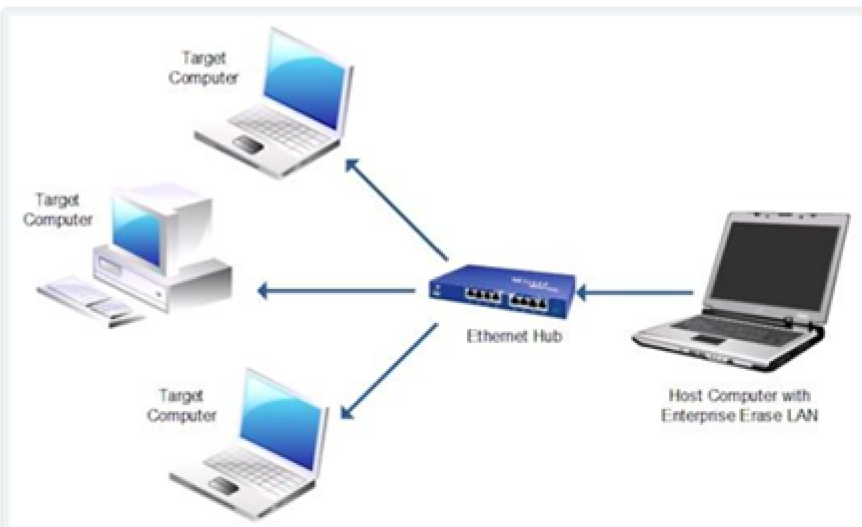
Lesson Proper for Week 3

Interconnection of Computer Networks

With the development of individual computer networks comes the need to interconnect them. Network designers are faced with the heterogeneity of networks just they were previously faced with the heterogeneity of computers within a single network. This paper shows that similar structuring techniques, namely multiplexing, switching, cascading, wrapping, and layering, can be applied and that a set of simple principles can be derived which facilitate greatly the design of the interconnection of computer networks.



These simple principles are applied to the analysis of some typical examples of network interconnection problems, in areas of addressing, routing, non-equivalent communication services, error control, flow control, and terminal access. Similar principles could be applied to some unresolved issues in computer network interconnection, such as congestion control or administrative functions. It is finally claimed that the final objective of network interconnection studies is to determine the set of international standards which are required to make network interconnection straightforward soon.

Data processing is gradually evolving from its original model to networking and distributed processing. Computers have been linked into individual networks to satisfy the needs of individual organizations. Now, networks must be interconnected to cater to inter-organizational relationships. Even though this requirement for interconnection of computer networks was identified early, it is only recently that the problem has been widely recognized. A set of simple rules can tremendously help to analyze specific interconnection problems, as well as improve the potential interconnectivity of a network through proper design choices. First question to be raised is "What is specific network interconnection, as opposed to building a single network ?".An interconnected set of networks can be considered from an external (user's) point of view and an internal (designer's) point of view. From a user's viewpoint, an interconnected set of networks is not different from a single network.

In particular, two identical networks can usually be integrated into a single bigger one. In addition, it is essential to preserve freedom in the design of future computer networks, but still, be able to interconnect them with existing ones. In other words, the question is "how to interconnect heterogeneous networks" rather than "how to build a worldwide homogeneous network".Before being faced with the constraint of interconnecting heterogeneous networks, network designers have been faced with the problem of interconnecting heterogeneous computers.

STRUCTURING TECHNIQUES

From experience, a few simple and powerful structuring techniques have merged which now form the basis of any computer network architecture, namely: multiplexing, switching, cascading, wrapping, and layering. These basic techniques are briefly reviewed in the following:

Multiplexing

In any network, many resources are concurrently shared among several users or more generally among several activities. A multiplexing mechanism will take care of distributing the resource to the various activities which need it (see figure 2-I). In simple cases the multiplexing mechanism is a local (non-distributed) activity; i.e., its decision concern only local resources and are based on the locally available information (e.g., allocation of transmission lines to packets for transmission between adjacent nodes).

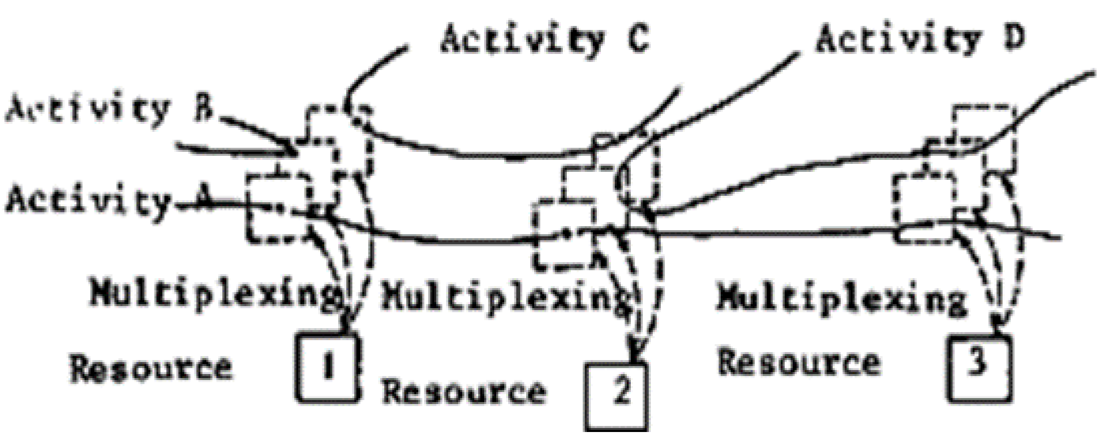


Figure 2-I : Multiplexing resources between activities

Switching

When one resource is shared among several activities, it must be able to identify which activity is concerned with its successive actions,(see figure 2-2) and possibly deduce where to forward a request for the following actions Switching implies an interpretation of addresses and routing of requests.

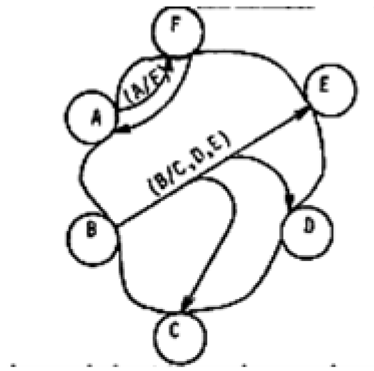


Figure 2-2 : Addressing actions

Cascading

Cascading consists of forming a linear string of entities (see figure 2-3) that forward requests along the cascade (e.g., forwarding a packet along the path between source and destination in a packet switching network). Cascading is the only way for communication between entities that are not directly connected.

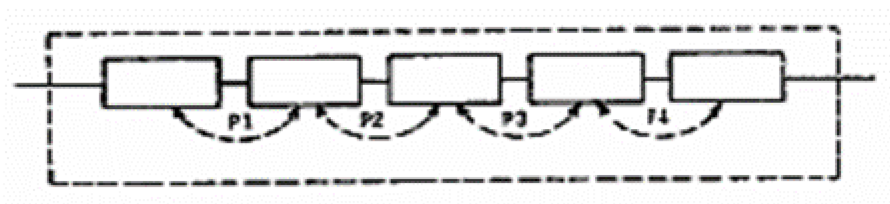


Figure 2-3 : Cascading assembly

Wrapping

When functions performed by a set of cooperating entities are not exactly those required by their users, a layer of entities can be added, wrapping the initial set (see figure 2-4). Entities in this wrapping layer communicate through the initial set and perform the additional or modified functions.

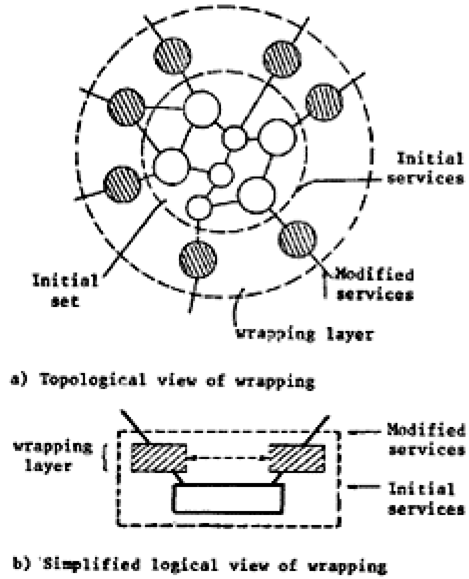
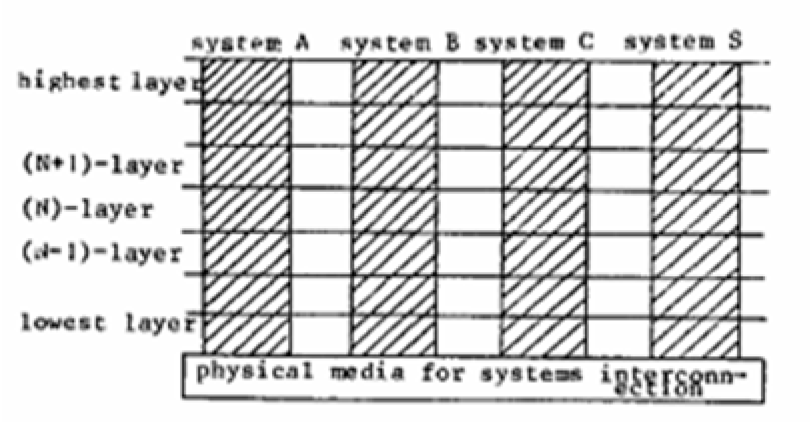


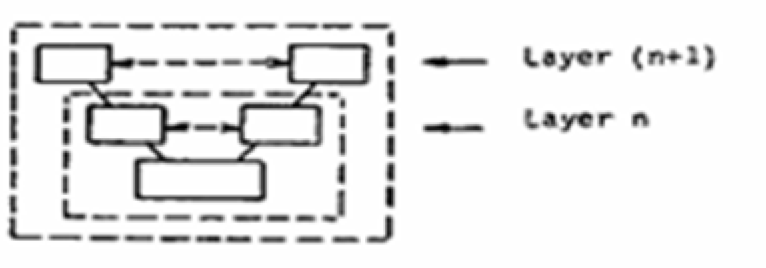
Figure 2-4 : Wrapping

Layering

Layering is the technique by which most distributed systems are logically organized (figure 2-5). Entities in the lowest layer are directly interconnected into a network and provide communication services between entities in the next higher layer. These entities, now provide services to entities in the layer above them. The layering structure expands up to the highest layer. Layering can simply be viewed as the recurrent application of wrapping.



a) A physical view of layering



b) A simplified logical view of layering

Figure 2-5:Layering assembly

Visibility

An essential concept underlying the structuring of computer networks is the concept of visibility in any part of a network. The internal functioning of a part of the network is not visible from the outside of it. This concept of restricted visibility permits heterogeneity to be reconciled with compatibility (i.e., common conventions between systems)

ARCHITECTURE PRINCIPLES FOR NETWORK INTERCONNECTION

Gateways

In general, networks are not compatible with each other and cannot be interconnected directly. Intermediate gateways are required then (see figure 3-I). A gateway function may be implemented in separate equipment connected to two or more networks, but it may also be implemented in one or several pieces as additional modules in already existing equipment. Now assume that the gateway functions are physically isolated. The resulting structure is a network of networks (global network)interconnected by gateways, as illustrated in figure 3-1.

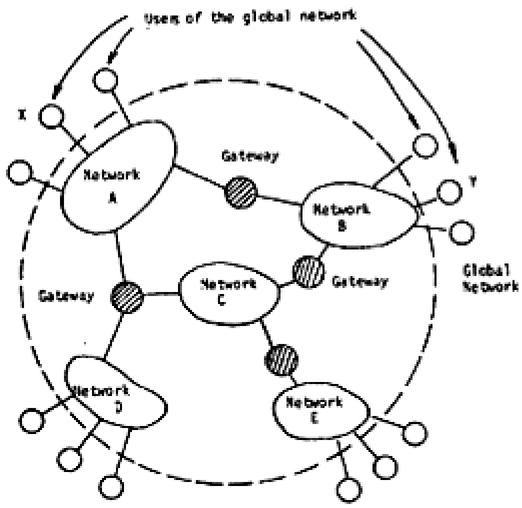


Fig.3-1 : Networks interconnected by gateways

Cascading of services by gateways

The minimum function of a gateway is to forward information from one network to another. A gateway is thus a place where individual network functions are cascaded. In this subsection, we examine some of the implications of this cascading role of a gateway on the general structure of the global network. Consider a simple example of the gateway between two networks A and B(in fig 3-I). We assume that each network has a layered structure but that both structures are not identical (see figure 3-2).

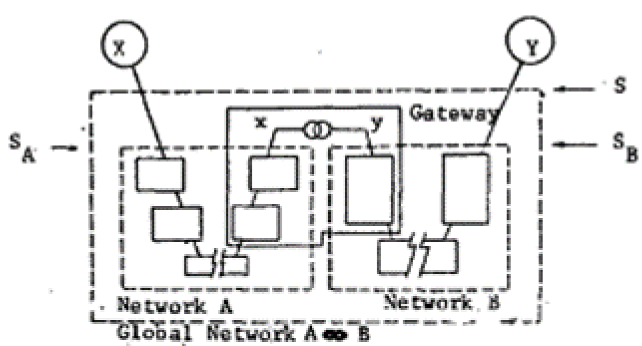


Fig. 3-2 :Cascading by Gateway

The purpose of the gateway in figure 3-2 is to present to users X and Y the concatenation of networks A and B as a single global networkA B, without intervening in the cooperation between X and Y.In order for the gateway to be able to cascade the two networks, services and cascaded by a gateway must be equivalent. Another implication is that services and must be "cascadable".To match these constraints, it is necessary to add a new layer to reach equivalent cascadable services (figure 3-3). This new layer appears only in the user equipment and in the gateway, thus wrapping (end-to-end) the original network without requiring any modification to intermediate nodes in the network.

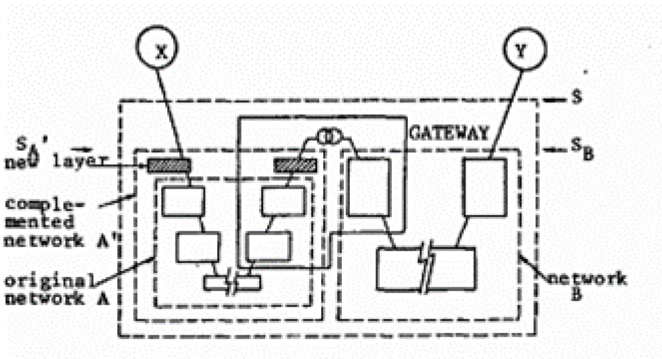


Fig. 3.3: Adapting services to be equivalent

Multiplexing of gateways

A gateway must be shared among several internetwork activities. This should be achieved by multiplexing gateway between the activities. Similarly, the interface between the gateway and each network must also be shared. There are cases where the network interface cannot be shared. Then the original network will have to be wrapped (end-to-end) in an additional layer which will provide interface multiplexing capability.

Switching by gateways

In the global network, gateways have to perform switching. If each network can interpret addresses of all users of a global network, the gateway has only to decide to which network it should forward the request. But, if an individual network can interpret only its own address space, the gateway must be prepared to decide for the local address of the final user. In this latter case, it is common practice to complement individual networks by wrapping them (end-to-end) into an additional layer that takes care of handling the global address space.

Level of interconnection

The assumption made here is that these users have common protocols which allow them to cooperate without the help of a gateway. These users may form the higher-level part of the global network - a common higher-level architecture(see figure 3-4).

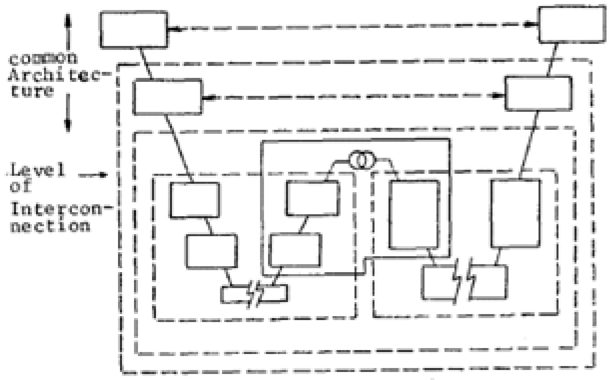


Fig 3.4 : Level of interconnection

Summary of interconnection principles

As outlined above, networks to be interconnected must exhibit levels of equivalent services, be possibly merged into a global network. If not, network(s) must be modified, usually by wrapping it (end-to-end) in an additional layer that externally exhibits the required interconnection capability. The principles above are illustrated by a series of examples in the following sections.

Addressing. and Routing

Being able to address a large population is a key aspect of network interconnection. This section is intended to illustrate how switching can be performed in such a global network. Packet network interconnection following the CATENET approach, Public Data Network interconnection, as well as the interconnection of private networks with public networks, have been chosen as examples for this illustration.

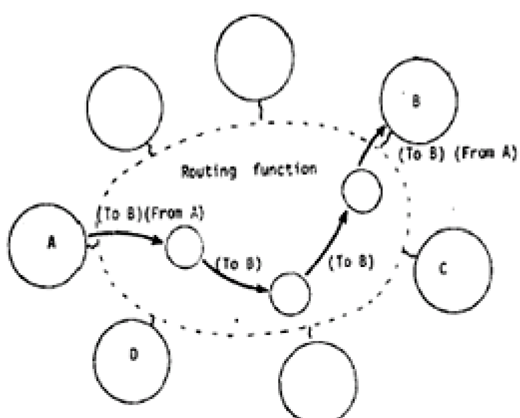


Figure 4-1 Addressing and Routing

The global network needs to provide a global address space(figure 4-3). This global address space has the first part of the global address as an individual network while the second part of the address identifies the user within that network(figure 4-2).

Network address	Local address

Figure 4-2 Hierarchical address

In the case where public networks offering virtual circuit services are interconnected using the X.75 interface, addresses cover any user connected to any public network in the world. In the case where a private network is interconnected with a public network, using the X.25 interface, the private network is provided with a single DTE address. Address extensions are required which can be performed by wrapping public networks in an additional layer of addressing covering the interconnection of public as well as private networks.

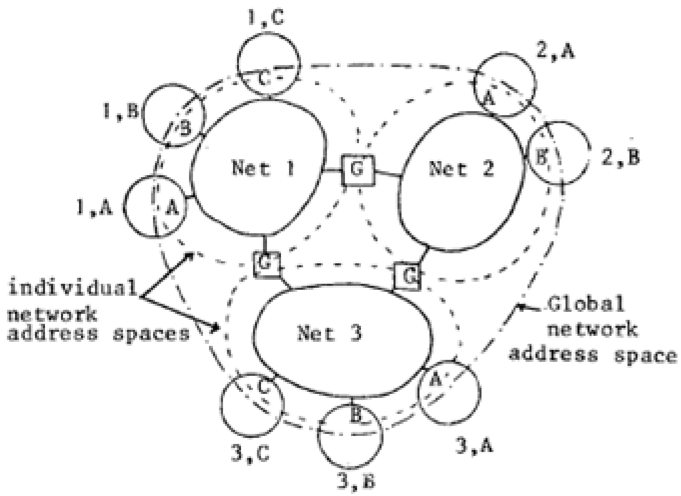


Figure 4-3 Global network addressing service

Routing functions

The global network in figure 4-3 needs to perform routing functions. In the CATANET approach, each node within each network can process both the first part of all global addresses and the second part of global addresses of its users. Routing functions within each network forward information closer to its final destination. The routing function can easily be cascaded. (figure 4-4).

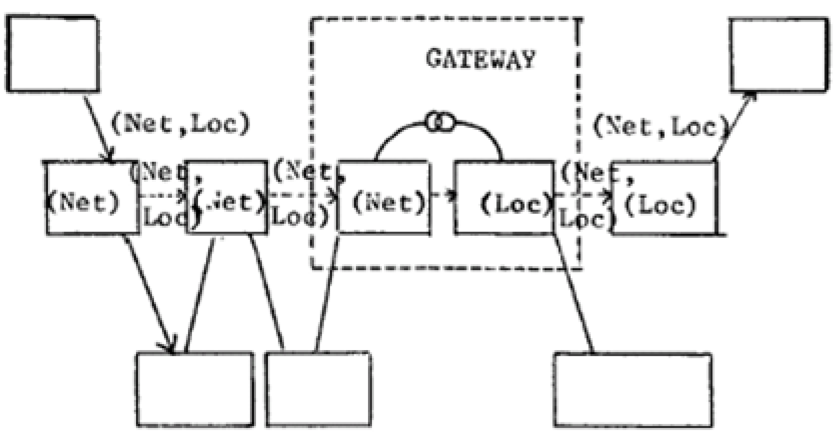


Figure 4-4 Routing in CATENET

In the interconnection of a public network, once an internetwork path has been established, it cannot be changed. In the example of figure 4-5 below, the alternate path through G2 and G3 cannot be used once G1 and G4 have been chosen.

Equivalence of services

Interconnection of networks can only be performed at a level providing equivalent services on either side. In addition, these services must be cascadable. For example, when a private network offering a datagram service is to be interconnected with a public network providing virtual circuit services, the question of choosing the appropriate level of service where the networks can be interconnected needs to be studied.

(1) One can choose to interconnect them at the level of virtual circuit services (see figure 5-l). In this case, a layer needs to be added wrapping the datagram network to perform virtual circuit functions on top of the datagram service. In practice, one access line to a public network cannot be shared by several addresses, an additional layer needs also to be provided wrapping virtual circuit functions for internetwork addressing and routing.

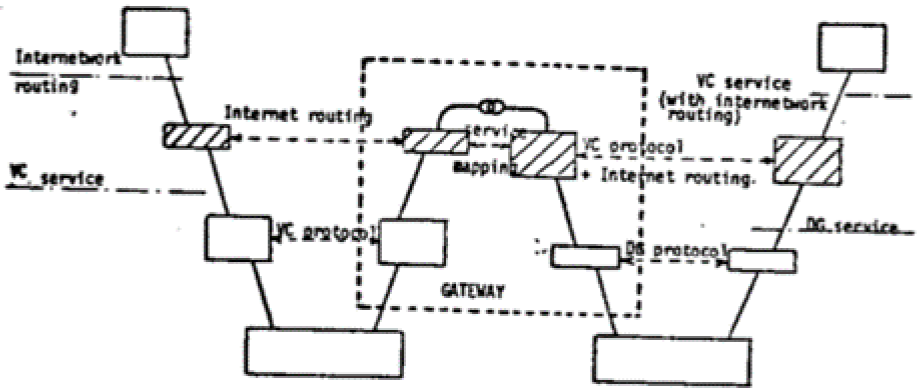


Figure 5-1 Interconnection at the VC level

(2) The other alternative is to interconnect the two networks at the level of datagram services (see figure 5-2). In this case, a layer needs to be added, wrapping the virtual circuit network to provide datagram services on top of virtual circuits

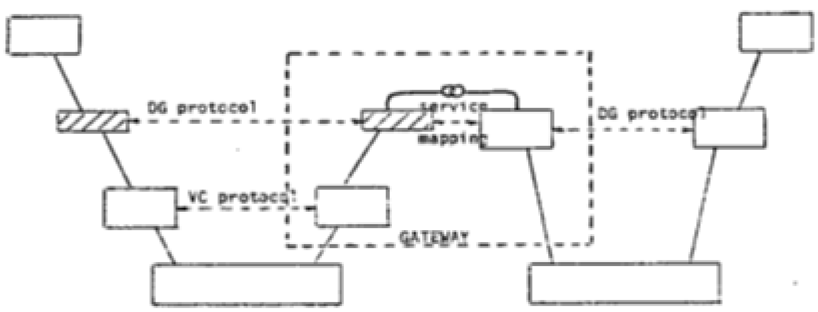


Figure 5-2 Interconnection at the DG level

Error control

Error control functions are generally based on transmitting, back to the source, control messages, referring to blocks of information transmitted from a source to a destination. Blocks are generally transmitted before previous blocks are acknowledged, to optimize available bandwidth utilization despite a possibly long round trip delay. Error control services provide two kinds of error protection. When interconnecting datagram networks, error control services can be kept unchanged for the global network (see figure 6-l).

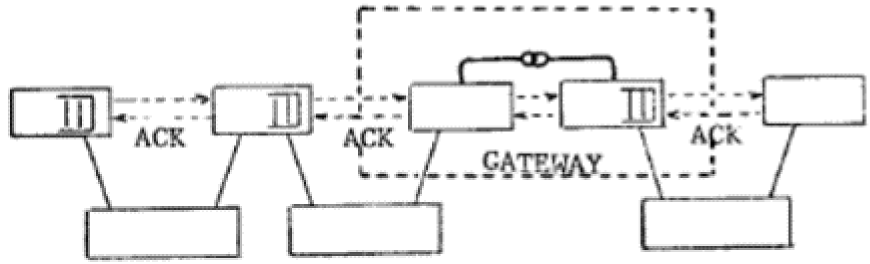


Figure 6-1 Cascade of error control

When error-control is performed end-to-end on both networks, the level of service may be preserved if the end-to-end significance of acknowledgments is also preserved. In other words, gateways must forward acknowledgments transparently (see figure 6-1).

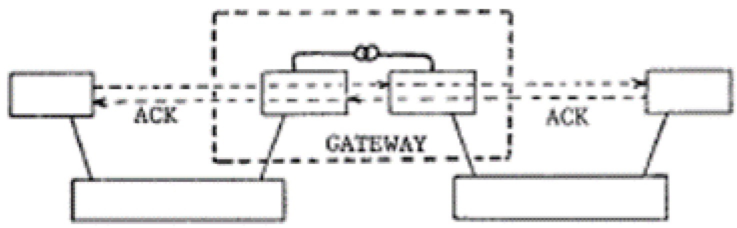


Figure 6-2 Passive gateway preserving end-to-end error control

The choice made in X.75 is to choose as a common service not to consider the end-to-end significance of acknowledgments on the network providing it. The gateways between such networks will be considered as the end-user (see figure 6-3).

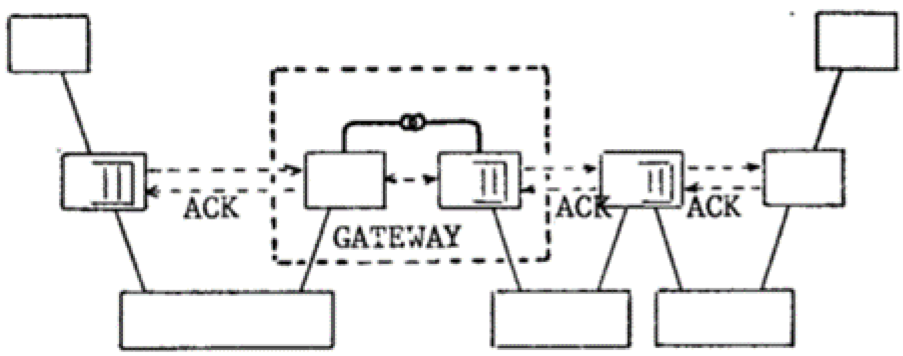
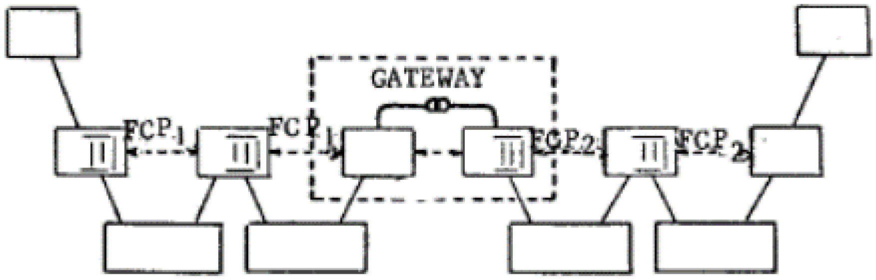


Figure 6-3 Loosing the end-to-end significange of acknowledgements

Flow control

As for error control functions, networks performing flow control in a cascade of flow control functions between adjacent nodes can easily be interconnected without modifying their properties. This is the case when interconnecting virtual circuit networks where flow control does not have end-to-end significance. (see figure 7-l).



FCP_i = Flow Control Protocol i

Figure 7-1 Cascade of Flow Control Protocols

End-to-end flow control services can be cascaded if the gateway simply translates flow control information.

Other examples and issues

The principles developed in section (3) can also be applied to other problems related to network interconnection, such as compatibilities of user interfaces and control languages. They have also been applied to adapt closed systems to an open systems environment this is, in particular, the case for congestion contro1 and administrative functions in general, such as network supervision and maintenance, diagnostics, accounting, and billing. Nowadays, the most usual way to solve these problems is to consider that the global network as such does not benefit from those functions which are handled independently within each network. This is acceptable for the initial usage of a small number of networks but would be intolerable in a few years with the expected extensive usage of myriads of networks.

Conclusion

The interconnection of computer networks is a complex problem and is largely still an open question. However, it has been solved satisfactorily in several cases, permitting partial interconnection. Experience shows that a set of simple rules can be applied to analyze network interconnection problems. Of course, these simple principles are not sufficient, and practical experience is still essential. It could reasonably be expected that the same type of techniques could be applied to the remaining network interconnection issues, but this is still to be tried. The final objective of all present studies and experiments in network interconnection should be to determine which common properties networks must exhibit to make them readily interconnectable and to establish them as international standards. Common levels of services, expandability of network addresses to global addresses, common layering structure, common protocols on top of common services are such candidates for standardization.

References:

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Fair Warning

Activities