenty per cent is to other group. To accomplish this ABC employs two LANs. The first is for the group. It is a thin 802.3 based 10 MBPS coaxial cable to connect the workgroup to each other. Each work group LAN in turn connects to a campus wide thick 802.3 coaxial cable. This backbone coaxial cable allows the different groups to communicate among themselves.

- PBX. The minicomputer supporting the administrative staff also connects to the backbone computer. The administrative group supports a large number of terminals. These terminals connect to the mini computer via a telephone switch. The switch allows support of a large number of terminal which all do not need to connect to the CPU at the same time.

- X.25. The sales offices around the continent are connected to head quarters via a public X.25 network. The X.25 network allows flexible configuration, and a demand based network. ABC is charged for actual data transfer between its remote computer systems.

- Point to Point Connection. The two main sites of ABC (marketing & administration and engineering & manufacturing) transmit large amounts of data to each other. For this purpose, ABC uses a direct telephone line.

Summary	SECTION
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From the study of ABC corporation we saw how a company wide network can be designed using the ISO OSI model. The different parts of the organization need different communications capability. This is done by using the layered architecture and employing a multitude networking products based on the OSI model. This allows ABC to:

- Share information between users.

- Provide higher reliability of information available.

- Share information between different computers.

- Communicate via electronic mail.

The OSI structure ensures the ABC has the capability to:

- Connect computers from multiple vendors.

- Design a flexible network with multiple technologies.

- Upgrade and modify the network easily.

- Protect ABCs investment in the computer network.

7.1 Biography

The author, Hassan Alam, has been with HP for two years. He is a network specialist for HP's international region. He has had work experience designing WANG's I/O system, and managing ROLM's military computer products. Hassan Alam holds a Bachelor's degree in computer science, a Bachelor's degree in Electrical Engineering from the Massachusetts Institute of Technology, and an MBA from Stanford University.