IDENTIFICATION IN COMPUTER NETWORKS*

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ABSTRACT

To communicate across a network system, entities within the system need to be able to identify one another. An identifier usually takes the form of a name or an address. Conventions for the assignment of these identifiers and their resolution affect many aspects of network design. Identification is thus a crucial issue for network architecture and standardization. In this paper, our discussion is first devoted to the semantics of names, addresses, and routes, with emphasis on the relationships among them. We then examine the implications of layered network architecture, syntactic differences of identifiers, and broadcast communication. Finally, we turn our attention to naming and addressing in large dynamic networks.

I. INTRODUCTION

To communicate across a network system, entities within a system need to identify one another. An identifier usually takes the form of a name or an address. Conventions for the assignment of these identifiers and their resolution affect many aspects of network design. Network interconnection, dynamic reconfiguration and large networks have a profound impact on naming and addressing. Identification has become a crucial issue for network architecture [Oppen81, Clark82, Mills81, Su82] and for network standardization [CCITT82, NBS82]. It has

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been the subject of discussion in many recent works [Cerf78, Shoch78, Sunshine82].

Shoch [Shoch78] has given informal definitions of a name, an address, and a route:

The name indicates WHAT we seek,
the address WHERE it is, and
the route HOW TO GET THERE.

These definitions are useful for differentiating the concepts. However, confusion persists. One of the possible reasons for this confusion appears to be the ambiguity of their semantic relationships. In this paper, we first present the semantics of names, addresses, and routes, with emphasis on the relationships among them. To further elaborate, we examine the implications of layered architecture, syntactic differences of identifiers, and broadcast communication. Finally, we turn our attention to naming and addressing in large dynamic networks.

II. THE SEMANTICS OF NAMES AND ADDRESSES

In networking, names are identifiers used for distinguishing entities from one another. In order to distinguish network entities, it is necessary that names be unique. To help identifying a network entity, a name often incorporates structured information that specifies characterizing attributes of the entity. Such attributes, at the user level for example, may be administrative, geographical, or network topology dependent. However, naming can be accomplished without incorporating any attribute. To illustrate, we borrow the example of U.S. Social Security Number. It is used for resident identification without incorporating characterizing attributes.

One class of characterizing attributes useful for identification specifies the location of an entity. Thus, we may conclude that addresses are names which incorporate location attributes, but a name may or may not be an address. A corollary to our observation is that an identifier that does not incorporate any characterizing attribute can only be a name. When a specific reference is necessary, we will refer to a name that is not an address as address-independent, and to one that is an address as address-dependent.

For location specification, the characterizing attributes must be defined with respect to a frame of reference, or a "space". Borrowing from mathematical concepts, one may consider location specification to be necessarily functionally related to a metric defined on that space. An address then specifies the location of a "point" in this space. A postal address, for example, specifies a geographic location. One may consider longitude and latitude to be metrics of the geographic address space. Political jurisdiction can be used for postal addressing because it is functionally related to the geographic space. For computer communications, it may not make much sense to address a host by its geographic location, since its geographic location is not necessarily functionally related to the address space for networking. The address space in this case may be defined by the set of network components and the connection relations among them. An address of a host, for example, should specify "where" in the networking system the host is located.

Paralleling Shoch's definitions for a name, an address, and a route, we may further observe that a route characterizes the location of the destination entity by indicating a path for reaching it. Since a route specifies the location it leads to, we may similarly conclude that a route is an address, while an address may or may not be a route. A source route, for example, can be considered an address.

III. LAYERED NETWORK ARCHITECTURE

For modularity, a layered approach is often adopted for network architecture [ISO82, Cerf82]. Taking such an approach, the network functions are partitioned into protocol layers. Each layer depends upon lower layer functions and provides services to its upper layers. Naming and addressing are crucial components of each protocol layer. The communicating entities within a layer refer to each other by name. The set of communicating entities at a lower

layer may form the basis for the address space of the layer above it. The address of an upper layer entity is often defined as the location of an entity within the lower layer with which the upper layer entity is associated. While an address defines the location of a "point" in the address space, a route can be thought of as defining a "line" leading from the originator to the destination in that space.

An identification space, however, need not necessarily coincide with a protocol layer. It is sometimes found advantageous in network design to introduce an extra identification layer. Such an extra layer may provide additional indirection. An indirection is the flexibility in binding between entities belonging to two different spaces. Logical addressing [Rosen81] is an example of an extra identification layer. It provides the advantages of a fixed-length numeric identifier without completing the binding to a network entity.

IV. SYNTACTIC DIFFERENCES OF IDENTIFIERS

Specifying conventions for network entity identification is an important aspect of network system design. An identifier may, for example, be in the form of a character or a numeric string of fixed or variable length. In existing computer networks, an identifier often takes one of two forms: a variable-length character string or a fixed-length numeric string.

A character string offers user-friendliness. Natural language terms meaningful to human users may be readily incorporated in a character string. Variable-length identification offers the possible accommodation of an arbitrary number of different identifiers. It is also useful for accommodating variation in identification. Communication between entities in two different systems can be accommodated, for example, by employing a common and variable-length addressing scheme. The Xerox internet address is 48 bits long, while the DARPA internet address is 32 bits. Without imposing the identification of one system on the other, one possible scheme to accommodate such a difference, at least in theory, is to employ variable-length addressing concatenating the internet address with a prefix for internet indication. Source routing as a form of addressing [Sunshine77] is another example of a situation in which variable-length identification comes in handy. For a hierarchical identification scheme, a variable-length address may also allow depth variation in the hierarchy. A proposed

convention for DARPA internet domain naming [Su82] is an example of a hierarchical identification scheme allowing depth variation. The disadvantage of variable-length identification is the inefficiency that results from its excessive processing requirements. However, with the continuing increase in processing speed, variable-length identification may become more and more attractive.

Fixed-length identification imposes a finite limit on the number of different identifiers. This limit is a function of the fixed length and the size of the encoding set (e.g., 16-bit identification provides 2^{16} , approximately 64,000, different identifiers). Although the limit is usually large enough for practical purposes, it could be significantly reduced when structured information is incorporated. One advantage of fixed-length identifier is that it can be conveniently embedded in a protocol header to allow efficient processing. The 32-bit DARPA internet addressing [Postel81] offers an example of ingenious incorporation of variable-length identification in a fixed-length format.

The difference between a fixed-length numeric string and a variable-length character string is syntactic, while the difference between a name and an address is semantic. The association of names with variable-length character strings and of addresses with fixed-length numerics often leads to the assumption that such an association is required. However, this is not the case. For example, "mbxA@hostB.netC", a variable-length character string, can semantically be an address specifying the location of a mailbox "mbxA" on host "hostB" that is connected to network "netC".

Name to address resolution is a binding process. When a name is resolved, it is mapped onto one or more specific addresses. The convention for naming affects when this binding takes place. The later the binding the more flexibility there is for the name-to-address mapping relation. Address-independent naming offers the flexibility of an indirection. A change of address can be accommodated by accordingly changing the mapping relation without affecting the identities of the communicating entities. Address-dependent naming offers little indirection. The relocation of a communicating entity from one network address to another may imply a change of its identity. However, the use of address-dependent names for identification allows efficient resolution. Resolution for an address-dependent name may involve only a syntactic translation, e.g., a translation from character strings to numeric ones. In the extreme case, when the same identifier is used for both the name and the address, the resolution process can be avoided all together. A proper choice of naming convention depends largely on the networking

environment. It can, however, have a significant impact on the system design.

V. BROADCAST COMMUNICATION

Computer networks initially evolved on the basis of point-to-point communication. This was true at both network and link levels, (e.g. ARPANET). In order to reach a destination in point-to-point communication, the originating entity resolves the destination name into a route, sometimes via an address. The route might be explicitly a source route or implicitly an incremental route. Transmission from an originator proceeds along a single link at a time, propagating toward the destination. Addresses and routes are in particular useful for point-to-point communication.

Broadcasting offers an address-independent mode of communication for computer networking. Broadcast transmission in a local networking environment (e.g., ETHERNET [Metcalfe76]) is an example of broadcast communication at the link level. To broadcast, the originator transmits to all entities attached to the network. Often found in practice is a combination of point-to-point communication at a higher level and broadcasting at a lower level. In order to communicate with a specific destination (i.e., point-to-point at the higher level), the originator incorporates a higher level identifier in the transmission, specifying the intended destination. The communication is established with the destination recognizing its identity, i.e., its name not its address.

By the nature of broadcast communication, every transmission from each participant in a communicating community would be received by all others. Without improvements in the technology, the resulting overhead of broadcasting communication may render its application over a large communicating community impractical. However, its address-independent mode of operation potentially provides solutions for the accommodation of multi-homing, multi-casting, and network dynamics [Dalal81].

VI. LARGE DYNAMIC NETWORKS

In this discussion, a large network system refers to a network or an internetwork with a large number of network entities. A critical concern for large networks is to locate the destination. Address-dependent naming can be very useful in that an address-dependent name incorporates at least some hint of where the destination is located. The telephone system is an example of a large network employing address-dependent naming. The telephone number a user of the network uses to identify the destination he is trying to reach is an address-dependent name, or an address. By area code and the prefix for local office, it describes where is the destination within the telephone system.

Networks that are capable of changing dynamically impose challenging requirements for network design. A dynamic networking environment may involve network partitioning, network merging, or mobile network entities [Cerf79]. The principle challenge arises from the fact that the location, and thus the address, of a network entity can change dynamically. In the case of a mobile network entity, its physical movement could cause a change of location with respect to a presumably stationary network environment. This environment constitutes the address space. In the case of network partitioning or merging, the address space itself changes. Such change may in turn affect the "location" of certain network entities relative to the network system.

In a dynamic networking environment, address-dependent naming may not be desirable. Any change of address would imply a change of identity. For connection-oriented communication, such as communication over virtual circuits, the connection established based upon identities of the source and destination could not be maintained. Using address-independent naming requires name resolution or broadcast communication. However, either approach can lead to inefficiency when a large communicating community is involved. Naming and addressing in large dynamic network systems remains an area for further investigation.

VII. SUMMARY

In this paper we discussed the semantics of a name, an address, and a route in computer networks and the relationships among them. An address may be a name, and a route may be an address, but their respective converses are not necessarily true. A rigid association of names with variable-length character strings and of addresses with numerics can lead to unnecessary confusion. The difference between a name and an address is semantic, not syntactic.

We observe that specification of naming and addressing conventions is a crucial aspect of the design of each protocol layer. Extra identification layers may be introduced for additional indirection. We also observed that broadcasting offers an address-independent mode of communication, which can be useful for the accommodation of some advanced communication requirements. Addressing and routing are in particular useful for point-to-point communication.

Finally, we pointed out that the underlying design issue for dynamic network systems is to accommodate the continual change of addresses. Architecture for large dynamic network systems remains a challenging area for further research.

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