Evolution of Routing and Capacity Management in International Switched Networks

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A great challenge for telecommunications providers is to translate revolutionary advances in switching, transmission, and signaling technologies into advanced network services, failure transparency, high transmission quality, and affordable prices. The companies and government agencies that provide international telecommunications services face diverse expectations from their customers, differences in regulatory environments, and a multitude of equipment choices. Hence, a service provider's globalization strategy will become a key to its overall success. Substantial disparities exist among providers in the development of their national telecommunications infrastructures and in their political, economic, and regulatory environments. Therefore, distinct network-evolution strategies will emerge for each such service provider. This paper surveys a variety of possible evolution strategies for an international network and their effect on network design.

Introduction

Today, the private or government entities that provide international switched and private-line services are faced with rapidly changing technologies, diverse customer expectations around the world, different regulatory environments, and many equipment choices. The challenge for these carriers, then, is to translate advances in switching, transmission, and signaling into advanced network services, transparency to network failures, high-quality transmission, and affordable prices. Clearly, a globalization strategy is one key to a carrier's overall success.

Because national telecommunications infrastructures develop at different rates and because local political, economic, and regulatory environments also influence this development, each telecommunications network may require a distinct evolution strategy. (The *infrastructure* includes such things as copper and fiber-optic cables, analog and digital switches and cross-connects, as well as other network elements. The operations support systems that control these elements might also be included.) This paper will examine several possible evolution schemes for developing an international network and the effect of these schemes on network design.

We characterize the design of an international network in terms of five fundamental dimensions: partnering, service, data collection, routing, and facilities. The ***partnering dimension*** reflects who is responsible for all network-design decisions. This dimension is unique to the international network and governs the entire network-design process. The ***services dimension*** provides the building blocks to offer various international telecommunications services. The ***data-collection dimension*** estimates the size of the demand in the network, while the ***routing dimension*** assigns the demand to logical routes between switches. The ***facilities dimension*** provides the physical capacity to carry the demand on cable and satellite facilities between international carriers. (*Logical route* refers to the trunk group between a pair of gateway switches in the two countries involved in an international call. Usually, international calls for all countries are routed through the originating country's national network to a small number of the network's switches, called *gateways*, and then through an international network to the foreign country's gateway.)

This paper discusses the possible

Panel 1. Abbreviations, Acronyms, and Terms

busy hour — the hour of the day when a telecommunications switch carries the most traffic

busy day — the day of the week (or month) when a telecommunications switch carries the most traffic

CCITT — International Telegraph and Telephone Consultative Committee

data-collection dimension — estimates the size of the demand in the network

DCME — digital circuit multiplication equipment

DXC — digital cross-connect

facilities dimension — provides the physical capacity to carry the demand on cable and satellite facilities between international carriers

final-trunk group — for a hierarchical network, the last choice of trunk group for a call to reach its destination

gateway — one of several domestic-network switches where all international circuits terminate

gateway approach — the country is partitioned into several regions, and all traffic from a region in that country to a foreign country is first routed to a specified gateway

global routing — routes are chosen wherever they are available, as if all routes were under the control of a single organization

GMT — Greenwich mean time

hierarchical routing — progressive call control (control moves from switch to switch) and a routing discipline that specifies a fixed order of trunk-group selection at each switch and does not allow mutual overflow

high-usage groups — trunk groups subtending to the final-trunk group. The final-trunk group is the alternate choice of many high-usage groups.

IEICE — Institute of Electronics, Information and Communication Engineers

IEEE — Institute of Electrical and Electronics Engineers

ISDN — Integrated Services Digital Network

ITC — International Teletraffic Congress

noncoincidence — the event when the heaviest load (either busy hour or busy season, or both) occurs at a different time on different facilities

nonhierarchical routing — routing that violates the requirements for hierarchical routing, usually by retaining call control at the originating switch, by allowing the routing to vary based on time of day or day of week, or by allowing mutual overflow between trunk groups

ORSA — Operations Research Society of America

partnering dimension — reflects who is responsible for all network-design decisions. This dimension is unique to international networks and governs the entire network-design process.

routing dimension — assigns the demand to logical routes between switches

services dimension — provides the building blocks to offer various international telecommunications services

SIG — special interest group

SIRCIT — System for International Routing of Circuits Integrated Tool

TA — telecommunications administration

transit routing — some calls are routed through facilities that belong to a third carrier and a transit fee is paid to that carrier

evolutionary strategies for the carriers, emphasizing network design for switched services. Network design spans the partnering, data-collection, routing, and facilities dimensions. First, we describe each dimension and present possible variations for it. Then, from this menu of choices for each dimension, we define sets of likely design strategies that have been under discussion in the recent telecommunications literature. For each evolution strategy, the paper describes the organizational and technical requirements, and the network performance benefits. (Panel 1 defines acronyms and terms used in this paper.)

Dimensions of the Network-Design Process

This section describes the fundamental dimensions that are relevant to network design. For each dimension, we present the possible variations and their effect on the network-design and planning processes.

Partnering. Partnering represents the administrative process by which decisions are made for network design and evolution. Typically, overseas cable and satellite capacity is owned and managed jointly by at least two carriers. Therefore, the total international network is a union of the many bilateral and multilateral subnetworks, where each decision requires the collaboration of at least two carriers.

Bilateral partnering. The smallest and most common partnering arrangement is a carrier pair. In this arrangement, each carrier in the pair owns a portion of the overseas cable capacity; i.e., a carrier owns the capacity from its cable landing point to mid-ocean. The same half-circuit concept applies to satellite circuits.

Each carrier pair makes planning and operations decisions for its own bandwidth. Therefore, the international network's equipment, interfaces, and operations procedures are generally diverse and compatible only within a given carrier pair.

Multilateral partnering. The multilateral partnering arrangements include the participation of three or more carriers in the decision-making process for design of the international network. This type of arrangement allows interworking among several carriers' networks to support joint telecommunications services or capabilities.

Because several, possibly diverse networks may be involved, this approach implies more complex planning and operations than are present with bilateral partnering. But if the planning can be done, the international network can evolve toward a single multilateral network with a common evolution plan and increased flexibility and efficiency.

The alternatives for a multilateral partnering arrangement are to form either a coalition or a company. Aside from the legal distinctions, ownership of the cable capacity is the principal difference between these two options. A *company* might own all the capacity, whereas a *coalition* would plan for the multilateral use of bilaterally owned capacity.

For both alternatives, the planning and operation of the network are for the mutual benefit of the partners. However, it can be challenging to maintain the stability of the partnerships under changing political and economical conditions, as well as determine the "fair" attribution of costs and benefits.

Data Collection. The first step in the network-design process is the collection of data to be used to estimate the traffic load offered to the network. For this dimension, the primary concerns are:

- What data is to be collected and shared by the partners
- How to integrate statistical information with macroeconomic modeling and business judgment to predict future demands.

Restricted trunk group data. Current data-collection practices focus on estimating the load and blocking on the trunk groups between gateways, usually on a trunk-group basis. Typically, this load and occupancy data is treated as proprietary and is not available immediately, even among "strategic partners." Because of this, each carrier's network manager is unable to identify the amount of idle capacity in the networks of others at the time of unexpected demand or failure conditions. Moreover, the network-design and routing-assignment processes cannot take full advantage of expected noncoincidence in traffic demand. (*Noncoincidence* means the heaviest load—either busy hour or busy season, or both—occurs at a different time on different facilities.)

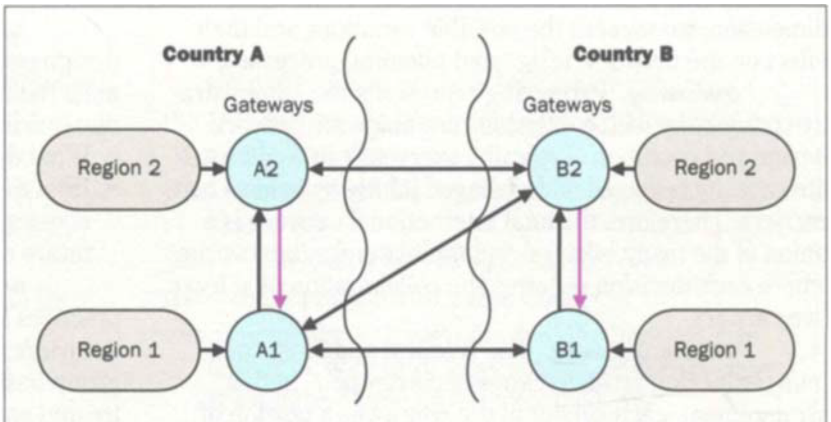
Shared node-to-node data. When the network-design process expands from a bilateral to a multilateral partnership, one must consider the changes in the types of data collected and shared among the carriers.

If we use experience with national networks as a guide, then the focus for the data should be on estimating node-to-node load, because these estimates allow us to predict caller-perceived network performance.[1] (*Node-to-node load* refers to the load between gateway switches, without regard for the actual trunk groups used.) Furthermore, the idle-capacity and blocking data should be shared among carriers, because the sharing of status information in real time allows quick response to surges in demand or to failure conditions.

Routing. Routing is the set of rules by which a logical path is selected between the originating and terminating switches. A variety of hierarchical and nonhierarchical routing options have been implemented or proposed by various carriers around the world.[2-5]

Hierarchical. Hierarchical routing is typically the choice for networks with progressive call control (i.e., control of the call moves from switch to switch). This routing option is characterized by a routing discipline that specifies a fixed order of trunk-group selection at each switch, and does not allow for mutual overflow.

Figure 1. Routing options in a network that uses the gateway approach. The country is partitioned into several regions, and all traffic from a region to a foreign country is first routed to a specified gateway. Because hierarchical routing selects trunk groups in a fixed order, traffic between a country's gateways can go in only one direction. Thus, if a call enters the network at Region 1's gateway and all circuits from that gateway are busy, the call can be routed through Region 2's gateway. However, a call that enters at Region 2's gateway cannot be routed on circuits from Region 1's gateway. Nonhierarchical routing also provides a path from Region 1's gateway to Region 2's gateway, but might also add a path in the opposite direction. Because traffic between the gateways can go in both directions, this scheme provides more alternate routes and uses the network more efficiently.



Initial trunk group	Alternate routes	
	Hierarchical (→)	Nonhierarchical (add →)
A1–B1	A1–B2–B1, A1–A2–B2–B1	A1–B2–B1, A1–A2–B2–B1
A1–B2	A1–A2–B2	A1–B1–B2, A1–A2–B2
A2–B2	None	A2–A1–B2, A2–A1–B1–B2

In hierarchical networks, trunk groups fit into two categories:

- *Final-trunk group* — the last trunk group to be selected in the path for the call to reach its destination. If all circuits in this group are busy, the call is blocked.
- *High-usage groups* — the subtending trunk groups. (Intermediate high-usage groups carry overflow.) If the circuits in the high-usage groups are all busy, then the call looks for an alternate path. The final-trunk group could be the alternate choice of many high-usage groups. (The trunk groups are "high usage" in the sense that they are busy a much higher percent of the time than the final-trunk group. Here, we use "the call looks" in the sense that a switch does the looking on behalf of the call.)

The final-trunk group is engineered to provide a chosen service level, while the high-usage groups are designed to minimize network costs.

Because of its operational simplicity and the minimal requirements that it imposes on network switching and signaling technology, hierarchical routing continues to be the choice of many national and international network providers.

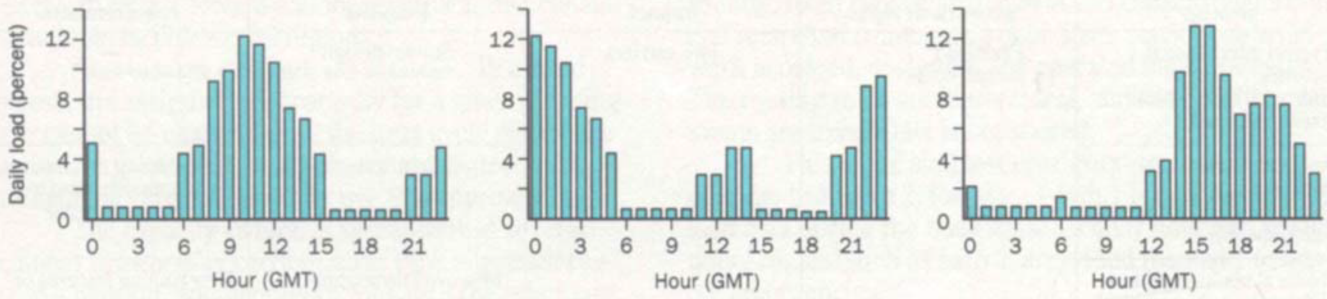
The routing of international calls is typically based on the *gateway* approach. When a network uses a gateway approach (Figure 1), the country is partitioned into several regions, and all traffic from a region in that country to a foreign country is first routed to a specified gateway. For example, in Figure 1, region 1 calls are routed to switch A1.

The dialed digits are analyzed to determine the initial destination switch. For a call from switch A1 to switch B1, the direct trunks from A1 to B1 are tested. If none are idle, then a trunk to the other gateway of country B, i.e., gateway B2, is selected. If no circuits are idle to that gateway, then a circuit to the other gateway of country A, i.e., gateway A2, is selected. At the second gateway, the overflow traffic is combined with traffic from the second gateway's regions. In this example, the A2–B2 trunk is the final destination. If there is no idle capacity on this trunk, the call is blocked.

The hierarchical-routing scheme means that calls entering the network at gateway A2 do not have the opportunity to be routed on circuits from the A1 gateway, even if capacity is available. They can only use the final-trunk group, A2–B2.

Clearly, different traffic streams experience different blocking. Those that enter the network at a low level receive better service than those that enter at a higher level.

Panel 2. Multicountry Noncoincidence



A. Load between countries A and B **B. Load between countries B and C** **C. Load between countries A and C**

The graphs use a common time scale to present the daily traffic load between two of three countries around the world. Each graph shows the percentage of the daily load that occurs during each hour of the day. The percentages represent data collected by the CCITT (Blue Book Recommendation E.523)[20] and are based on the number of hours that separate the two countries. To provide a common base, we give the time of day in Greenwich mean time (GMT).

Graph A shows the load profile for two countries that are separated by 9 hours. The busy hour (i.e., 1000 GMT) indicates that one country is in Europe and the other is in the Pacific. The profile in Graph B is also for countries that are separated by 9 hours, but its busy hour (i.e., 0000 GMT) indicates that one country is in the Pacific and the other is in the Americas. Graph C shows a load profile for countries that are separated by 6 hours. One country is in the Americas, and the other is in Europe.

Notice that if we choose countries that are separated in this way, then the busy hour of one traffic stream occurs during the off-peak hours of the other two streams. By capitalizing on this noncoincidence, circuits can be used to carry more than one traffic stream, resulting in greater efficiency and economy in the network.

Nonhierarchical. Routing is nonhierarchical whenever any of the constraints of hierarchical routing are violated. This could occur, for example, by:

- Retaining call control at the originating switch
- Allowing mutual overflow between trunk groups
- Permitting the order of trunk selection in alternate routes to vary.

By removing such constraints, nonhierarchical routing can increase the network's efficiency and improve the network's ability to respond to unexpected loads, forecast errors, and node and circuit failures. This routing scheme was first studied and introduced in a variety of national networks.[2–5]

When applied to an international network between gateways, nonhierarchical routing remains bilateral. But for each call from each region, the routing discipline might examine a sequence of paths that contains all possible direct circuits to the destination carrier. For the network in Figure 1, with nonhierarchical routing, traffic between the gateways would be able to go in both directions. However, the gateway switches must know that they are not to route a call to an alternate gateway if the call has already tested the alternate. The sequence of paths may depend on the time of the day or the state of the network.

Transit. In the transit method of routing, some calls are planned to be routed through facilities that belong to a third carrier. In return for this usage, a transit fee is paid to the third carrier.

By comparing the cost of an additional direct circuit and the transit fees associated with the load this circuit is expected to carry over a year, a carrier can decide if the installation of the circuit is justified economically. Thus, the network design will be based not only on the busy season's busy-hour load *and* the cost of a direct circuit, but also on the load profile between the two original carriers, the transit fee, and the seasonality of the load.

Table I. Comparison of Design Alternatives for an International Network

Network-design strategy*	Basis for network design	Organizational impact	Benefits	Design requirements
Typical international network (bilateral, hierarchical, fixed, restricted)	Peak load Circuit costs	Two carriers	Simple design	—
Automatic safety network (bilateral, hierarchical, fixed, shared)			Robustness	Data sharing mechanism Switch modification to automate data use
Bilateral nonhierarchical (bilateral, nonhierarchical, fixed, restricted)			Improved throughput and blocking	New routing features on switch
Planned transit (bilateral, transit, fixed, restricted)	Daily load profile Circuit costs Transit fee	Three carriers	Network cost savings	Resolve tandem DCME problem
Mutual planned transit (multilateral, transit, fixed, shared)		At least three carriers (Partner choice is critical.)		
Collective routing design (multilateral, global, fixed, shared)	Daily load profiles Global historic traffic data Global network topology		Network cost savings Better traffic performance	Operations-support-system development Methods for fair cost and benefit division
Collective facilities design (multilateral, global, flexible, shared)	Daily load profiles Global facilities network topology Facilities costs		Network cost savings Common transport network evolution	Operations-support-system development Complex network management Financial methods

* The design-dimension variations appear in parentheses. Refer to the text discussion for details about each strategy.

Global. The global approach assumes that the capacity available in an international network is used as efficiently as possible. This means that routes are chosen wherever they are available, as if they were all under the control of a single carrier.

The design process is carried out the same way that a national network design would be executed. This implies, for example, that inexpensive alternate paths may be expanded greatly to carry traffic between gateways whose direct connections are very expensive, and that the noncoincidence described in Panel 2 is exploited in those alternate paths.

Facilities. The facilities dimension provides the physical capacity to carry the demand on cable and satellite facilities between carriers. This dimension is implemented by the capacity-allocation and capacity-expansion processes.

Capacity allocation is typically a one-year planning process. The objective of the process is to assign the switched and private-line demand onto existing cable and satellite routes. The allocation of capacity is constrained by:[6]

- Availability of capacity on the facilities.
- Possible constraints on cable or satellite loading.
- Ratio of the demand on the digital and analog facilities.
- Digital-compression levels.
- Compatibility of digital circuit multiplication equipment (DCME).
- Route diversity requirements. (Here, *diversity* means that the physical paths available for the calls must be sufficiently disjointed that the paths protect the traffic against failure of a particular piece of equipment or of a particular cable.)

Capacity expansion is a planning process that determines the optimal locations, sizes, and types of new facilities for 5 to 15 years. The current international practice is to design a single cable for a particular region such as the Pacific, Atlantic, or Mediterranean.[7] The process might evolve toward a global approach that considers multiple facilities in all regions.[8]

Fixed capacity expansion and allocation. In a fixed process, the assignment of capacity for a given planning cycle cannot be changed until the next cycle even if the demand far exceeds capacity on certain routes. Most international carriers currently use this approach.

The capacity (which is spread across several facilities) is owned by carrier pairs. Typically, each carrier in a pair individually determines with the other carrier how they will use their capacity and then negotiates bilaterally with the other carriers to reach agreement.

We stress that, in current practices, a capacity segment on a facility is dedicated to a certain carrier pair and another carrier pair cannot use that segment, except by using routing features available in the switch.

Flexible capacity expansion and allocation. In a flexible process, the assignment of capacity is based on demand and varies with time. For example, route assignments are based on the time of day or the day of the month.

In this approach, the noncoincidence of busy hours (discussed in Panel 2) is exploited by network elements that determine how the call is assigned to a facility. (In the transit- and global-routing variations already discussed, the switch uses this noncoincidence when it determines how the call is logically routed.) Here, this exploitation requires reconfiguration of capacity among carriers through digital cross-connect (DXC) equipment, rather than the use of routing schemes at the gateways. This facility reconfiguration capability could be used to reduce the total capacity required to carry the demand and/or improve the network's performance under overload or failure conditions.

Network-Design Strategies

In this section, we analyze some common combinations of the network-design dimensions, outlining the advantages and requirements of each. The strategies will be characterized by one variation selected from each dimension of the network-design process:

- Bilateral or multilateral partnering
- Restricted or shared data
- Hierarchical, nonhierarchical, or global routing
- Fixed or flexible capacity expansion and allocation.

Table I compares the various design strategies.

Typical International Network. The most common configuration today is bilateral partnering, hierarchical routing, fixed capacity expansion and capacity allocation, and restricted trunk-group data. Each carrier pair's network is owned, designed, and operated independently. The routing rules are hierarchical, and the facility assignments are fixed. Data is not shared.

This is the simplest configuration to own and operate. In Figure 2, the size of path 1 is based on the load data during the busy season's busy hour and additional routes, such as path 2, are added manually to handle emergencies.

Automatic Safety Network. This network configuration is similar to the previous one (i.e., bilateral partnering, hierarchical routing, and fixed capacity expansion and allocation) but now data is shared.

The addition of real-time data, shared among multiple carriers, permits automatic identification of idle capacity in the network and automatic distribution of the appropriate information about alternate routes to the gateway switches. If the switches are able to use this information to implement alternate-routing lists, then the routing changes can also be automatic.

Typically, the carriers collect information that indicates where the idle capacity is, but no method is provided for distributing the data automatically. For this reason, this design strategy also requires a distribution mechanism and a way for the switches to use the data they currently do not receive.

Therefore, at least one development—the data-sharing system—is required to implement this configuration. In addition, a switch modification may be needed to enable the switches to use the data automatically.

In Figure 2, the size of path 1 is again based on the load during the busy hour of the busy season. However, path-2 routes are now added automatically, providing a "safety net" for an unexpected load or failure. This step is a possible precursor to widespread alternate routing in the international network because almost all forms of flexible routing use some distribution of status information or load history.[9,10]

Bilateral Nonhierarchical. This network-design strategy is also similar to the first strategy presented (i.e., bilateral partnering, fixed capacity expansion and capacity allocation, and restricted trunk-group data) but uses nonhierarchical routing instead.

If nonhierarchical routing is introduced into the

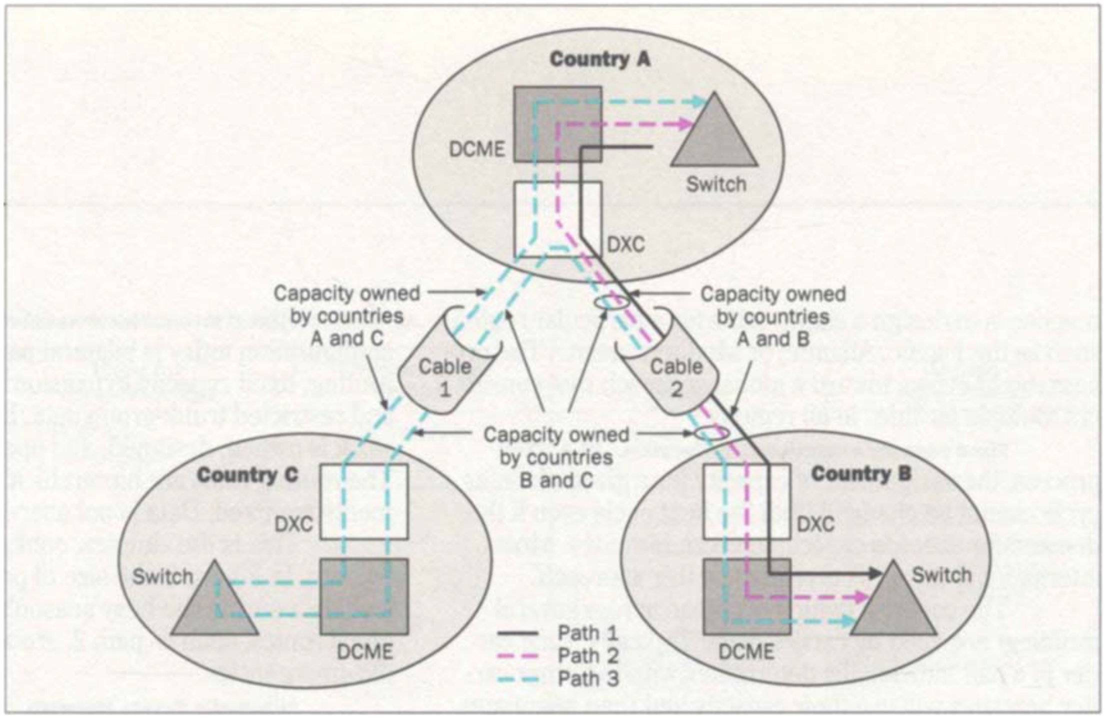


Figure 2. Call-routing paths. Path 1 represents the direct network between countries A and B. In a typical bilateral network, path 1 is owned exclusively by countries A and B, and its size is based on the load during the busy season's busy hour; additional routes with different owners (such as path 3) are added manually for emergencies. In a network with global routing, path 1's size is based on the best size for the network as a whole; and the use of a particular alternate route (e.g., path 3) depends on the overall network conditions. For both these schemes, the switches select the alternate routes. In a network with flexible facility allocation, the path 1 connections between countries A and B are still direct circuits, but access to additional capacity that has other owners is now done by the digital cross-connect (DXC) in country A. At various times during the day, the cross-connects in the network may rearrange the circuits to be used for traffic with the heaviest load.

direct network between two carriers, as illustrated in Figure 1, performance and cost improvements can be achieved without the need to resort to capacity that is owned by other carriers.

Nonhierarchical routing provides only marginal gains in network throughput in cases of perfect load forecasts. But studies have shown[11] that, in practice (because of conditions such as errors in the forecast of gateway-to-gateway load, focused overload, and facility failure), nonhierarchical routing an improve throughput by several percent compared to hierarchical routing, while equalizing the blocking experienced by all traffic streams. This level of performance can be achieved in the hierarchical network environment only at significant expense (i.e., by adding 5 to 10 percent more trunks).

If this scheme is to be implemented, the minimum requirement is that the gateway switches be capable of routing calls based on the dialed number *and* the identity of the incoming trunk. However, both carriers of a carrier pair need not introduce the nonhierarchical approach simultaneously, because trunk reservation can be used to protect the level of blocking in the final-trunk group of the carrier that does not use the approach.[12]

Planned Transit. This network-design strategy uses bilateral partnering, fixed capacity expansion and allocation, restricted trunk-group data, and transit routing (instead of the other routing variations).

The introduction of transit as an option in the bilateral design process is the planned use of a third carrier to reduce the size of the direct bilateral network. In Figure 2, the number of direct circuits between countries A and B is based on the daily traffic-load profile and seasonal profile, as well as on the transit fee of country C and the cost of the direct circuits. In the A-to-B profile shown in Panel 2, the base load would be carried on direct circuits, while the peak load during hours 10, 11, and 12 would be carried through country C. Studies have indicated that savings of 20 percent are often possible when this approach in used; in unusual situations, 40-percent savings can be achieved.[13]

The transit carrier is usually chosen from among carriers whose busy hour with each of the two network carriers differs from the busy hour in the direct network, as described in Panel 2. The transmission delay and setup time must not be excessive, and the degradation that may be associated with tandem use of circuit multiplication equipment (i.e., DCME) must be avoided. (Some technologies may eliminate this concern.) The advantage of this approach is that the technology required to implement it is already widespread; for example, transit routing is used currently when network failures occur. However, the current planning process does not take advantage of the presence of this capability by reducing the size of the direct network and routinely routing some peak hour load through the transit carrier. Instead, the direct network's size is based on the busy-hour load and the given blocking objectives, typically 1 percent.

Mutual Planned Transit. This is the first multilateral network configuration and occurs when at least three carriers agree mutually to implement the planned-transit strategy (i.e., the *bilateral, transit, fixed, shared* strategy). This multilateral approach works best when the carriers agree to reduce the transit fees to each other enough that substantial amounts of traffic will be routed through the transit carrier. In this arrangement, the peaks of each load profile in Panel 2 are carried in the off-peak hours of the other two profiles.

This approach has the most benefit for carriers located in widely separated time zones. As the fees go down, efficiencies are gained and the total network costs are reduced. However, the benefits that accrue to different carriers may fluctuate as the fee changes. This fact represents a possible source of instability as the coalition grows and as competition or technology allow for reductions in the transit fee. A second aspect of this approach is the ability to expand the coalition. The addition of a new carrier can be beneficial to some of the existing carriers, yet detrimental to others. Both of these points illustrate the importance of correctly selecting and, if conditions require, changing partners.

The technology required to implement this strategy is already in place in many switches, as noted previously for the planned-transit case.

Collective Routing Design. This network design—the second of the multilateral partnering strategies to be analyzed—uses global routing, fixed capacity expansion and allocation, and restricted trunk-group data.

If the design objectives for the international network is to minimize total network costs, then one could use existing methods in national networks to implement this strategy. (However, an operations support system to control such a network may have to be developed.)

The participating carriers design the networks between them simultaneously, and assign traffic to routes in a way that maximizes network throughput. In particular, routes are deployed based on cost and load-profile characteristics, while the selection of alternate routes in real time is based on the location of spare capacity at that time.

According to the literature,[14-17] a network designed in this way will be more efficient and will have superior performance characteristics under failure or overload conditions. This is true for two reasons:

- The size of path 1 in Figure 2 is based on the best size for the network as a whole.
- The use of a particular alternate route, such as path 2, is based on the overall conditions in the network.

The "fair" division of benefits and costs is the most difficult issue in this approach.

Collective Facilities Design. Our final approach—multilateral partnering, global routing, flexible capacity expansion and allocation, and shared data—is substantially different from the previous design strategies. The dynamic allocation of capacity among carriers now occurs when network elements, such as digital cross-connects, rearrange large units of capacity, instead of when the switches reroute individual calls. Networks that operate this way are examples of "fully shared" networks.[18,19]

As before, the path 1 connections between countries A and B are direct circuits in Figure 2. But now, the digital cross-connect in country A provides access to additional capacity between countries A and B by adding capacity that is owned by countries B and C (i.e., path 2). This eliminates the need to go through the switch in country C to access this capacity. These circuits (i.e., paths 1 and 2) may be rearranged at various times during the day to be used for the traffic with the highest load. For example, in hour 10, they could be used for the traffic between countries A and B and in hour 0 for traffic between countries B and C.

However, capacity allocations controlled by network elements are not designed for rapid rearrangement. Therefore, with this approach, the network will be "slowly varying" in the sense of hourly changes in capacity allocation, as opposed to per-call changes. Routing refinements can be added to gain additional reliability and versatility in network operations.

Several important advantages accrue under this approach:

- The efficiency advantages that accrue from capitalizing on the noncoincidence of busy hours remain, as in the strategies that are based on call routing.

- The cross-connect at country A can be reconfigured during the off-peak hours of the load between countries B and C to carry peak traffic between countries A and B. As an example, if a call made in the United States is destined for England, AT&T need not route the call through Japan to access capacity that England and Japan own in the Atlantic Ocean.
- Transmission quality degradation, which results from multiple passes through the compression equipment (i.e., path 3 in Figure 2), is also avoided.
- New network services (such as the fast provisioning of private lines) are also supported by the reconfiguration capabilities of the cross-connects.
- On a strategic level, the planning required for coordinated rearrangements of the network permits a common view of transport-network evolution among many carriers.

The drawbacks of this approach are the additional coordination and cooperation needed to manage the network. Also, capacity rearrangements and financial arrangements require a potentially complex control structure.

Conclusion

In this paper, we illustrated various concepts and partnership arrangements that can be used to alter the design of an international network. The alternatives range from changes within a simple bilateral network to completely new approaches that involve joint planning by many carriers to develop flexible routing with dynamic capacity allocation.

As Table I shows, this movement—from the most simple bilateral networks to multilateral networks and, finally, to global networks—requires increased organizational, financial, and technological complexities. On the other hand, the multilateral network solutions would bring many network-design benefits, such as:

- Reduced network cost
- Improved blocking and throughput
- The ability to respond to network failure and unexpected demand conditions
- Efficient and flexible use of network resources.

Also, the requirements imposed by joint network planning increase the chances that a common infrastructure will evolve for the global network. This may facilitate rapid introduction of new services and capabilities on a global scale.

Thus, our analysis demonstrates that international carriers have something to gain by moving away from the traditional methods of static, bilateral, network design and toward a more flexible approach. Because of these advantages, we believe increasing numbers of carriers will use these approaches in the future.

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