INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

E.360.4

(05/2002)

SERIES E: OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

International routing plan

QoS routing and related traffic engineering methods – Routing table management methods and requirements

ITU-T Recommendation E.360.4

ITU-T E-SERIES RECOMMENDATIONS

OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

INTERNATIONAL OPERATION	
Definitions	E.100–E.103
General provisions concerning Administrations	E.104–E.119
General provisions concerning users	E.120–E.139
Operation of international telephone services	E.140–E.159
Numbering plan of the international telephone service	E.160–E.169
International routing plan	E.170–E.179
Tones in national signalling systems	E.180–E.189
Numbering plan of the international telephone service	E.190–E.199
Maritime mobile service and public land mobile service	E.200–E.229
OPERATIONAL PROVISIONS RELATING TO CHARGING AND ACCOUNTING IN THE INTERNATIONAL TELEPHONE SERVICE	
Charging in the international telephone service	E.230–E.249
Measuring and recording call durations for accounting purposes	E.260–E.269
UTILIZATION OF THE INTERNATIONAL TELEPHONE NETWORK FOR NON-TELEPHONY APPLICATIONS	
General	E.300–E.319
Phototelegraphy	E.320–E.329
ISDN PROVISIONS CONCERNING USERS	E.330–E.349
INTERNATIONAL ROUTING PLAN	**E.350–E.399**
NETWORK MANAGEMENT	
International service statistics	E.400–E.409
International network management	E.410–E.419
Checking the quality of the international telephone service	E.420–E.489
TRAFFIC ENGINEERING	
Measurement and recording of traffic	E.490–E.505
Forecasting of traffic	E.506–E.509
Determination of the number of circuits in manual operation	E.510–E.519
Determination of the number of circuits in automatic and semi-automatic operation	E.520–E.539
Grade of service	E.540–E.599
Definitions	E.600–E.649
Traffic engineering for IP-networks	E.650–E.699
ISDN traffic engineering	E.700–E.749
Mobile network traffic engineering	E.750–E.799
QUALITY OF TELECOMMUNICATION SERVICES: CONCEPTS, MODELS, OBJECTIVES AND DEPENDABILITY PLANNING	
Terms and definitions related to the quality of telecommunication services	E.800–E.809
Models for telecommunication services	E.810–E.844
Objectives for quality of service and related concepts of telecommunication services	E.845–E.859
Use of quality of service objectives for planning of telecommunication networks	E.860–E.879
Field data collection and evaluation on the performance of equipment, networks and services	E.880–E.899

For further details, please refer to the list of ITU-T Recommendations.

ITU-T Recommendation E.360.4

QoS routing and related traffic engineering methods – Routing table management methods and requirements

Summary

The E.360.x series of Recommendations describes, analyses, and recommends methods which control a network's response to traffic demands and other stimuli, such as link failures or node failures. The functions discussed, and recommendations made, related to traffic engineering (TE) are consistent with the definition given in the Framework document of the Traffic Engineering Working Group (TEWG) within the Internet Engineering Task Force (IETF):

Internet Traffic Engineering is concerned with the performance optimization of operational networks. It encompasses the measurement, modelling, characterization, and control of Internet traffic, and the application of techniques to achieve specific performance objectives, including the reliable and expeditious movement of traffic through the network, the efficient utilization of network resources, and the planning of network capacity.

The methods addressed in the E.360.x series include call and connection routing, QoS resource management, routing table management, dynamic transport routing, capacity management, and operational requirements. Some of the methods proposed herein are also addressed in or are closely related to those proposed in ITU-T Recs E.170 to E.179 and E.350 to E.353 for routing, E.410 to E.419 for network management and E.490 to E.780 for other traffic engineering issues.

The recommended methods are meant to apply to IP-based, ATM-based, and TDM-based networks, as well as the interworking between these network technologies. Essentially, all of the methods recommended are already widely applied in operational networks worldwide, particularly in PSTN networks employing TDM-based technology. However, these methods are shown to be extensible to packet-based technologies, that is, to IP-based and ATM-based technologies, and it is important that networks which evolve to employ these packet technologies have a sound foundation of methods to apply. Hence, it is the intent that the methods recommended in this series of Recommendations be used as a basis for requirements for specific methods, and, as needed, for protocol development in IP-based, ATM-based, and TDM-based networks to implement the methods.

The methods encompassed in this Recommendation include traffic management through control of routing functions, which include QoS resource management. Results of analysis models are presented which illustrate the tradeoffs between various approaches. Based on the results of these studies as well as established practice and experience, methods are recommended for consideration in network evolution to IP-based, ATM-based, and/or TDM-based technologies.

Source

ITU-T Recommendation E.360.4 was prepared by ITU-T Study Group 2 (2001-2004) and approved under the WTSA Resolution 1 procedure on 16 May 2002.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

CONTENTS

Page

Introduction

Routing table management typically entails the automatic generation of routing tables based on network topology and other information such as status. Routing table management information, such as topology update, status information, or routing recommendations, is used for purposes of applying the routing table design rules for determining path choices in the routing table. This information is exchanged between one node and another node, such as between the originating node (ON) and destination node (DN), for example, or between a node and a network element such as a bandwidth-broker processor (BBP). This information is used to generate the routing table, and then the routing table is used to determine the path choices used in the selection of a path.

This automatic generation function is enabled by the automatic exchange of link, node, and reachable address information among the network nodes. In order to achieve automatic update and synchronization of the topology database, which is essential for routing table management, IP- and ATM-based networks already interpret HELLO protocol mechanisms to identify links in the network. For topology database synchronization, the link state advertisement (LSA) is used in IP-based networks, and the PNNI topology-state-element (PTSE) exchange is used in ATM-based networks to automatically provision nodes, links, and reachable addresses in the topology database. Use of a single peer group/autonomous system for topology update leads to more efficient routing and easier administration, and is best achieved by minimizing the use of topology state (LSA and PTSE) flooding for dynamic topology state information. It is required in 8.4 that a topology state element (TSE) be developed within TDM-based networks. When this is the case, then the HELLO and LSA/TSE/PTSE parameters will become the standard topology update method for interworking across IP-, ATM-, and TDM-based networks.

Status update methods are required for use in routing table management within and between network types. In TDM-based networks, status updates of link and/or node status are used [E.350], [E.351]. Within IP- and ATM-based networks, status updates are provided by a flooding mechanism. It is required in 8.4 that a routing status element (RSE) be developed within TDM-based networks, which will be compatible with the PNNI topology state element (PTSE) in ATM-based networks and the link state advertisement (LSA) element in IP-based networks. When this is the case, then the RSE/PTSE/LSA parameters will become the standard status update method for interworking across TDM-, ATM-, and IP-based networks.

Query for status methods are required for use in routing table management within and between network types. Such methods allow efficient determination of status information, as compared to flooding mechanisms. Such query for status methods are provided in TDM-based networks [E.350], [E.351]. It is required in 8.4 that a routing query element (RQE) be developed within ATM-based and IP-based networks. When this is the case, then the RQE parameters will become the standard query for status method for interworking across TDM-, ATM-, and IP-based networks.

Routing recommendation methods are proposed for use in routing table management within and between network types. For example, such methods provide for a database, such as a BBP, to advertise recommended paths to network nodes based on status information available in the database. Such routing recommendation methods are provided in TDM-based networks [E.350], [E.351]. It is required in 8.4 that a routing recommendation element (RRE) be developed within ATM-based and IP-based networks. When this is the case, then the RRE parameters will become the standard query for status method for interworking across TDM-, ATM-, and IP-based networks.

ITU-T Recommendation E.360.4

QoS routing and related engineering methods – Routing table management methods and requirements

1 Scope

The E.360.x series of Recommendations describes, analyses, and recommends methods which control a network's response to traffic demands and other stimuli, such as link failures or node failures. The functions discussed, and recommendations made, related to traffic engineering (TE) are consistent with the definitions given in the Framework document of the Traffic Engineering Working Group (TEWG) within the Internet Engineering Task Force (IETF):

Internet Traffic Engineering is concerned with the performance optimization of operational networks. It encompasses the measurement, modelling, characterization, and control of Internet traffic, and the application of techniques to achieve specific performance objectives, including the reliable and expeditious movement of traffic through the network, the efficient utilization of network resources, and the planning of network capacity.

The methods addressed in the E.360.x series include call and connection routing, QoS resource management, routing table management, dynamic transport routing, capacity management, and operational requirements. Some of the methods proposed herein are also addressed in or are closely related to those proposed in ITU-T Recs E.170 to E.179 and E.350 to E.353 for routing, E.410 to E.419 for network management and E.490 to E.780 for other traffic engineering issues.

The recommended methods are meant to apply to IP-based, ATM-based, and TDM-based networks, as well as the interworking between these network technologies. Essentially, all of the methods recommended are already widely applied in operational networks worldwide, particularly in PSTN networks employing TDM-based technology. However, these methods are shown to be extensible to packet-based technologies, that is, to IP-based and ATM-based technologies, and it is important that networks which evolve to employ these packet technologies have a sound foundation of methods to apply. Hence, it is the intent that the methods recommended in this series of Recommendations be used as a basis for requirements for specific methods, and, as needed, for protocol development in IP-based, ATM-based, and TDM-based networks to implement the methods.

Hence the methods encompassed in this series of Recommendations include:

- traffic management through control of routing functions, which include call routing (number/name translation to routing address), connection routing, QoS resource management, routing table management, and dynamic transport routing;
- capacity management through control of network design, including routing design;
- operational requirements for traffic management and capacity management, including forecasting, performance monitoring, and short-term network adjustment.

Results of analysis models are presented which illustrate the tradeoffs between various approaches. Based on the results of these studies, as well as established practice and experience, TE methods are recommended for consideration in network evolution to IP-based, ATM-based, and/or TDM-based technologies.

2 References

See clause 2/E.360.1.

3 Definitions

See clause 3/E.360.1.

4 Abbreviations

See clause 4/E.360.1.

5 Routing table management for IP-based networks

IP networks typically run the OSPF protocol for intra-domain routing [RFC2328], [S95] and the BGP protocol for inter-domain routing [RL00], [S95]. OSPF and BGP are designed for routing of datagram packets carrying multimedia internet traffic. Within OSPF, a link-state update topology exchange mechanism is used by each IP node to construct its own shortest path routing tables. Through use of these routing tables, the IP nodes match the destination IP address to the longest match in the table and thereby determine the shortest path to the destination for each IP packet. In current OSPF operation, this shortest path remains fixed unless a link is added or removed (e.g. fails), and/or an IP node enters or leaves the network. However, the protocol allows for possibly more sophisticated dynamic routing mechanisms to be implemented. MPLS is currently being developed as a means by which IP networks may provide connection oriented, QoS-routing services, such as with ATM layer-2 switching technology [RVC99], and differentiated services (DiffServ) [RFC2475], [ST98] is being developed to provide priority queuing control in IP-based networks. MPLS and DiffServ both provide essential capabilities for QoS resource management, as discussed in ITU-T Rec. E.360.3.

These IP-based protocols provide for:

a) exchange of node and link status information;

b) automatic update and synchronization of topology databases; and

c) fixed and/or dynamic route selection based on topology and status information.

For topology database synchronization, each node in an IP-based OSPF/BGP network exchanges HELLO packets with its immediate neighbors and thereby determines its local state information. This state information includes the identity and group membership of the node's immediate neighbors, and the status of its links to the neighbors. Each node then bundles its state information in LSAs, which are reliably flooded throughout the autonomous system (AS), or group of nodes exchanging routing information and using a common routing protocol, which is analogous to the PNNI peer group used in ATM-based networks. The LSAs are used to flood node information, link state information and reachability information. As in PNNI, some of the topology state information is static and some is dynamic. In order to allow larger AS group sizes, a network can use OSPF in such a way so as to minimize the amount of dynamic topology state information flooding, such as available link bandwidth, by setting thresholds to values that inhibit frequent updates.

IP-based routing of connection/bandwidth-allocation requests and QoS-routing support are in the process of standardization, primarily within the MPLS and DiffServ [RFC2475], [ST98] activities in the IETF. IGPs, such as OSPF, are still applicable to determine routing in an MPLS architecture, but are only one of many proposed capabilities to implement traffic engineering (TE) with MPLS. ITU-T Rec. E.360.1 [ACEWX00] calls for many TE mechanisms, distributed, centralized, off-line, on-line, time-dependent, state-dependent, event-dependent, some, but not all, of which would involve interior gateway protocols such as OSPF.

As described in ITU-T Rec. E.360.1, a number of enhancements are needed to conventional link state IGPs, such as OSPF and IS-IS, to allow them to distribute additional state information required for constraint-based routing. Essentially, these enhancements require the propagation of additional information in link state advertisements. Specifically, in addition to normal link-state information, an enhanced IGP is required to propagate topology state information needed for constraint-based routing. Some of the additional topology state information includes link attributes such as reservable bandwidth and link resource class attribute (an administratively specified property of the link). Deployment of MPLS for traffic engineering applications has commenced in some service provider networks. One operational scenario is to deploy MPLS in conjunction with an IGP (IS-IS-TE or OSPF-TE) that supports the traffic engineering extensions, in conjunction with constraint-based routing for explicit route computations, and a signalling protocol (e.g. RSVP-TE or CRLDP) for LSP instantiation.

In contemporary MPLS traffic engineering contexts, network administrators specify and configure link attributes and resource constraints such as maximum reservable bandwidth and resource class attributes for links (interfaces) within the MPLS domain. A link state protocol that supports TE extensions (IS-IS-TE or OSPF-TE) is used to propagate information about network topology and links attributes to all routers in the routing area. Network administrators also specify all the LSPs that are to originate at each router. For each LSP, the network administrator specifies the destination node and the attributes of the LSP which indicate the requirements that are to be satisfied during the path selection process. Each router then uses a local constraint-based routing process to compute explicit paths for all LSPs originating from it. Subsequently, a signalling protocol is used to instantiate the LSPs. By assigning proper bandwidth values to links and LSPs, congestion caused by uneven traffic distribution can generally be avoided or mitigated. In order to perform constraint-based routing on a per-class basis for LSPs, the conventional IGPs (e.g. IS-IS and OSPF) should provide extensions to propagate per-class resource information.

There are also proposals for using more centralized policy models to support TE implementation [WHJ00], [IYBKQ00]. As described in ITU-T Rec. E.360.1, off-line (and on-line) TE considerations would be of limited utility if the network could not be controlled effectively to implement the results of TE decisions and to achieve desired network performance objectives. Capacity augmentation is a coarse-grained solution to traffic engineering issues. However, it is simple and may be advantageous if bandwidth is abundant and cheap, or if the current or expected network workload demands it. However, bandwidth is not always abundant and cheap, and the workload may not always demand additional capacity. Adjustments of administrative weights and other parameters associated with routing protocols provide finer grained control, but is difficult to use and imprecise because of the routing interactions that occur across the network. In certain network contexts, more flexible, finer grained approaches which provide more precise control over the mapping of traffic to routes, and over the selection and placement of routes, may be appropriate and useful. Control mechanisms can be manual (e.g. administrative configuration), partially automated (e.g. scripts) or fully automated (e.g. policy-based management systems). Automated mechanisms are particularly required in large-scale networks. Multi-vendor interoperability can be facilitated by developing and deploying standardized management systems (e.g. standard MIBs) and policies (PIBs) to support the control functions required to address traffic engineering objectives such as load distribution and protection/restoration.

MPLS depends on layer 3 mechanisms to determine LSP routes, and also the way that the routes are used. That is, MPLS has no routing of its own built in (it is "between layer 3 and layer 2"). Unlike layer 3 protocols, MPLS lacks addressing and routing components. It has to rely on IP, OSPF/BGP etc. for that. MPLS is not a layer 2 protocol either as it does not have a single format for data transmission which is a requirement for a layer 2 protocol. How exactly the OSPF/IS-IS extensions get used, how policy-based capabilities get used, etc., to determine MPLS routing, is going to be a matter of vendor implementation. What is emerging are a lot of different capabilities to implement MPLS/TE in many ways, and service providers may provide requirements for a standardized "generic TE method", somewhat like a generic CAC in the ATM context discussed below. These standards requirement would then be used to drive the vendor implementations in the direction of network operator requirements and vendor interoperability.

The following assumptions are made regarding the outcomes of these IP-based routing standardization directions:

a) Call routing in support of connection establishment functions on a per-connection basis to determine the routing address based on a name/number translation, and uses a protocol such as H.323 [H.323], or the session initiation protocol (SIP) [RFC2543]. It is assumed that the call routing protocol interworks with the broadband ISDN user part (B-ISUP) [Q.2761] and bearer-independent call control (BICC) protocols [Q.1901] to accommodate setup and release of connection requests.

b) Connection/bandwidth-allocation routing in support of bearer-path selection is assumed to employ OSPF/BGP path selection methods in combination with MPLS. MPLS employs a constraint-based routing label distribution protocol (CRLDP) [J00], [CDFFSV99] or a resource reservation protocol (RSVP) [RFC2205] to establish constraint-based routing label switched paths (CRLSPs). Bandwidth allocation to CRLSPs is managed in support of QoS resource management, as discussed in ITU-T Rec. E.360.3.

c) The MPLS label request message (equivalent to the setup message) carries the explicit route parameter specifying the via nodes (VNs) and destination node (DN) in the selected CRLSP and the depth-of-search (DoS) parameter specifying the allowed bandwidth selection threshold on a link.

d) The MPLS notify (equivalent to the release) message is assumed to carry the crankback/bandwidth-not-available parameter specifying return of control of the connection/bandwidth-allocation request to the originating node (ON), for possible further alternate routing to establish additional CRLSPs.

e) Call control routing is coordinated with connection/bandwidth-allocation for bearer-path establishment.

f) Reachability information is exchanged between all nodes. To provision a new IP address, the node serving that IP address is provisioned. The reachability information is flooded to all nodes in the network using the OSPF LSA flooding mechanism.

g) The ON performs destination name/number translation, service processing, and all steps necessary to determine the routing table for the connection/bandwidth-allocation request across the IP network. The ON makes a connection/bandwidth-allocation request admission if bandwidth is available and places the connection/bandwidth-allocation request on a selected CRLSP.

IP-based networks employ an IP addressing method to identify node endpoints [S94]. A mechanism is needed to translate E.164 AESAs to IP addresses in an efficient manner. Work is in progress [F00], [B91] to interwork between IP addressing and E.164 numbering/addressing, in which a translation database is required, based on domain name system (DNS) technology, to convert E.164 addresses to IP addresses. With such a capability, IP nodes could make this translation of E.164 AESAs directly, and thereby provide interworking with TDM- and ATM-based networks which use E.164 numbering and addressing. If this is the case, then E.164 AESAs could become a standard addressing method for interworking across IP-, ATM-, and TDM-based networks.

As stated above, path selection in an IP-based network is assumed to employ OSPF/BGP in combination with the MPLS protocol that functions efficiently in combination with call control establishment of individual connections. In OSPF-based layer 3 routing, as illustrated in Figure 1, an ON N1 determines a list of shortest paths by using, for example, Dijsktra's algorithm.

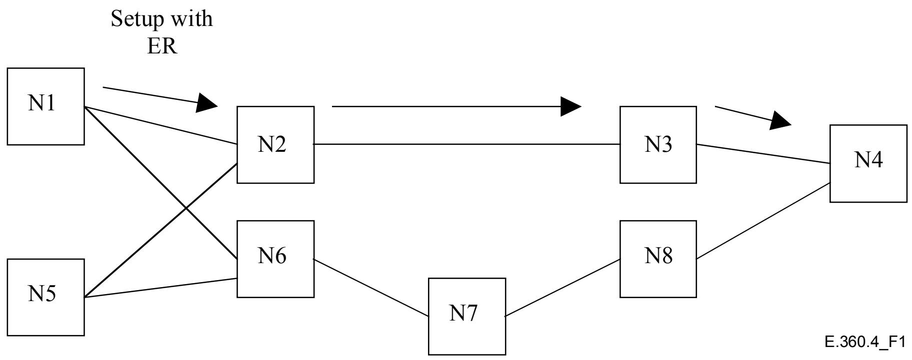

Figure 1/E.360.4 – IP/MPLS routing example

This path list could be determined based on administrative weights of each link, which are communicated to all nodes within the AS group. These administrative weights may be set, for example, to 1 + epsilon × distance, where epsilon is a factor giving a relatively smaller weight to the distance in comparison to the hop count. The ON selects a path from the list based on, for example, FR, TDR, SDR, or EDR path selection, as described in ITU-T Rec. E.360.2. For example, to establish a CRLSP on the first path, the ON N1 sends an MPLS label request message to VN N2, which in turn forwards the MPLS label request message to VN N3, and finally to DN N4. The VNs N2 and N3 and DN N4 are passed in the explicit route (ER) parameter contained in the MPLS label request message. Each node in the path reads the ER information, and passes the MPLS label request message to the next node listed in the ER parameter. If the first-choice path is blocked at any of the links in the path, a MPLS notify message with crankback/bandwidth-not-available parameter is returned to the ON which can then attempt the next path. If FR is used, then this path is the next path in the shortest path list, for example path N1-N6-N7-N8-N4. If TDR is used, then the next path is the next path in the routing table for the current time period. If SDR is used, OSPF implements a distributed method of flooding link status information, which is triggered either periodically and/or by crossing load state threshold values. As described in the beginning of this clause, this method of distributing link status information can be resource-intensive and, indeed, may not be any more efficient than simpler path selection methods such as EDR. If EDR is used, then the next path is the last successful path, and if that path is unsuccessful another alternate path is searched out according to the EDR path selection method.

Bandwidth-allocation control information is used to seize and modify bandwidth allocation on LSPs, to release bandwidth on LSPs, and for purposes of advancing the LSP choices in the routing table. Existing CRLSP label request (setup) and notify (release) messages, as described in [J00], can be used with additional parameters to control CRLSP bandwidth modification, DoS on a link, or CRLSP crankback/bandwidth-not-available to an ON for further alternate routing to search out additional bandwidth on alternate CRLSPs. Actual selection of a CRLSP is determined from the routing table, and CRLSP control information is used to establish the path choice. Forward information exchange is used in CRLSP set up and bandwidth modification, and includes, for example, the following parameters:

1) LABEL REQUEST-ER: The explicit route (ER) parameter in MPLS specifies each VN and the DN in the CRLSP, and used by each VN to determine the next node in the path.
2) LABEL REQUEST-DoS: The depth-of-search (DoS) parameter is used by each VN to compare the load state on each CRLSP link to the allowed DoS threshold to determine if the MPLS setup or modification request is admitted or blocked on that link.
3) LABEL REQUEST-MODIFY: The MODIFY parameter is used by each VN/DN to update the traffic parameters (e.g. committed data rate) on an existing CRLSP to determine if the MPLS modification request is admitted or blocked on each link in the CRLSP.

The setup-priority parameter serves as a DoS parameter in the MPLS LABEL REQUEST message to control the bandwidth allocation, queuing priorities, and bandwidth modification on an existing CRLSP [AAFJLLS00].

Backward information exchange is used to release a connection/bandwidth-allocation request on a link such as from a DN to a VN or from a VN to an ON, and includes, for example, the following parameter:

4) NOTIFY-BNA: The bandwidth-not-available parameter in the notify (release) message sent from the VN to ON or DN to ON, and allows for possible further alternate routing at the ON to search out alternate CRLSPs for additional bandwidth.

A bandwidth-not-available parameter is already planned for the MPLS NOTIFY message to allow the ON to search out additional bandwidth on additional CRLSPs.

In order to achieve automatic update and synchronization of the topology database, which is essential for routing table design, IP-based networks already interpret HELLO protocol mechanisms to identify links in the network. For topology database synchronization, the OSPF LSA exchange is used to automatically provision nodes, links, and reachable addresses in the topology database. This information is exchanged between one node and another node and, in the case of OSPF, a flooding mechanism of LSA information is used.

5) HELLO: Provides for the identification of links between nodes in the network.

6) LSA: Provides for the automatic updating of nodes, links, and reachable addresses in the topology database.

In summary, IP-based networks already incorporate standard signalling for routing table management functions, which includes the ER, HELLO, and LSA capabilities. Additional requirements needed to support QoS resource management include the DoS parameter and MODIFY parameter in the MPLS LABEL REQUEST message, the crankback/bandwidth-not-available parameter in the MPLS notify message, as proposed in [FIA99], [AALJ99], and the support for QUERY, STATUS, and RECOM routing table design information exchange, as required in 8.4. Call control with the H.323 [H.323] and session initiation protocol [RFC2543] protocols needs to be coordinated with MPLS CRLSP connection/bandwidth-allocation control.

6 Routing table management for ATM-based networks

PNNI is a standardized signalling and dynamic routing strategy for ATM networks adopted by the ATM Forum [ATM960055]. PNNI provides interoperability among different vendor equipment and scaling to very large networks. Scaling is provided by a hierarchical peer group structure that allows the details of topology of a peer group to be flexibly hidden or revealed at various levels within the hierarchical structure. Peer group leaders represent the nodes within a peer group for purposes of routing protocol exchanges at the next higher level. Border nodes handle inter-level interactions at call setup. PNNI routing involves two components:

a) a topology distribution protocol; and

b) the path selection and crankback procedures.

The topology distribution protocol floods information within a peer group. The peer group leader abstracts the information from within the peer group and floods the abstracted topology information to the next higher level in the hierarchy, including aggregated reachable address information. As the peer group leader learns information at the next higher level, it floods it to the lower level in the hierarchy, as appropriate. In this fashion, all nodes learn of network-wide reachability and topology.

PNNI path selection is source-based in which the ON determines the high-level path through the network. The ON performs number translation, screening, service processing, and all steps necessary to determine the routing table for the connection/bandwidth-allocation request across the

ATM network. The node places the selected path in the designated transit list (DTL) and passes the DTL to the next node in the SETUP message. The next node does not need to perform number translation on the called party number but just follows the path specified in the DTL. When a connection/bandwidth-allocation request is blocked due to network congestion, a PNNI crankback/bandwidth-not-available is sent to the first ATM node in the peer group. The first ATM node may then use the PNNI alternate routing after crankback/bandwidth-not-available capability to select another path for the connection/bandwidth-allocation request. If the network is flat, that is, all nodes have the same peer group level, the ON controls the edge-to-edge path. If the network has more than one level of hierarchy, as the call progresses from one peer group into another, the border node at the new peer group selects a path through that peer group to the next peer group downstream, as determined by the ON. This occurs recursively through the levels of hierarchy. If at any point the call is blocked, for example when the selected path bandwidth is not available, then the call is cranked back to the border node, or ON, for that level of the hierarchy, and an alternate path is selected. The path selection algorithm is not stipulated in the PNNI specification, and each ON implementation can make its own path selection decision unilaterally. Since path selection is done at an ON, each ON makes path selection decisions based on its local topology database and specific algorithm. This means that different path selection algorithms from different vendors can interwork with each other.

In the routing example illustrated in Figure 1 now used to illustrate PNNI, an ON N1 determines a list of shortest paths by using, for example, Dijsktra's algorithm. This path list could be determined based on administrative weights of each link which are communicated to all nodes within the peer group through the PTSE flooding mechanism. These administrative weights may be set, for example, to 1 + epsilon × distance, where epsilon is a factor giving a relatively smaller weight to the distance in comparison to the hop count. The ON then selects a path from the list based on any of the methods described in ITU-T Rec. E.360.2, that is FR, TDR, SDR, and EDR. For example, in using the first choice path, the ON N1 sends a PNNI setup message to VN N2, which in turn forwards the PNNI setup message to VN N3, and finally to DN N4. The VNs N2 and N3 and DN N4 are passed in the DTL parameter contained in the PNNI setup message. Each node in the path reads the DTL information, and passes the PNNI setup message to the next node listed in the DTL.

If the first path is blocked at any of the links in the path, or overflows, or is excessively delayed at any of the queues in the path, a crankback/bandwidth-not-available message is returned to the ON which can then attempt the next path. If FR is used, then this path is the next path in the shortest path list, for example, path N1-N6-N7-N8-N4. If TDR is used, then the next path is the next path in the routing table for the current time period. If SDR is used, PNNI implements a distributed method of flooding link status information, which is triggered either periodically and/or by crossing load state threshold values. As described in the beginning of this clause, this flooding method of distributing link status information can be resource-intensive and, indeed, may not be any more efficient than simpler path selection methods such as EDR. If EDR is used, then the next path is the last successful path, and if that path is unsuccessful, another alternate path is searched out according to the EDR path selection method.

Connection/bandwidth-allocation control information is used in connection/bandwidth-allocation set up to seize bandwidth in links, to release bandwidth in links, and to advance path choices in the routing table. Existing connection/bandwidth-allocation setup and release messages [ATM960055] can be used with additional parameters to control SVP bandwidth modification, DoS on a link, or SVP bandwidth-not-available to an ON for further alternate routing. Actual selection of a path is determined from the routing table, and connection/bandwidth-allocation control information is used to establish the path choice. Forward information exchange is used in connection/bandwidth-allocation set up, and includes for example the following parameters:

1) SETUP-DTL/ER: The designated-transit-list/explicit-route (DTL/ER) parameter in PNNI specifies each VN and the DN in the path, and used by each VN to determine the next node in the path.

2) SETUP-DoS: The DoS parameter used by each VN to compare the load state on the link to the allowed DoS to determine if the SVC connection/bandwidth-allocation request is admitted or blocked on that link.

3) MODIFY REQUEST-DoS: The DoS parameter used by each VN to compare the load state on the link to the allowed DoS to determine if the SVP modification request is admitted or blocked on that link.

It is required that the DoS parameter be carried in the SVP MODIFY REQUEST and SVC SETUP messages, to control the bandwidth allocation and queuing priorities.

Backward information exchange is used to release a connection/bandwidth-allocation request on a link such as from a DN to a VN or from a VN to an ON, and includes for example the following parameter:

4) RELEASE-CB: The crankback/bandwidth-not-available parameter in the release message is sent from the VN to ON or DN to ON, and allows for possible further alternate routing at the ON.

5) MODIFY REJECT-BNA: The bandwidth-not-available parameter in the modify reject message is sent from the VN to ON or DN to ON, and allows for possible further alternate routing at the ON to search out additional bandwidth on alternate SVPs.

SVC crankback/bandwidth-not-available is already defined for PNNI-based signalling. We propose a bandwidth-not-available parameter in the SVP MODIFY REJECT message to allow the ON to search out additional bandwidth on additional SVPs.

In order to achieve automatic update and synchronization of the topology database, which is essential for routing table design, ATM-based networks already interpret HELLO protocol mechanisms to identify links in the network. For topology database synchronization, the PTSE exchange is used to automatically provision nodes, links, and reachable addresses in the topology database. This information is exchanged between one node and another node, and in the case of PNNI a flooding mechanism of PTSE information is used.

6) HELLO: Provides for the identification of links between nodes in the network.

7) PTSE: Provides for the automatic updating of nodes, links, and reachable addresses in the topology database.

In summary, ATM-based networks already incorporate standard signalling and messaging directly applicable to routing implementation, which includes the DTL, crankback/bandwidth-not-available, HELLO, and PTSE capabilities. ATM protocol capabilities are being progressed [ATM000102], [AM99] to support QoS resource management, which include the DoS parameter in the SVC SETUP and SVP MODIFY REQUEST messages, the bandwidth-not-available parameter in the SVP MODIFY REJECT message, and the QUERY, STATUS, and RECOM routing table design information exchange, as required in 8.4.

7 Routing table management for TDM-based networks

TDM-based voice/ISDN networks have evolved several dynamic routing methods, which are widely deployed and include TDR, SDR, and EDR implementations [A98]. TDR includes dynamic non-hierarchical routing (DNHR), deployed in the US Government FTS-2000 network. SDR includes dynamically controlled routing (DCR), deployed in the Stentor Canada, Bell Canada, MCI, and Sprint networks, and real-time network routing (RTNR), deployed in the AT&T network. EDR includes dynamic alternate routing (DAR), deployed in the British Telecom network, and STT, deployed in the AT&T network.

TDM-based network call routing protocols are described for example in [Q.1901] for BICC, and in [Q.2761] for the B-ISUP signalling protocol. We summarize here the information exchange required between network elements to implement the TDM-based path selection methods which include connection control information required for connection set up, routing table design information required for routing table generation, and topology update information required for the automatic update and synchronization of topology databases.

Routing table management information is used for purposes of applying the routing table design rules for determining path choices in the routing table. This information is exchanged between one node and another node, such as between the ON and DN, for example, or between a node and a network element such as a BBP. This information is used to generate the routing table, and then the routing table is used to determine the path choices used in the selection of a path. The following messages can be considered for this function:

1) QUERY: Provides for an ON to DN or ON to BBP link and/or node status request.
2) STATUS: Provides ON/VN/DN to BBP or DN to ON link and/or node status information.
3) RECOM: Provides for an BBP to ON/VN/DN routing recommendation.

These information exchange messages are already deployed in non-standard TDM-based implementations, and need to be extended to standard TDM-based network environments.

In order to achieve automatic update and synchronization of the topology database, which is essential for routing table design, TDM-based networks need to interpret, at the gateway nodes, the HELLO protocol mechanisms of ATM- and IP-based networks to identify links in the network, as discussed above, for ATM-based networks. Also needed for topology database synchronization is a mechanism analogous to the PTSE exchange, as discussed above, which automatically provisions nodes, links, and reachable addresses in the topology database.

Path-selection and QoS-resource management control information is used in connection/bandwidth-allocation set up to seize bandwidth in links, to release bandwidth in links, and for purposes of advancing path choices in the routing table. Existing connection/bandwidth-allocation setup and release messages, as described in ITU-T Recs Q.71 and Q.2761, can be used with additional parameters to control path selection, DoS on a link, or crankback/bandwidth-not-available to an ON for further alternate routing. Actual selection of a path is determined from the routing table, and connection/bandwidth-allocation control information is used to establish the path choice.

Forward information exchange is used in connection/bandwidth-allocation set up, and includes for example the following parameters:

4) SETUP-DTL/ER: The designated-transit-list/explicit-route (DTL/ER) parameter specifies each VN and the DN in the path, and used by each VN to determine the next node in the path.
5) SETUP-DoS: The DoS parameter is used by each VN to compare the load state on the link to the allowed DoS to determine if the connection/bandwidth-allocation request is admitted or blocked on that link.

In B-ISUP these parameters could be carried in the initial address message (IAM).

Backward information exchange is used to release a connection/bandwidth-allocation on a link such as from a DN to a VN or from a VN to an ON, and includes for example the following parameter:

6) RELEASE-CB: The crankback/bandwidth-not-available parameter in the release message is sent from the VN to ON or DN to ON, and allows for possible further alternate routing at the ON.

In B-ISUP signalling, this parameter could be carried in the RELEASE message.

8 Signalling and information exchange requirements

Table 1 summarizes the required signalling and information exchange methods supported within each routing technology which are required to be supported across network types. Table 1 identifies:

a) the required information-exchange parameters, shown in non-bold type, to support the routing methods; and

b) the required standards, shown in bold type, to support the information-exchange parameters.

Table 1/E.360.4 – Required signalling and information-exchange parameters to support routing methods (required standards in bold)

Routing method		**Network technology (standards source)**				
		PSTN/ TDM- based (ITU-T Recommendations)	**ATM-based (ATMF standards)**	**IP-based (IETF standards)**	**PSTN/ ATM-based (harmonized standards)**	**PSTN/ IP-based (harmonized standards)**
Call routing (Number/name translation to routing address)		E.164-ADR, INRA **E.164, E.191** **E.351, E.353** **clause 8.1**	E.164-AESA, CIC **UNI, PNNI,** **AINI**	E.164-AESA, INRA, IP-ADR, CIC **clause 8.1**	E.164-AESA, INRA, IP-ADR, CIC **clause 8.1**	E.164-AESA, INRA, IP-ADR, CIC **clause 8.1**
Connection routing	Fixed routing	DTL/ER, CBK/BNA **E.170, E.350,** **E.351** **clause 8.2**	DTL, CBK **UNI, PNNI,** **AINI,** **BW-MODIFY**	ER, BNA **OSPF, BGP,** **MPLS**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**
	Time dep. routing	DTL/ER, CBK/BNA **E.170,** **E.350, E.351** **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**
	State dep. routing	DTL/ER, CBK/BNA **E.170,** **E.350, E.351** **clause 8.2**	DTL, CBK **UNI, PNNI,** **AINI,** **BW-MODIFY**	ER, BNA **OSPF, BGP,** **MPLS**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**
	Event dep. routing	DTL/ER, CBK/BNA **E.170,** **E.350, E.351** **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**	DTL/ER, CBK/BNA **clause 8.2**

Table 1/E.360.4 – Required signalling and information-exchange parameters to support routing methods (required standards in bold)

Routing method		Network technology (standards source)				
		PSTN/ TDM- based (ITU-T Recommendations)	**ATM-based (ATMF standards)**	**IP-based (IETF standards)**	**PSTN/ ATM-based (harmonized standards)**	**PSTN/ IP-based (harmonized standards)**
QoS resource management	BW alloc. & protect.	QoS-PAR, TRAF-PAR, DoS, MOD **E.351 clause 8.3**	QoS-PAR, TRAF-PAR, DoS, MOD **UNI, PNNI, AINI, BW-MODIFY**	QoS-PAR, TRAF-PAR, DoS, MOD **OSPF, BGP, MPLS**	QoS-PAR, TRAF-PAR, DoS, MOD **clause 8.3**	QoS-PAR, TRAF-PAR, DoS, MOD **clause 8.3**
	Priority routing	DoS E.351 **clause 8.3**	DoS **UNI, PNNI, AINI, BW-MODIFY**	DoS **OSPF, BGP, MPLS**	DoS **clause 8.3**	DoS **clause 8.3**
	Priority queuing	N/A	DIFFSERV **UNI, PNNI, AINI, BW-MODIFY**	DIFFSERV **DIFFSERV, OSPF, BGP, MPLS**	DIFFSERV **clause 8.3**	DIFFSERV **clause 8.3**
Routing Table Management	Topology update	HELLO, TSE **E.351 clause 8.4**	HELLO, PTSE **UNI, PNNI, AINI, BW-MODIFY**	HELLO, LSA **OSPF, BGP, MPLS**	HELLO, TSE **clause 8.4**	HELLO, TSE **clause 8.4**
	Status update	RSE **E.170, E.350, E.351 clause 8.4**	PTSE **UNI, PNNI, AINI, BW-MODIFY**	LSA **OSPF, BGP, MPLS**	RSE **clause 8.4**	RSE **clause 8.4**
	Query for status	RQE **E.170, E.350, E.351 clause 8.4**	RQE **clause 8.4**	RQE **clause 8.4**	RQE **clause 8.4**	RQE **clause 8.4**
	Routing recom.	RRE **E.170, E.350, E.351 clause 8.4**	RRE **clause 8.4**	RRE **clause 8.4**	RRE **clause 8.4**	RRE **clause 8.4**

These information-exchange parameters and methods are required for use within each network type, and for interworking across network types. Therefore it is required that all information-exchange parameters identified in Table 1 be supported by the standards identified in the table, for each of the five network technologies. That is, it is required that standards be developed for all information-exchange parameters not currently supported, which are identified in Table 1 as references to clauses of this Recommendation. This will ensure information-exchange compatibility when interworking between the TDM-, ATM-, and IP-based network types, as denoted in the left three network technology columns. To support this information-exchange interworking across network types, it is further required that the information exchange at the interface be compatible across network types. Standardizing the required information routing methods and information-exchange parameters also supports the network technology cases in the right two columns of Table 1, in which PSTNs incorporate ATM- or IP-based technology.

We first discuss the routing methods identified by the rows of Table 1, and then discuss the harmonization of PSTN/ATM-Based and PSTN/IP-Based information exchange, as identified by columns 4 and 5 of Table 1. In 8.1 to 8.4, we describe, respectively the call routing (number translation to routing address), connection routing, QoS resource management, and routing table management information-exchange parameters required in Table 1. In 8.5, we discuss the harmonization of routing methods standards for the two technology cases in the right two columns of Table 1 in which PSTNs incorporate ATM- or IP-based technology.

8.1 Call routing (number translation to routing address) information-exchange parameters

As stated before, in the Recommendation we assume the separation of call-control signalling for call establishment from connection/bandwidth-allocation-control signalling for bearer-channel establishment. Call-control signalling protocols are described for example in [Q.2761] for the B-ISUP signalling protocol, [Q.1901] for BICC, [H.323] for the H.323 protocol, [RFC2805], [GR99] for the media gateway control (MEGACO) protocol, and in [RFC2543] for SIP. Connection control protocols include for example [Q.2761] for B-ISUP signalling, [ATM960055] for PNNI signalling, [ATM960061] for UNI signalling, [ATM000148], [DN99] for SVP signalling, and [J00], [ABGLSS00] for MPLS signalling.

As discussed in ITU-T Rec. E.360.2, number/name translation should result in the E.164 AESA addresses, INRAs, and/or IP addresses. It is required that provision be made for carrying E.164-AESA addresses, INRAs, and IP addresses in the connection-setup IE. In addition, it is required that a call identification code (CIC) be carried in the call-control and bearer-control connection-setup IEs in order to correlate the call-control setup with the bearer-control setup, [ATM000146]. Carrying these additional parameters in the Signalling System No. 7 (SS7) ISDN User Part (ISUP) connection-setup IEs is specified in the BICC protocol [Q.1901].

As shown in Table 1, it is required that provision be made for carrying E.164-AESA addresses, INRAs, and IP addresses in the connection-setup IE. In particular, it is required that E.164-AESA-address, INRA, and IP-address elements be developed within IP-based and PSTN/IP-based networks. It is required that number translation/routing methods supported by these parameters be developed for IP-based and PSTN/IP-based networks. When this is the case, then E.164-AESA addresses, INRAs, and IP addresses will become the standard addressing method for interworking across TDM-, ATM-, and IP-based networks.

8.2 Connection routing information-exchange parameters

Connection/bandwidth-allocation control information is used to seize bandwidth on links in a path, to release bandwidth on links in a path, and for purposes of advancing path choices in the routing table. Existing connection/bandwidth-allocation setup and connection-release IEs, as described in [Q.2761], [ATM960055], [ATM960061], [ATM000148] and [J00], can be used with additional parameters to control SVC/SVP/CRLSP path routing, DoS bandwidth-allocation thresholds, and crankback/bandwidth-not-available to allow further alternate routing. Actual selection of a path is determined from the routing table, and connection/bandwidth-allocation control information is used to establish the path choice.

Source routing can be implemented through the use of connection/bandwidth-allocation control signalling methods employing the DTL or ER parameter in the connection-setup (IAM, SETUP, MODIFY REQUEST, and LABEL REQUEST) IE and the crankback (CBK)/bandwidth-not-available (BNA) parameter in the connection-release (RELEASE, MODIFY REJECT, and NOTIFY) IE. The DTL or ER parameter specifies all VNs and DN in a path, as determined by the ON, and the crankback/bandwidth-not-available parameter allows a VN to return control of the connection request to the ON for further alternate routing.

Forward information exchange is used in connection/bandwidth-allocation setup, and includes for example the following parameters:

1) Setup with designated-transit list/explicit-route (DTL/ER) parameter: The DTL parameter in PNNI or the ER parameter in MPLS specifies each VN and the DN in the path, and is used by each VN to determine the next node in the path.

Backward information exchange is used to release a connection/bandwidth-allocation request on a link such as from a DN to a VN or from a VN to an ON, and the following parameters are required:

2) Release with crankback/bandwidth-not-available (CBK/BNA) parameter: The CBK/BNA parameter in the connection-release IE is sent from the VN to ON or DN to ON, and allows for possible further alternate routing at the ON.

It is required that the CBK/BNA parameter be included (as appropriate) in the RELEASE IE for TDM-based networks, the SVC RELEASE and SVP MODIFY REJECT IE for ATM-based networks, and MPLS NOTIFY IE for IP-based networks. This parameter is used to allow the ON to search out additional bandwidth on additional SVC/SVP/CRLSPs.

As shown in Table 1, it is required that the DTL/ER and CBK/BNA elements be developed within TDM-based networks, which will be compatible with the DTL element in ATM-based networks and the ER element in IP-based networks. It is required [E.350], [E.351] that path-selection methods be developed supported by these parameters for TDM-based networks. Furthermore, it is required that TDR and EDR path-selection methods be developed supported by these parameters for ATM-based, IP-based, PSTN/ATM-based, and PSTN/IP-based networks. When this is the case, then the DTL/ER and CBK/BNA parameters will become the standard path-selection method for interworking across TDM-, ATM-, and IP-based networks.

8.3 QoS resource management information-exchange parameters

QoS resource management information is used to provide differentiated service priority in seizing bandwidth on links in a path and also in providing queuing resource priority. These parameters are required:

3) Setup with QoS parameters (QoS-PAR): The QoS-PAR include QoS thresholds such as transfer delay, delay variation, and packet loss. The QoS-PAR parameters are used by each VN to compare the link QoS performance to the requested QoS threshold to determine if the connection/bandwidth-allocation request is admitted or blocked on that link.

4) Setup with traffic parameters (TRAF-PAR): The TRAF-PAR include traffic parameters such as average bit rate, maximum bit rate, and minimum bit rate. The TRAF-PAR parameters are used by each VN to compare the link traffic characteristics to the requested TRAF-PAR thresholds to determine if the connection/bandwidth-allocation request is admitted or blocked on that link.

5) Setup with depth-of-search (DoS) parameter: The DoS parameter is used by each VN to compare the load state on the link to the allowed DoS to determine if the connection/bandwidth-allocation request is admitted or blocked on that link.

6) Setup with modify (MOD) parameter: The MOD parameter is used by each VN to compare the requested modified traffic parameters on an existing SVP/CRLSP to determine if the modification request is admitted or blocked on that link.

7) Differentiated services (DIFFSERV) parameter: The DIFFSERV parameter is used in ATM-based and IP-based networks to support priority queuing. The DIFFSERV parameter is used at the queues associated with each link to designate the relative priority and management policy for each queue.

It is required that the QoS-PAR, TRAF-PAR, DTL/ER, DoS, MOD, and DIFFSERV parameters be included (as appropriate) in the initial address message (IAM) for TDM-based networks, the

SVC/SVP SETUP IE and SVP MODIFY REQUEST IE for ATM-based networks, and MPLS LABEL REQUEST IE for IP-based networks. These parameters are used to control the routing, bandwidth allocation, and routing/queuing priorities.

As shown in Table 1, it is required that the QoS-PAR and TRAF-PAR elements be developed within TDM-based networks to support bandwidth allocation and protection, which will be compatible with the QoS-PAR and TRAF-PAR elements in ATM-based and IP-based networks. In addition, it is required that the DoS element be developed within TDM-based networks, which will be compatible with the DoS element in ATM-based and IP-based networks. Finally, it is required that the DIFFSERV element should be developed in ATM-based and IP-based networks to support priority queuing. It is required that QoS-resource-management methods be developed supported by these parameters for TDM-based networks. When this is the case, then the QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters will become the standard QoS-resource-management methods for interworking across TDM-, ATM-, and IP-based networks.

8.4 Routing table management information-exchange parameters

Routing table management information is used for purposes of applying the routing table design rules for determining path choices in the routing table. This information is exchanged between one node and another node, such as between the ON and DN, for example, or between a node and a network element such as a BBP. This information is used to generate the routing table, and then the routing table is used to determine the path choices used in the selection of a path.

In order to achieve automatic update and synchronization of the topology database, which is essential for routing table design, ATM- and IP-based based networks already interpret HELLO protocol mechanisms to identify links in the network. For topology database synchronization, the PTSE exchange is used in ATM-based networks, and LSA is used in IP-based networks to automatically provision nodes, links, and reachable addresses in the topology database. Hence, these parameters are required for this function:

8) HELLO parameter: Provides for the identification of links between nodes in the network.

9) Topology-state-element (TSE) parameter: Provides for the automatic updating of nodes, links, and reachable addresses in the topology database.

These information exchange parameters are already deployed in ATM- and IP-based network implementations, and are required to be extended to TDM-based network environments.

The following parameters are required for the status query and routing recommendation function:

10) Routing-query-element (RQE) parameter: Provides for an ON to DN or ON to BBP link and/or node status request.

11) Routing-status-element (RSE) parameter: Provides for a node to BBP or DN to ON link and/or node status information.

12) Routing-recommendation-element (RRE) parameter: Provides for an BBP to node routing recommendation.

These information exchange parameters are being standardized with ITU-T Recs E.350 and E.351 [E.350], [E.351], and are required to be extended to ATM- and IP-based network environments.

As shown in Table 1, it is required that a TSE parameter be developed within TDM-based PSTN networks. It is required that topology update routing methods supported by these parameters be developed for PSTN/TDM-based networks. When this is the case, then the HELLO and TSE/PTSE/LSA parameters will become the standard topology update method for interworking across TDM-, ATM-, and IP-based networks.

As shown in Table 1, it is required that a RSE parameter be developed within TDM-based networks, which will be compatible with the PTSE parameter in ATM-based networks and the LSA parameter in IP-based networks. It is required [E.350], [E.351] that status update routing methods supported by these parameters be developed for TDM-based networks. When this is the case, then the RSE/PTSE/LSA parameters will become the standard status update method for interworking across TDM-, ATM-, and IP-based networks.

As shown in Table 1, it is required that a RQE parameter be developed within ATM-based, IP-based, PSTN/ATM-based, and PSTN/IP-based networks. It is required that query-for-status routing methods supported by these parameters be developed for ATM-based, IP-based, PSTN/ATM-based, and PSTN/IP-based networks. When this is the case, then the RQE parameters will become the standard query for status method for interworking across TDM-, ATM-, and IP-based networks.

As shown in Table 1, it is required that a RRE parameter be developed within ATM-based, IP-based, PSTN/ATM-based, and PSTN/IP-based networks. It is required that routing-recommendation methods be developed supported by these parameters for ATM-based, IP-based, PSTN/ATM-based, and PSTN/IP-based networks. When this is the case, then the RRE parameters will become the standard query for status method for interworking across TDM-, ATM-, and IP-based networks.

8.5 Harmonization of information-exchange standards

Harmonization of information-exchange standards is needed for the two technology cases in the two right-hand columns of Table 1, in which PSTNs incorporate ATM- or IP-based technology. For example, the harmonized standards pertain to the case when PSTNs such as network B and network C in Figure 3/E.360.1 incorporate IP- or ATM-based technology. Assuming network B is a PSTN incorporating IP-based technology, established routing methods and compatible information-exchange are required to be applied. Achieving this will affect recommendations both with ITU-T and IETF that apply to the impacted routing and information exchange functions.

Contributions to the IETF and ATM Forum are necessary to address:

a) needed number translation/routing functionality, which includes support for international network routing address and IP address parameters;

b) needed routing table management information-exchange functionality, which includes query-for-status and routing-recommendation methods;

c) needed path selection information-exchange functionality, which includes time dependent routing and event dependent routing.

8.6 Open routing Application Programming Interface (API)

Application programming interfaces (APIs) are being developed to allow control of network elements through open interfaces available to individual applications. APIs allow applications to access and control network functions including routing policy, as necessary, according to the specific application functions. The API parameters under application control, such as those specified for example in [PARLAY], are independent of the individual protocols supported within the network, and therefore can provide a common language and framework across various network technologies, such as TDM-, ATM-, and IP-based technologies.

The signalling/information-exchange connectivity management parameters specified in this clause which need to be controlled through an applications interface include QoS-PAR, TRAF-PAR, DTL/ER, DoS, MOD, DIFFSERV, E.164-AESA, INRA, CIC, and perhaps others. The signalling/information-exchange routing policy parameters specified in this clause which need to be controlled through an applications interface include TSE, RQE, RRE, and perhaps others. These parameters are required to be specified within the open API interface for routing functionality, and in this way, applications will be able to access and control routing functionality within the network independent of the particular routing protocol(s) used in the network.

9 Examples of internetwork routing

A network consisting of various subnetworks using different routing protocols is considered in this clause. As illustrated in Figure 2, consider a network with four subnetworks denoted as networks A, B, C, and D, where each network uses a different routing protocol. In this example, network A is an ATM-based network which uses PNNI EDR path selection, network B is a TDM-based network which uses centralized periodic SDR path selection, network C is an IP-based network which uses MPLS EDR path selection, and network D is a TDM-based network which uses TDR path selection. Internetwork E is defined by the shaded nodes in Figure 2 and is a virtual network where the interworking between networks A, B, C, and D is actually taking place.

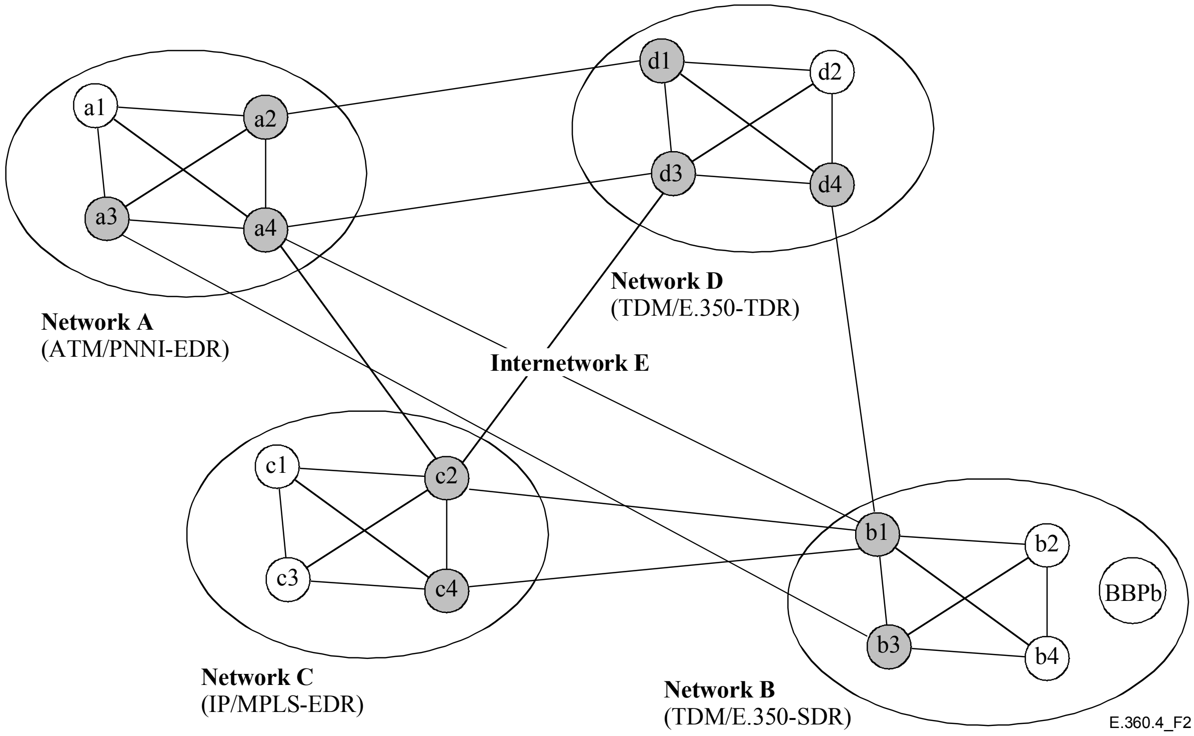

Figure 2/E.360.4 – Example of an internetwork routing scenario

BBPb denotes a bandwidth broker processor in network B for a centralized periodic SDR method. The set of shaded nodes is internetwork E for routing of connection/bandwidth-allocation requests between networks A, B, C, and D.

9.1 Internetwork E uses a mixed path selection method

Internetwork E can use various path selection methods in delivering connection/bandwidth-allocation requests between the subnetworks A, B, C, and D. For example, internetwork E can implement a mixed path selection method in which each node in internetwork E uses the path selection method used in its home subnetwork. Consider a connection/bandwidth-allocation request from node a1 in network A to node b4 in network B. Node a1 first paths the connection/bandwidth-allocation request to either node a3 or a4 in network A and, in doing so, uses EDR path selection. In that regard, node a1 first tries to route the connection/bandwidth-allocation request on the direct link a1-a4, and assuming that link a1-a4 bandwidth is unavailable, then selects the current successful path a1-a3-a4 and routes the connection/bandwidth-allocation request to node a4 via node a3. In so doing, node a1 and node a3 put the DTL/ER parameter (identifying ON a1, VN a3, and DN a4) and QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection/bandwidth-allocation request connection-setup IE.

Node a4 now proceeds to route the connection/bandwidth-allocation request to node b1 in subnetwork B using EDR path selection. In that regard, node a4 first tries to route the connection/bandwidth-allocation request on the direct link a4-b1, and assuming that link a4-b1 bandwidth is unavailable, then selects the current successful path a4-c2-b1 and routes the connection/bandwidth-allocation request to node b1 via node c2. In so doing, node a4 and node c2 put the DTL/ER parameter (identifying ON a4, VN c2, and DN b1) and QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection/bandwidth-allocation request connection-setup IE.

If node c2 finds that link c2-b1 does not have sufficient available bandwidth, it returns control of the connection/bandwidth-allocation request to node a4 through use of a CBK/BNA parameter in the connection-release IE. If node a4 now finds that link d4-b1 has sufficient idle bandwidth capacity based on the RSE parameter in the status response IE from node b1, then node a4 could next try path a4-d3-d4-b1 to node b1. In that case, node a4 routes the connection/bandwidth-allocation request to node d3 on link a4-d3, and node d3 is sent the DTL/ER parameter (identifying ON a4, VN d3, VN d4, and DN b1) and the DoS parameter in the connection-setup IE. In that case, node d3 tries to seize idle bandwidth on link d3-d4 and, assuming that there is sufficient idle bandwidth routes, the connection/bandwidth-allocation request to node d4 with the DTL/ER parameter (identifying ON a4, VN d3, VN d4, and DN b1) and the QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection-setup IE. Node d4 then routes the connection/bandwidth-allocation request on link d4-b1 to node b1, which has already been determined to have sufficient idle bandwidth capacity. If, on the other hand, there is insufficient idle d4-b1 bandwidth available, then node d3 returns control of the call to node a4 through use of a CRK/BNA parameter in the connection-release IE. At that point, node a4 may try another multilink path, such as a4-a3-b3-b1, using the same procedure as for the a4-d3-d4-b1 path.

Node b1 now proceeds to route the connection/bandwidth-allocation request to node b4 in network B using centralized periodic SDR path selection. In that regard, node b1 first tries to route the connection/bandwidth-allocation request on the direct link b1-b4, and assuming that link b1-b4 bandwidth is unavailable then selects a two-link path b1-b2-b4 which is the currently recommended alternate path identified in the RRE parameter from the BBPb for network B. BBPb bases its alternate routing recommendations on periodic (say every 10 seconds) link and traffic status information in the RSE parameters received from each node in network B. Based on the status information, BBPb then selects the two-link path b1-b2-b4 and sends this alternate path recommendation in the RRE parameter to node b1 on a periodic basis (say every 10 seconds). Node b1 then routes the connection/bandwidth-allocation request to node b4 via node b2. In so doing, node b1 and node b2 put the DTL/ER parameter (identifying ON b1, VN b2, and DN b4) and QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection/bandwidth-allocation request connection-setup IE.

A connection/bandwidth-allocation request from node b4 in network B to node a1 in network A would mostly be the same as the connection/bandwidth-allocation request from a1 to b4, except with all the above steps in reverse order. The difference would be in routing the connection/bandwidth-allocation request from node b1 in network B to node a4 in network A. In this case, based on the mixed path selection assumption in virtual network E, the b1 to a4 connection/bandwidth-allocation request would use centralized periodic SDR path selection, since node b1 is in network B, which uses centralized periodic SDR. In that regard, node b1 first tries to route the connection/bandwidth-allocation request on the direct link b1-a4 and, assuming that link b1-a4 bandwidth is unavailable, then selects a two-link path b1-c2-a4 which is the currently recommended alternate path identified in the RRE parameter from the BBPb for virtual network E. BBPb bases its alternate routing recommendations on periodic (say every 10 seconds) link and traffic status information in the RSE parameters received from each node in virtual subnetwork E. Based on the status information, BBPb then selects the two-link path b1-c2-a4 and sends this alternate path recommendation in the RRE parameter to node b1 on a periodic basis (say every 10 seconds). Node b1 then routes the connection/bandwidth-allocation request to node a4 via VN c2. In so doing, node b1 and node c2 put the DTL/ER parameter (identifying ON b1, VN c2, and DN a4) and QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection/bandwidth-allocation request connection-setup IE.

If node c2 finds that link c2-a4 does not have sufficient available bandwidth, it returns control of the connection/bandwidth-allocation request to node b1 through use of a CRK/BNA parameter in the connection-release IE. If node b1 now finds that path b1-d4-d3-a4 has sufficient idle bandwidth capacity based on the RSE parameters in the status IEs to BBPb, then node b1 could next try path b1-d4-d3-a4 to node a4. In that case, node b1 routes the connection/bandwidth-allocation request to node d4 on link b1-d4, and node d4 is sent the DTL/ER parameter (identifying ON b1, VN d4, VN d3, and DN a4) and the QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection-setup IE. In that case, node d4 tries to seize idle bandwidth on link d4-d3 and, assuming that there is sufficient idle bandwidth, routes the connection/bandwidth-allocation request to node d3 with the DTL/ER parameter (identifying ON b1, VN d4, VN d3, and DN a4) and the QoS-PAR, TRAF-PAR, DoS, and DIFFSERV parameters in the connection-setup IE. Node d3 then routes the connection/bandwidth-allocation request on link d3-a4 to node a4 which is expected, based on status information in the RSE parameters, to have sufficient idle bandwidth capacity. If, on the other hand, there is insufficient idle d3-a4 bandwidth available, then node d3 returns control of the call to node b1 through use of a CRK/BNA parameter in the connection-release IE. At that point, node b1 may try another multilink path, such as b1-b3-a3-a4, using the same procedure as for the b1-d4-d3-a4 path.

Allocation of end-to-end performance parameters across networks is addressed in clause 9/I.356. An example is the allocation of the maximum transfer delay to individual network components of an end-to-end connection, such as national network portions, international portions, etc.

9.2 Internetwork E uses a single path selection method

Internetwork E may also use a single path selection method in delivering connection/bandwidth-allocation requests between the networks A, B, C, and D. For example, internetwork E can implement a path selection method in which each node in internetwork E uses EDR. In this case, the example connection/bandwidth-allocation request from node a1 in network A to node b4 in network B would be the same as described above. A connection/bandwidth-allocation request from node b4 in network B to node a1 in network A would be the same as the connection/bandwidth-allocation request from a1 to b4, except with all the above steps in reverse order. In this case, the routing of the connection/bandwidth-allocation request from node b1 in network B to node a4 in network A would also use EDR in a similar manner to the a1 to b4 connection/bandwidth-allocation request described above.

10 Conclusions/recommendations

The conclusions/recommendations reached in this Recommendation are as follows:

- Per-VNET bandwidth allocation is recommended and is preferred to per-flow allocation because of the much lower routing table management overhead requirements. Per-VNET bandwidth allocation is essentially equivalent to per-flow bandwidth allocation in network performance and efficiency, as discussed in ITU-T Rec. E.360.3.
- EDR TE methods are recommended and can lead to a large reduction in ALB flooding overhead without loss of network throughput performance. While SDR TE methods typically use ALB flooding for TE path selection, EDR TE methods do not require ALB flooding. Rather, EDR TE methods typically search out capacity by learning models, as in the STT method. ALB flooding can be very resource intensive, since it requires link bandwidth to carry LSAs, processor capacity to process LSAs, and the overhead can limit area/autonomous system (AS) size.

- EDR TE methods are recommended and lead to possible larger administrative areas as compared to SDR-based TE methods because of lower routing table management overhead requirements. This can help achieve single-area flat topologies which, as discussed in ITU-T Rec. E.360.3, exhibit better network performance and, as discussed in ITU-T Rec. E.360.6, greater design efficiencies in comparison with multi-area hierarchical topologies.

Annex A

Modelling of traffic engineering methods

In this annex, we again use the full-scale national network model developed in ITU-T Rec. E.360.2 to study various TE scenarios and tradeoffs. The 135-node national model is illustrated in Figure A.1/E.360.2, the multiservice traffic demand model is summarized in Table A.1/E.360.2, and the cost model is summarized in Table A.2/E.360.2.

As we have seen, routing table management entails many different alternatives and tradeoffs, such as:

- centralized routing table control versus distributed control;
- pre-planned routing table control versus on-line routing table control;
- per-flow traffic management versus per-virtual-network traffic management;
- sparse logical topology versus meshed logical topology;
- FR versus TDR versus SDR versus EDR path selection;
- multilink path selection versus two-link path selection;
- path selection using local status information versus global status information;
- global status dissemination alternatives including status flooding, distributed query for status, and centralized status in a bandwidth-broker processor.

Here we evaluate the tradeoffs in terms of the number of information elements and parameters exchanged, by type, under various TE scenarios. This approach gives some indication of the processor and information exchange load required to support routing table management under various alternatives. In particular, we examine the following cases:

- 2-link DC-SDR;
- 2-link STT-EDR;
- multilink CP-SDR;
- multilink DP-SDR;
- multilink DC-SDR;
- multilink STT-EDR.

Tables A.1 and A.2 summarize the comparative results for these cases, for the case of SDR path selection and STT path selection, respectively. The 135-node multiservice model was used for a simulation under a 30% general network overload in the network busy hour.

Table A.1/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with SDR per-flow bandwidth allocation – Number of IE parameters exchanged under 30% general overload in network busy hour (135-node multiservice network model)

TE function	Information Element (IE) parameters	2-link DC-SDR	Multilink CP-SDR	Multilink DP-SDR	Multilink DC-SDR
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**21 511 629**	**21 511 629**	**21 511 629**	**21 511 629**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**24 009 586**	**21 511 629**	**21 511 629**	**21 511 629**
	CBK/BNA	**287 288**	**0**	**0**	**0**
Routing table management	TSE		**48 600**	**14 405 040**	
	RSE	**1 651 497**			**0**
	RQE	**1 651 497**			**0**
	RRE		**48 600**		

Table A.2/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with STT-EDR bandwidth allocation – Number of IE parameters exchanged under 30% general overload in network busy hour (135-node multiservice network model)

TE function	Information Element (IE) parameters	2-link STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-virtual-network bandwidth allocation)
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**21 511 629**	**21 511 629**	**21 511 629**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**32 093 788**	**21 511 629**	**3 159 027**
	CBK/BNA	**2 197 414**	**0**	**0**
Routing table management	TSE			
	RSE			
	RQE			
	RRE			

Tables A.3 and A.4 summarize the comparative results for the case of SDR path selection and STT path selection, respectively, in which the 135-node multiservice model was used for a simulation under a 6-times focused overload on the OKBK node in the network busy hour.

Table A.3/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with SDR per-flow bandwidth allocation – Number of IE parameters exchanged under 6X focused overload on OKBK in network busy hour (135-node multiservice network model)

TE function	Information Element (IE) parameters	2-link DC-SDR	Multilink CP-SDR	Multilink DP-SDR	Multilink DC-SDR
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**18 758 992**	**18 758 992**	**18 758 992**	**18 758 992**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**19 390 137**	**18 469 477**	**18 469 477**	**18 829 782**
	CBK/BNA	**103 885**	**30 459**	**30 459**	**10 899**
Routing table management	TSE		**48 600**	**14 405 040**	
	RSE	**1 072 869**			**1 507 684**
	RQE	**1 072 869**			**1 507 684**
	RRE		**48 600**		

Table A.4/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with STT-EDR bandwidth allocation – Number of IE parameters exchanged under 6X focused overload on OKBK in network busy hour (135-node multiservice network model)

TE function	Information Element (IE) parameters	2-link STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-virtual-network bandwidth allocation)
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**18 758 992**	**18 758 992**	**18 758 992**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**164 677 262**	**18 839 216**	**2 889 488**
	CBK/BNA	**134 077 188**	**12 850**	**14 867**
Routing table management	TSE			
	RSE			
	RQE			
	RRE			

Tables A.5 and A.6 summarize the comparative results for the case of SDR path selection and STT path selection respectively, in which the 135-node multiservice model was used for a simulation under a facility failure on the CHCG-NYCM link in the network busy hour.

Table A.5/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with SDR per-flow bandwidth allocation – Number of IE parameters exchanged under failure of CHCG-NYCM link in network busy hour (135-node multiservice network model)

TE function	Information Element (IE) parameters	2-link DC-SDR	Multilink CP-SDR	Multilink DP-SDR	Multilink DC-SDR
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**16 547 302**	**16 547 302**	**16 547 302**	**16 547 302**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**16 735 827**	**16 561 929**	**16 561 929**	**16 561 929**
	CBK/BNA	**7894**	**64 519**	**64 519**	**64 519**
Routing table management	TSE		**48 600**	**14 405 040**	
	RSE	**277 796**			**1 653 869**
	RQE	**277 796**			**1 653 869**
	RRE		**48 600**		

Table A.6/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with STT-EDR bandwidth allocation – Number of IE parameters exchanged under failure of CHCG-NYCM link in network busy hour (135-node multiservice network model)

TE function	Information Element (IE) parameters	2-link STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-virtual-network bandwidth allocation)
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**16 547 302**	**16 547 302**	**16 547 302**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**16 770 061**	**16 652 418**	**2 790 003**
	CBK/BNA	**22 685**	**64 519**	**13 957**
Routing table management	TSE			
	RSE			
	RQE			
	RRE			

Tables A.7 to A.9 summarize the comparative results for the case of STT path selection, in the hierarchical network model shown in Figure A.5/E.360.2, for the 30% general overload, the 6-times focused overload, and the link failure scenarios, respectively. Both the per-flow bandwidth allocation and per-virtual network bandwidth allocation cases are given in these tables.

Table A.7/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with STT-EDR per-virtual-network bandwidth allocation – Number of IE parameters exchanged under 30% general overload in network busy hour (135-edge-node and 21-backbone-node hierarchical multiservice network model)

TE function	Information Element (IE) parameters	Multilink STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-virtual-network bandwidth allocation)
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**21 511 629**	**21 511 629**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**21 511 629**	**3 161 371**
	CBK/BNA	**0**	**0**
Routing table management	TSE		
	RSE		
	RQE		
	RRE		

Table A.8/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with STT-EDR per-virtual-network bandwidth allocation – Number of IE parameters exchanged under 6X focused overload on OKBK in network busy hour; (135-edge-node and 21-backbone-node hierarchical multiservice network model)

TE function	Information Element (IE) parameters	Multilink STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-virtual-network bandwidth allocation)
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**18 758 992**	**18 758 992**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**18 758 992**	**3 037 552**
	CBK/BNA	**140 098**	**138 896**
Routing table management	TSE		
	RSE		
	RQE		
	RRE		

Table A.9/E.360.4 – Signalling and information-element parameters exchanged for various TE methods with STT-EDR per-virtual-network bandwidth allocation – Number of IE parameters exchanged under failure of CHCG-NYCM link in network busy hour; (135-edge-node and 21-backbone-node hierarchical multiservice network model)

TE function	Information Element (IE) parameters	Multilink STT-EDR (per-flow bandwidth allocation)	Multilink STT-EDR (per-virtual-network bandwidth allocation)
Call & connection routing	E.164-AESA, INRA, IP-ADR, CIC	**16 547 302**	**16 547 302**
QoS resource management	DTL/ER, QoS-PAR, TRAF-PAR, DoS, MOD	**16 712 295**	**2 809 705**
	CBK/BNA	**165 603**	**41 539**
Routing table management	TSE		
	RSE		
	RQE		
	RRE		

Tables A.1 to A.9 illustrate the potential benefits of EDR methods in reducing the routing table management overhead. In ITU-T Rec. E.360.3 we discussed EDR methods applied to QoS resource management in which the connection bandwidth-allocation admission control for each link in the path is performed, based on the local status of the link. That is, the ON selects any path for which the first link is allowed according to QoS resource management criteria. Each VN then checks the local link status of the links specified in the ER parameter against the DoS parameter. If a subsequent link is not allowed, then a release with crankback/bandwidth-not-available is used to return to the ON which may then select an alternate path. The use of this EDR path selection method then, which entails the use of the release with crankback/bandwidth-not-available mechanism to search for an available path, is an alternative to the SDR path selection alternatives which may entail flooding of frequently changing link state parameters such as available-cell-rate.

A "least-loaded routing" strategy, based on available-bit-rate on each link in a path, is used in the SDR dynamic routing methods illustrated in the above tables, and is a well-known, successful way to implement dynamic routing. Such SDR methods have been used in several large-scale network applications in which efficient methods are used to disseminate the available-link-bandwidth status information, such as the query for status method using the RQE and RRE parameters. However, there is a high overhead cost to obtain the available-link-bandwidth information when using flooding techniques, such as those which use the TSE parameter for link-state flooding. This is clearly evident in Tables A.1 to A.9. As a possible way around this, the EDR routing methods illustrated above do not require the dynamic flooding of available-bit-rate information. When EDR path selection with crankback is used in lieu of SDR path selection with link-state flooding, the reduction in the frequency of such link-state parameter flooding allows for larger peer group sizes. This is because link-state flooding can consume substantial processor and link resources, in terms of message processing by the processors, and link bandwidth consumed on the links. Crankback/bandwidth-not-available is then an alternative to the use of link-state-flooding algorithm for the ON to be able to determine which subsequent links in the path will be allowed.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series B	Means of expression: definitions, symbols, classification
Series C	General telecommunication statistics
Series D	General tariff principles
Series E	**Overall network operation, telephone service, service operation and human factors**
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	TMN and network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile and leased circuits
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks and open system communications
Series Y	Global information infrastructure and Internet protocol aspects
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2003