Progress on the network layer of the OSI reference model

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ABSTRACT

Work in the International Standards Organization on communication protocols is structured in terms of the Open Systems Interconnection Reference Model. The network layer of this model provides independence of network technology, including details of routing and switching. The standardization activities involve definition of the service provided by this layer in the Open Systems Interconnection structure, the organization of functions within the layer, and the specification of protocols to support them. The structure described allows communication systems to exploit a wide range of different network types while preserving a uniform set of user facilities. The work on the network layer is of vital importance to the acceptance of the new communication standards and their early application to practical networking problems.
A. THE OSI ARCHITECTURE

Work on a general set of standards covering many aspects of data communication has been in progress within the International Standards Organization (ISO) for several years. The project is known as Open System Interconnection (OSI). An OSI reference model has been created to provide a structure for work on the protocol standards needed for interconnection of computers. The aim of this model is to encourage parallel work on different facets of the interconnection problem by placing them within a consistent architectural framework. This can be achieved by dividing the functions that need to be performed into a number of nested layers. Each layer is based on the capabilities resulting from the more basic functions in the layers below, which are said to provide a supporting service. Each layer in turn offers some more powerful set of capabilities to higher layers, which communicate by using them; these capabilities are represented as the service provided by the layer.

The functions allocated to the network layer in the reference model are primarily those involved in management of location. It is concerned with routing and switching mechanisms, and with the combination of different communication technologies. In this it can be contrasted with the layer above, the transport layer, which is independent of these considerations and provides a quality of service enhancement resulting from protocol exchanges between the single pair of entities that use the network service directly.

The basic reference model produced by ISO was concerned with communication describable by the operation of a connection. It identifies connection establishment, connection use, and connection termination. However, further work is now in progress to extend the Reference Model to include operation that does not require a connection; this so-called connectionless operation can be used to model certain existing types of networks; it has thus become of considerable practical importance in discussions of the network layer.

B. TECHNICAL OBJECTIVES OF NETWORK STANDARDIZATION

The standardization committee concerned with the network layer within ISO is Subcommittee 6 (data communication) of Technical Committee 97 (data processing). This committee cooperates closely with Subcommittee 16, which is concerned with the higher layers of the reference model, and with general architectural questions. SC6 brings together many different networking interests. There are representatives of computer manufacturers, common carriers, and computer users. They reflect interests in both local and wide-area networks, operating both in the private and in the public domain. The discussions therefore range over a wide spectrum of existing and projected network types. The unifying factor in the discussions, however, is a desire for widespread simple interoperation. The aim of OSI in general is to remove the technical impediment of unnecessary variety from the communication process. In the network layer, the emphasis is on allowing equipment attached to any type of network to communicate, via suitable intermediaries, with equipment attached to any other type of network. Particular importance is given to the interconnection of private local area networks via wide-area public networks (see Figure 1). The main thrust of the work is therefore toward unification of the user view of many different technologies.

C. TECHNOLOGICAL VARIETY

The main barrier to the simple and uniform view of communication desired is the wide range of technological solutions...
available to network constructors. Major differences that need to be resolved are

1. The difference of approach between circuit-switched and packet-switched communication. This difference in the way the communication resource is managed has wide-ranging consequences in terms of the richness of the service the user sees. As a consequence of the resource-sharing and queuing facilities included within packet-switched networks, there are user-visible control functions such as reset and interrupt mechanisms. These features do not form part of the network when a channel is dedicated to the user in a circuit-switched system.

2. The difference between connection-oriented and datagram-oriented networks. Connections provide a certain level of communication management that must be provided outside the network in the datagram case. However, the provision of connections is not without cost, and there is as yet no general agreement on a single optimum solution.

3. The variation in costing of communication. The major difference here is between private networks, charged on the basis of capital depreciation, independent of detailed use patterns, and public networks, charged on the basis of actual use. Within the public domain, different tariff structures give radically different weights to data-transmission, connection-establishment and connection-holding time. These differences all tend to be reflected in different design choices for the network protocols.

D. ADMINISTRATIVE REGIMES AND NETWORKS

One of the major problems in attempting to establish a uniform communication system is the fact that different components are likely to be managed by different organizations. The resultant division of responsibility implies a need for a careful definition of what a network is. This is not a simple matter, because the standardization of protocols turns on who caused each message to be sent and who took what action on it, not on physical groupings of equipment. For example, a PTT-operated network contains many functions. Some of them are concerned with allowing user-to-user communication; some of them are involved with value-added user-to-network communication. Conversely, some of the basic communication functions are in equipment supplied by the network user.

In consequence of this distribution of function, the term subnet has been introduced to describe the physical collection of equipment, in contrast with an OSI-Network, which bound a particular collection of functions. A subnet may provide either more or less function than the idealized OSI-Network. Any function that is not provided must be made good by the users of the subnet, in cooperation with one another. This division of function is reflected in the organization of networking standards, described in section F below.

In addition to straightforward protocol implications, the division of responsibility for communication has some more subtle implications with regard, for example, to addressing or network maintenance.

The problem of addressing is that the organizations responsible for the different elements will need to act independently in allocating addresses. It would not be acceptable, for instance, if a private network manager had to liaise with the PTT providing him or her with remote access whenever he or she wished to allocate a new address. Where the organization is hierarchical, this problem can be mitigated by the use of hierarchical addressing schemes, although problems of the unpredictable size of the address space still remain. When the organizations are autonomous peers, however, there are more severe problems, which now seem soluble only by construction of an artificial hierarchy. Other problems arise when an organization divides, when two previously independent organizations are combined, or when existing functions are relocated at a different site.

In considering network maintenance, the major issue is the allocation of responsibility for errors. The user of the network will receive error indications when unrecoverable errors occur, and may need to know which component has failed in order to apply pressure on an organization that is not providing him or her with the contracted quality of service. These issues of diagnosis raise management problems that have not yet been resolved in the standards discussions, but that do have an impact on the design of network protocols, because additional information must be passed with error reports where more than two components are involved.

E. THE NETWORK SERVICE

The general architectural approach of defining abstract services before fixing protocol detail was introduced above. The development of a network service definition is well advanced. It is proceeding by collaboration between ISO and CCITT. The two organizations have been holding meetings alternately, taking note of each other’s progress, so that the technical content of their two service descriptions is well coordinated, and the drafts are fairly stable. The major area of instability at present centers on the need for and precise definition of an expedited-data (interrupt) facility.

The network service provides for the transparent exchange of network service data units (NSDUs) between transport entities. Transport entities are unambiguously identified to other transport entities and to the network service provider by their network addresses.

The network service provides to the transport entities independence from routing and relaying considerations. This includes the case where several transmission resources are used in tandem or in parallel. It makes invisible to transport entities how the network layer uses underlying resources such as data-link connections to provide the network service.

The network service defines

1. A connection that may be established or terminated between the network service users for the purpose of exchanging data. More than one network connection may exist between the same pair of network addresses.
2. Associated with each connection, certain measures of quality that are agreed on by the network service provider and the network service users when the connection is established.

3. Means of transferring NSDUs on a connection; the transfer is transparent, in that the boundaries of NSDUs, the sequence of the NSDUs, and the contents of NSDUs are preserved unchanged by the service, and in that there are no constraints on the data values imposed by the service; the transmission of these data is subject to flow control.

4. Means by which the connection can be returned to a defined state, and the activities of the two users synchronized by use of a reset service.

5. Means for the service user to confirm receipt of data.

6. Means for the service user to send expedited data that are not subject to the normal flow control.

7. The unconditional and therefore possibly destructive termination of a network connection.

The description of the components of the network service is in terms of exchange of primitive actions, or primitives for short, between the users and the provider of the service. For example, the significant events in the establishment of a connection are described as follows:

1. The calling user issues an N-CONNECT request primitive to the service provider.

2. After a certain time, the service provider issues an N-CONNECT indication to the other service user.

3. If prepared to accept the connection, the called user issues an N-CONNECT response to the service provider.

4. Finally, after some time, the service provider issues an N-CONNECT confirm to the calling user, showing that the connection is complete.

The groups of primitives defined in the current network service definition are given in summary form in Figure 2. The use of primitives allows the simple expression of the constraints on the available sequence of actions. It does not, however, allow the direct expression of more complex communication properties, such as the existence of flow control or the properties of expedited data. To this end, the operation of the service provider is modeled in more detail by the operation of a dynamically modified queue.

This description applies to the connection-oriented service. The description of the connectionless service is not so well advanced.

However, the service is inherently simpler, in that it allocates more of the functions to the communication user. The service description can therefore be expected to progress rapidly.

Nevertheless, there are problems in the description of the properties of real networks that require the interrelation of different actions made by the service users. For example, most of the current local-area technologies can be described by a connectionless service but also have the property of maintaining the sequence of user actions. This sequencing property is of importance when one is considering user-to-user protocols, and queue-like models for expressing these properties are being studied.

F. INTERNAL ORGANIZATION OF THE NETWORK LAYER

Work has been taking place to define an internal organization for the network layer, in order to allow the interworking between different subnetwork types. The role of the subnetwork in representing the real-world networks, rather than the regimes using particular protocols, was explained in Section D. The result of this analysis of the practical constraints has been the identification of four groupings of functions:

1. The subnetwork access functions, which are associated with those protocols needed to support the direct interactions between a pair of entities using a particular subnetwork type. The operation of these functions can be described abstractly by a subnetwork service specific to the subnetwork concerned. For example, there is a service corresponding to capabilities of an X.25 network, abstractable from (and more stable under review than) the specific X.25 protocol.

2. The subnetwork-dependent convergence functions, which are the functions that, for a particular subnetwork type, are not included in the set of subnetwork access functions but are needed to convey the information required to support the OSI network service across the particular type of subnetwork.

3. The subnetwork-independent convergence functions, which are the functions that are needed to convey the information required to support the OSI network service but can be defined without reference to a particular subnetwork type.

4. The concatenation and routing functions, which are the functions needed, in addition to the subnetwork access and subnetwork-dependent and independent convergence functions, to concatenate a pair of subnetworks so as to provide the appearance of a single, uniform subnetwork. These functions correlate the activities related to the individual subnetworks and can be defined in terms of the services of the two subnetworks. They are localized functions and do not add to the protocol required.

The division of function is shown diagrammatically in Figure 3.

The distinction between subnetwork-dependent and subnetwork-independent convergence functions needs some further explanation. It arises from the wide range of technical and economic constraints applied to the network layer. An apparently simple strategy for convergence would be to set a minimum functional requirement for any subnetwork, and place almost all the functions in one standard, universal network protocol. The subnetwork-specific work to be done would then be the definition of an essentially trivial mapping of the minimum requirements onto the particular subnetwork.
Figure 2—Summary of network service primitive time sequence diagrams
service. This is the philosophy adopted by the designers of so-called internet-protocols. An alternative strategy, the so-called hop-by-hop enhancement approach, involves identifying as many parallels as possible between the subnetwork and the idealized OSI network service, and applying the minimum enhancement necessary for each subnetwork. Broadly speaking, the first approach minimizes implementation cost, while the second minimizes operational cost. In consequence of the wide range of interests to be satisfied, neither of these extreme approaches is altogether satisfactory. The division of functions into subnetwork dependent and subnetwork independent is an attempt to provide a framework allowing use of the best features of the two approaches on a case-by-case basis. It emphasizes common elements, while allowing use to be made of the strengths of the individual subnetworks when this gives rise to economic benefits.

In the long term, the existence of an agreed ISO network service will affect the activities of subnetwork providers. The evolution of X.25 and of the future ISDN services may well bring them closer to the OSI network service, so that both the convergence functions become null. On the other hand, the work on local-area network standardization is at present essentially unconstrained, and the subnetwork access function and the subnetwork-dependent convergence function are expected to be null, leaving the subnetwork-independent, internet-like protocol using a data-link-like service.

This internal organization of the network layer is still the subject of active debate, but it does seem to offer a way for progress to be made in a very heavily constrained field.

G. FUTURE WORK IN ISO

The connection-oriented and connectionless network service definitions can be expected to stabilize in the near future, and this stability will be reflected by their progress from the technical to the procedural phase of standardization, starting with their formal registration as ISO Draft Proposals.

The major activity that is only just beginning is the specification of the protocols which support the convergence functions. Distinct subnetwork-dependent convergence protocols will be needed for the major technologies. Initial work is expected to cover at least the local-area network field and the widely available PTT networks based on recommendations X.25 and X.21. The emerging ISDN standards will also need to be covered. Moreover, it is in the nature of the variety reduction that lies behind the work that it will continue for as long as new types of networks continue to develop and so need to be assimilated. The benefit of standardization will, however, be the ability for equipment from diverse suppliers to communicate easily and efficiently whenever desired.

REFERENCES