Alternative Multiple Spanning Tree Protocol (AMSTP) for Optical Ethernet Backbones

Guillermo Ibáñez, Alberto García, Arturo Azcorra
Dpto. Ingeniería Telemática
Escuela Politécnica Superior
Universidad Carlos III de Madrid
Av. Universidad 30
28911 LEGANES (Madrid), SPAIN
Email: gibanez@it.uc3m.es

Abstract

The availability and affordable cost of Gigabit and 10 Gigabit Ethernet switches has impacted the deployment of Metropolitan Area Networks (MANs) and campus networks. This paper presents a new protocol, Alternative Multiple Spanning Tree Protocol (AMSTP), that uses multiple source based spanning trees for backbones using Ethernet switches. It provides minimum paths and more efficient usage of optical backbone infrastructure than currently proposed protocols such as Resilient Packet Ring and Rapid Spanning Tree. The protocol exhibits features similar to MAC routing protocols like Link State Over MAC (LSOM) such as optimum path and effective infrastructure usage, without requiring MAC routing due to the use of the spanning tree protocol paradigm. AMSTP is not restricted to specific topologies such as ring or tree, but performs efficiently in arbitrary topologies. Among the application areas are optical backbones of campus and metropolitan area networks.

1. Introduction

Metropolitan Area Networks (MAN) currently face drastic changes provoked by improvements in bandwidth, scalability, cost and ease of management that provide Gigabit and 10 Gigabit Ethernet. Up to the present day, SDH/SONET has been the predominant technology, with satisfactory protection mechanisms based on ring topologies that allow reconfiguration in less than 50 milliseconds. Alternatives to SDH/SONET such as IEEE 802.17 (Resilient Packet Ring, RPR) [1] are under study to provide recovery comparable to SDH/SONET in packet networks with ring topologies.

However the ring topology on which self-healing is based imposes a restriction to applicability in networks with arbitrary topology. The existing basic standard mechanism for Ethernet backbone networks is the 802.1D IEEE Spanning Tree Protocol (STP) [2]. STP builds a frame distribution tree that prunes some links from the active topology to prevent loops. STP optimizes path cost from the root bridge to each node, but the path length among nodes belonging to the same ST is not minimal. Additionally, the STP protocol is timer based, with stabilization times exceeding 30 seconds, which can be unacceptable in several scenarios. Recently, the IEEE 802.1w Rapid Spanning Tree Protocol (RSTP) [3] has been proposed, reducing the recovery time of the topology to a range from tens of milliseconds to one second, taking advantage of the fact that full duplex links are the norm on current Ethernet networks. However, RSTP still results in a tree structure for the active topology. Another alternative, the Multiple Spanning Tree Protocol (IEEE 802.1s) [4], is based on the configuration of multiple tree instances in a region, and the mapping of VLANs to tree instances, enabling distribution of the load, and an increase in the number of the links of the network infrastructure used.

Unfortunately, there are several reasons against the use of VLANs: VLANs are suited to separating traffic, not to aggregating traffic; VLAN trunking protocols are needed between switches and VLAN configuration is complex. VLAN use (unless VLAN stacking is used) is targeted to the Access Layer of networks. Finally, the Link State Over MAC protocol (LSOM) [5] has been proposed for a Metropolitan Area Networks backbone scenario based in Ethernet switches. For achieving better usage of the infrastructure, LSOM re-lies on a link state routing protocol that uses MAC addresses instead of IP addresses. We consider multiple spanning trees a better alternative than MAC routing because spanning trees are required anyway, for frame broadcast and easier interworking with standard switches.

In this article we describe a protocol, AMSTP, in which each bridge of the backbone is the root of its own spanning tree instance. AMSTP is applicable to the Metropolitan Area Networks backbone scenario, and achieves better link usage and minimum hop distance among switches with simple configuration, in these ways combining the advantages of RSTP and MAC routing protocols.

The rest of the article is organized as follows: section two explains the AMSTP protocol and its application scenario. Finally, section three is an evaluation of AMSTP protocol against LSOM, RPR and RSTP.

2. AMSTP Protocol

AMSTP is an evolution of RSTP and MSTP that benefits from many of their basic concepts like the multiple BPDU format, but it is designed for simplicity and performance, thus suited to backbones instead of Access or Distribution Layers. In this section we first introduce both RSTP and MSTP to provide the context required to understand the application scenario and the AMSTP protocol, then highlight differences between AMSTP and MSTP.

2.1 RSTP

The Rapid Spanning Tree Protocol uses full duplex link connectivity to provide faster convergence than STP. To achieve convergence in less than one second, RSTP substitutes the timer based mechanism that STP requires to realize when the algorithm has converged, with a locally controlled proposal-agreement mechanism between adjacent switches. This mechanism in turn requires full duplex links. Another characteristic of RSTP is that all switches autonomously emit BPDUs containing their distance from the root bridge every Hello Time, instead of doing so only after reception of a BPDU from the root bridge. Several mechanisms contribute to achieving rapid reconfiguration: when a Bridge receives less preferred (higher bridge ID or path cost) BPDU information from a root or designated port, the bridge responds immediately to the neighbor bridge with its own BPDU to propagate the best information it has. With this mechanism a bridge losing its connection to the root bridge rapidly receives BPDU info from neighbor bridge(s) still connected to the root bridge, choosing the best of them to select the new root port. Figure 1 shows the standard BPDU format for RSTP and the layout of the flags octet. Flags are used by neighbor switches to communicate and acknowledge the port roles, states and their transitions. RSTP provokes flushing of learnt MAC addresses only when connectivity is incremented . The diffusion of topology changes in RSTP uses inmediate flooding over the whole topology both up and down the spanning tree, instead of the slower hierarchical flooding from root bridge that is specified in STP.

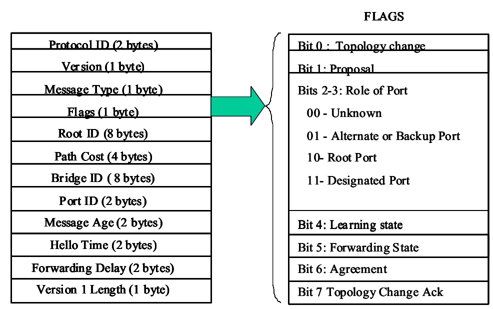

Fig. 1. Layout of RSTP BPDU and flags

2.2 MSTP protocol

MSTP (IEEE 802.1s) is based on RSTP (IEEE 802.1w) and VLAN (IEEE 802.1Q). It implements a set of multiple and independent spanning tree instances (MSTI) in a network region that is interconnected via a common spanning tree (CST) to another MST regions. Inside a region, several VLANs can be mapped to a single tree instance. Multiple tree instances at each region make it possible to improve the usage of the links. At each region, there is a tree instance (IST), identified with the number 0, that acts as the basic spanning tree. The CIST or total spanning tree is comprised of the CST that connects all the regions, and the IST that provides connectivity inside each region. This architecture is shown in figure 2. It allows separated management of the regions, appearing to the outside as a unique and separate “superbridge”, i.e. the whole region connects to the CST via one Regional Root Bridge port and a number of designated ports, like a single bridge. Therefore, no change in internal topology is influenced or produced by outside topology changes.

As a result of this architecture, MSTP configuration is complex. VLANs must be mapped to tree instances and this configuration table must be exactly the same for all bridges of the same region. Serious malfunction occurs if VLAN mapping

Proceedings of the 29th Annual IEEE International Conference on Local Computer Networks (LCN’04)
0742-1303/04 $ 20.00 IEEE

discrepancies between bridges in the same region exist. To verify mapping integrity in a region, a Configuration Identifier is used. It consists of a name, revision number and a digest (MD5) of the configuration table. This MST Configuration Identifier is included in the MSTP BPDU instead of the complete VLAN mapping to tree instances. Also, VLANs do no scale to MAN applications due to the limited numbe of supported VLANs, 4096.

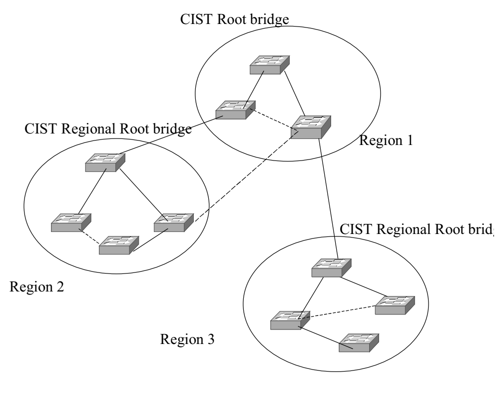

Figure 2. MST regions, trees and Regional Root Bridges

MSTP extends the RSTP BPDUs, taking care of backward compatibility. This is achieved by making the MSTP BPDUs being readable in the "RSTP" part by bridges running only RSTP. MSTP uses multiple Bridge IDs, one per tree instance. To reduce the number of MAC addresses needed, the so called MAC address reduction mechanism is used, where the two byte priority prefix of bridge ID is decomposed into 4 MSB bits, plus 12 bits for the VLAN ID. The remaining 6 bytes of the Bridge ID contain the bridge MAC address as usual. In this way a unique bridge ID for each tree instance is obtained.

2.3 Backbone Application Scenario

A scenario that we consider suited for the proposed AMSTP protocol is the Metropolitan Area backbone. A simplified example is shown in figure 3, similar to the one proposed for MAC routing protocols [5]. In this scenario, the backbone is formed by a number of switches interconnected by 10 GE links, with each switch receiving traffic from the LANs via 1GE links. Typically the LANs would be connected to the backbone via Rrouters. In these conditions, the number of MAC addresses visible for switches in the domain is limited, and the so called MAC address explosion problem (all MAC addresses of all LANs interconnected are visible in the backbone) does not occur. The switches will only learn MAC addresses of other switches and terminal nodes.

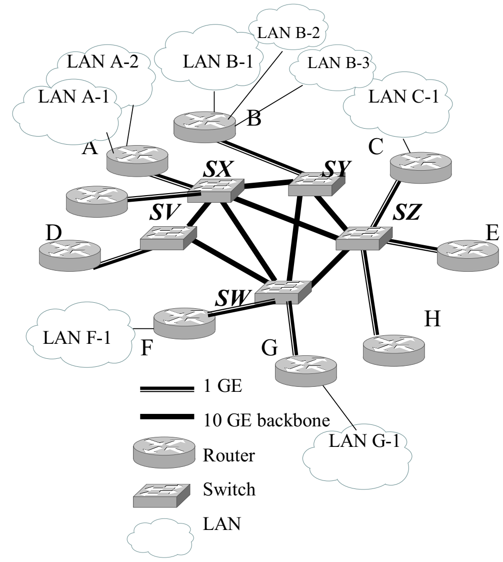

Fig. 3. MAN backbone with switches

2.3 AMSTP Protocol description

AMSTP is a multiple spanning tree protocol that uses one tree instance rooted at each source bridge in the backbone to forward frames to backbone destination bridges. We call these instances *source based spanning trees*. We define as a *complete multitree* the set of tree instances, one rooted at every bridge, that interconnects all bridges in the backbone. Backbone Switches (BS) are interconnected Ethernet switches that run AMSTP protocol between them. The protocol is designed to provide simplest configuration and maximum performance for the particular scenario of an Ethernet backbone in which Backbone Switches (BS) are connected. Therefore, the protocol is only run on the specific ports (backbone ports) that interconnect switches of the backbone. The rest of the BS ports use other standard protocols such as RSTP or STP (IEEE 802.1D). To describe the AMSTP protocol, we consider its two main functionalities: building and maintaining the spanning trees, and processing and forwarding frames in the bridges.

2.3.1 Building the trees. The process of tree building consists of two main aspects: 1) building the main tree, and 2) building the rest of the instances, called Alternate Multiple Spanning Tree Instances (AMSTI), until one tree instance per bridge is built, as shown in figure 4. Building the main tree works like in RSTP. Every bridge autonomously emits Bridge Protocol Data Units (BPDU) every Hello Time (configurable from milliseconds) to neighboring bridges. Firstly the Bridge with the lowest Bridge ID (best configured priority with *[I'm assuming you mean concatenation rather than addition]* lower MAC address appended) is elected as the Root Bridge of the main spanning tree, as each bridge receiving BPDUs from this Bridge will adopt it as the Root and propagate it in subsequently emitted BPDUs. These BPDUs (described later in the AMSTP BPDU paragraph) contain the minimum path cost from the emitting bridge to the elected Root Bridge. Every other Bridge attaches to the spanning tree by selecting as the root port the port that is receiving the "best" BPDU with minimum path cost to the root bridge. Each bridge builds its own BPDU with the result of BPDUS received from other bridges, selecting "superior" BPDUs according to the standard STP criteria (lower Bridge ID, lower path cost, lower port priority, lower port ID) and transmits them via the main tree for the continuous maintenace of the optimum main spanning tree.

The process of building all other tree instances, one per tree, is as follows: Each Backbone Bridge appends to the main tree BPDU the details of all AMSTI tree instances that the bridges participate in, i.e. all tree instances, one per BS bridge. The information appended per tree instance is called the *AM-Record* and contains similar information to BPDU tree building. The difference with other spanning tree protocols is that there is no bridge election. In our protocol the Bridge claims itself as Tree Root Bridge of its own instance and accepts equally every other Bridge as the Root of its own instance. The bridge is accepted as root by other bridges without negotiation for its tree instance (except when malfunction is detected). This source based tree instance is identified by the source bridge MAC address (root). The rest of the process is analogous to the building of up of the MSTI tree instances used by MSTP inside a MST region [4]: tree paths are selected in the bridge according to the same minimum path cost criteria as MSTP, using port priority, and port ID for tie breaking. A flag octet, identical to the one for building the basic tree instance, is used by the bridges to communicate and negotiate transitions of port states and roles per tree instance.

2.3.2 Frame processing in Backbone Switches. When processing a frame, a Backbone Switch (BS) may act as an ingress, transit or egress BS. As an ingress BS, the switch encapsulates the frame with an additional Layer 2 header containing its MAC source address, and the destination MAC address of the switch of the backbone that will act as the egress BS. The ingress BS forwards the encapsulated frame through its own source based spanning tree instance towards the egress BS. This path is minimum because the tree has been built by minimizing path cost from each root to the rest of the nodes. Source Based Trees for the example network of figure 3 are shown in figure 4, showing the source based trees built.

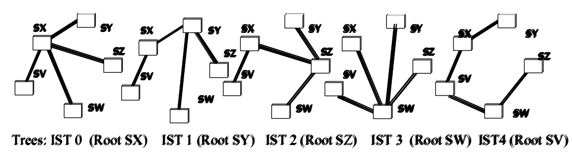

Fig. 4. The five Alternative Multiple Spanning Tree Instances for the five node network of Fig. 3

BSs learn from the received frames the MAC addresses of other BSs. They also learn the MACs of the connected backbone leaf nodes (see figure 5) by the inspection of the inner Ethernet MAC addresses of the encapsulated frames. This learning process is called double MAC backward learning. A table per switch port that includes the MAC address pairs learnt at this port is built by inspecting the packets received, since the inner source address MAC identifies the remote target to include in the table, and the outer source address MAC identifies the table to work with. When a BS has to forward a packet, it performs a lookup in the tables for the MAC destination address of the packet, obtaining the MAC of the destination Backbone Bridge (BS DA) and the switch port where the BS has been learnt, i.e. the port at which the frames were received. If there is no information for the destination MAC found in the table, a reserved multicast MAC address is inserted as destination address in the additional layer two header of the encapsulated frame, the all AMSTP switches multicast address.

The ports of switches that are not connected to AMSTP capable backbone switches do not run AMSTP, so they are kept out of the backbone forwarding mechanism. For Backbone Switches running AMSTP to interoperate with legacy switches running STP or RSTP, it seems reasonable to use a mechanism like the standard port migration protocol used by MSTP. Basically the mechanism is that if a port of an MSTP switch listens for BPDUs of protocol version 0 (STP protocol) it will emit STP BPDUs only. Recovery is not automatic; the port will not emit MSTP BPDUs until a configuration command restarts the protocol migration process, forcing renegotiation between neighboring switches.

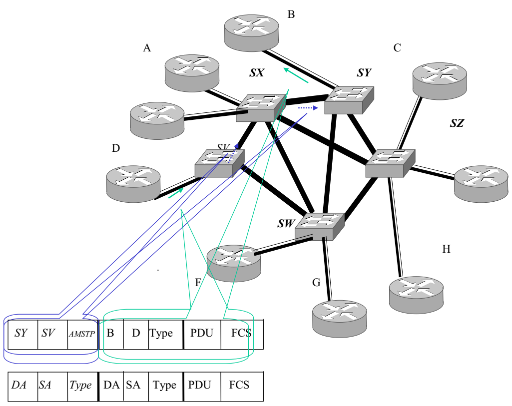

Fig. 5 Frame encapsulation/decapsulation in backbone

2.3.3 AMSTP BPDU layout. AMSTP BPDUs have a structure similar to MSTP BPDUs since both are comprised of a basic BPDU with several AM-Records appended. The AMSTP BPDU structure is shown in figure 6. The basic BPDU is used for the basic tree (0) negotiation between switches. Each of the appended AM-Records is used to negotiate a specific tree instance (AMSTI).

As in the MSTP case the BPDUs carrying the rapid spanning tree information distributed via instance 0 also carry the information of all the spanning tree instances appended to the RSTP BPDU as AM records. This avoids excessive broadcasting and simplifies the BPDU processing at the switches.

Every AM-record includes an octet flag identical to the one described for RSTP tree (fig.1). These flags are used to negotiate all transitions of each tree instance between connected ports of neighboring switches. The layout of the AM-record and the usage of flags are identical to those used for building the RSTP tree, shown in figure 2.

Minimum configuration is an important requirement for Backbone Switches. While multiple spanning tree algorithms enable much better usage of the existent infrastructure, they are usually complex to configure because a way to assign frames to tree instances is needed. In the case of MSTP, this means that the mapping of VLANs to tree instances (MSTIs) has to be configured manually at each bridge, resulting in a complex and error-prone process.

AMSTP uses Source Based Spanning Tree instances instead of VLAN mapped trees and all tree instances are automatically created, so no tree configuration is needed. The parameters to configure are those common to RSTP, such as selection of the Root Bridge and configuration of the Backup Bridges for the region and their priorities.

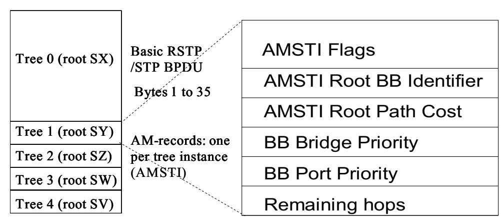

Fig. 6. AMSTP BPDU layout

2.3.4 AMSTP versus MSTP. To fully clarify the behaviour of AMSTP, we are going to highlight the main differences between it and the most similar protocol, MSTP. First of all, we must consider that MSTP is targeted to different scenarios, because while MSTP uses VLANs for traffic separation, AMSTP uses source based trees for maximum performance and traffic balancing. MSTP is suitable for Access and Distribution Layers, AMSTP applies to the Core layer. Table 1 shows the main differences between MSTP and AMSTP protocols.

3. AMSTP Benefits

In this section we analyse the proposed AMSTP protocol, beginning with some qualitative considerations that show some of the benefits of AMSTP:

• Load balancing. AMSTP performs load balancing by distributing traffic among multiple spanning trees, so the usual problem of congestion at the root bridge is avoided. Better optimization of traffic distribution may be obtained via specific configuration of path costs per tree instance for the same link..

• Efficient bandwidth usage. Multiple trees permit any topology to be used, not restricting the topologies to trees or rings. Backbone MANs are cheaper without such topology restrictions.

Table 1
Main protocol differences MSTP vs AMSTP

Protocol feature	MSTP	AMSTP
Criteria for Frame assign. to a tree	VLAN tag on frame (802.1Q)	Source MAC of frame
Tree instance formation criteria	Set of VLANs are mapped to each tree instance by configuration	Source MAC address of Backbone Bridge (automatic)
Number of tree instances	1 to 64	One per backbone bridge
Root bridge election per tree instance	As STP (lower bridge ID including bridge priority)	No election. Every bridge is root of its instance.
Bridge ID	4 MSB bit priority, 12 bit VLAN ID, 6 byte MAC	Only 6 byte MAC strictly needed
Single / Multiple regions	Multiple	Single
Main application environment	Interconnected VLAN based regions	Backbones, Core Layer

• Minimum configuration. AMSTP is simple to configure. In practice this means superior operational network reliability.

• Improved resilience. AMSTP does not use MAC routing, but relies only on spanning tree protocols. Link State MAC routing protocols need an spanning tree protocol to build a spanning tree to broadcast the Link State Advertisements to all switches.

Next, we present a quantitative analysis comparing backbone delay and maximum network throughput, derived from work performed by Garcia, Duato and Silla [5]. In this work performance of the Link State Over MAC (LSOM) protocol was compared with that of alternative protocols such as RSTP and Resilient Packet Ring (RPR) for selected four node and nine node topologies. LSOM is a link state protocol that uses MAC addresses for routing. The topologies selected as representative and appropriate for backbones are full connectivity for four nodes RSTP, dual ring for RPR and full connectivity for AMSTP and LSOM. For nine nodes we will compare dual ring for RPR and LSOM and open mesh for AMSTP, LSOM and RSTP.The same applies to sixteen node and thirty-six node topologies.

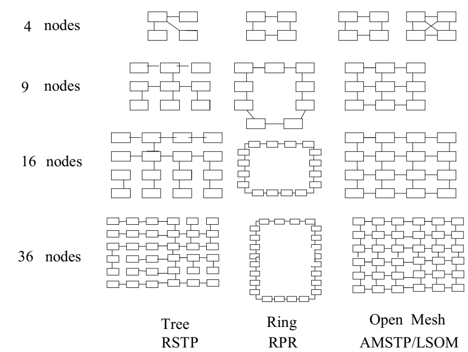

Fig. 7. Network topologies compared

AMSTP performs like LSOM since the multiple path protocol results in the same paths as the obtained through MAC routing. However, LSOM still needs a spanning tree to broadcast its link state adverstisements to all nodes. Regarding the average backbone delay performance, in the same conditions, the performance results of LSOM are applicable to AMSTP. As shown in [5] the main factor contributing to delay in optical backbones in absence of congestion is the propagation time on the fiber. At 10 Gb/s the link distances are the essential factor influencing delay (50 microseconds for a 10 Km link). No mechanisms for congestion avoidance are considered because the objective is to compare the traffic carrying capacities between protocols in selected topologies. The computed average delays obtained from average path lengths of the topologies compared are shown in fig. 8 and Table 2.

Table 2
Average backbone delay

Average Backbone Delay (microsec.)	Tree RSTP	Dual ring RPR LSOM	Mesh LSOM AMSTP
4 node	75	66,5	50
9 node	121	125	101.5
16 node	162	200	133.5
36 node	256.5	463	224.3

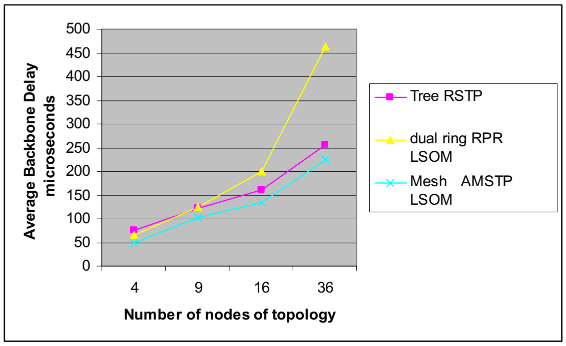

Fig. 8. Average backbone delay

The maximum throughput of the different topologies has also been compared. Fig. 9 and Table 3 show the saturation in the network topologies relative to λ (λ=1 corresponds to 8 Gbps of injected traffic at each backbone node). Open mesh topology saturates later and scales better due to better network utilization. RPR performance degrades rapidly with increasing ring size and RSP. The improvement factors in the maximum throughput of AMSTP and LSOM versus RPR are: 1.5 (four-node), 1.3 (nine-node and 3.27 (sixteen-node). If we compare AMSTP or LSOM open mesh topology with tree RSTP the improvement factors are: 3, 2 and 2.18 respectively. Tree and RPR configurations do not are not efficient beyond 16 node So the throughput of 64 node topologies was computed only for the open mesh configurations.

Table 3.
Maximum throughput as a function of topologies and protocols.

Maximum throughput (lambda)	Tree RSTP	Dual Ring RPR	Mesh AMSTP / LSOM
4 nodes	1	2	3
9 nodes	0.5	0.77	1.0
16 nodes	0.42	0.28	0.91
36 nodes	0.14	0.14	0.81
64 nodes	NA	NA	0.61

As a summary of AMSTP performance, we can say that it performs identical to LSOM or MAC based routing protocols in terms of average and maximum path length. AMSTP Maximum path length is always less than for RSTP and regarding applicability to different topologies, AMSTP is as flexible as LSOM. The maximum network size that AMSTP scales to needs to be determined, but does not seem to be critical. MSTP protocol was standardized with a maximum of 64 tree instances. The main criteria for this limit was to limit bandwidth consumed by the BPDUs for maintaining the trees. This bandwidth consumption is irrelevant in 10 GE backbones.

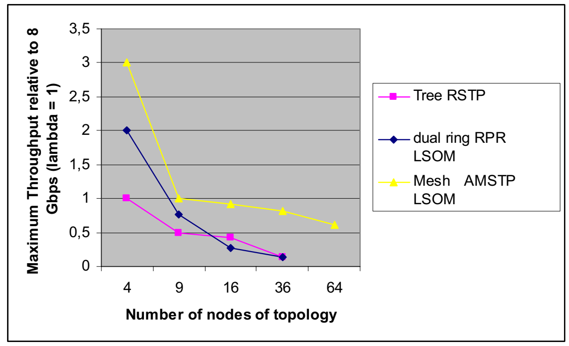

Fig. 9 Maximum throughput of network topologies

In the performance analysis above we have considered only two-dimensional connectivity in networks. Among them, open mesh topologies are likely the most economical for metropolitan networks because the cost of a high degree of connectivity in the network is important in terms of optical fiber interconnections between distant nodes. However, when applied to local networks the additional cost of higher connectivity is low (lengths of kilometers instead of tens of km.). When a high degree of connectivity is feasible, as in the core tier of local networks or in specific cases of metropolitan networks), higher connectivity topologies like n-ary hypercubes are worth to consider. We have evaluated the performance of a few n-dimensional topologies for 8, 16 and 32 nodes. The performance of these topologies is shown in Table 4, under the same conditions as for previous topologies. The saturation traffic does not decrease but increases sligthly. That permits scalability at the cost of additional links.

Table 4
Performance of high connectivity topologies

	Average Backbone Delay (microsec.)	Maximum throughput (λ)
8 node cube	86	2.19
16 node hypercube	115	2.34
32 node hypercube	129	2.42

4. Related work

As Ethernet becomes the User Network Interface of choose to access MAN and WAN, organizations like IETF, ITU, IEEE and Metro Ethernet Forum are defining Ethernet services for Wide Area Networks (WAN) and MANs [6]. Those dealing with WAN are outside the scope of our proposal to MAN backbones The IEEE 802.1 group deals with Metropolitan Area Networks standards. Currently, RPR is under the standardization process as 802.17. Metro Ethernet Networks are being standardized for Service Providers under the 802.1 group [7] as extensions to native Ethernet (IEEE) protocol, because 802.1Q is limited to 4096 VLANs and does not scale appropriately to MAN applications. Alternatively, MPLS over IP is the other alternative to transport Ethernet over the MAN. Metro Ethernet Networks, however, deal (via frame encapsulation) with the MAC addresses explosion problem. The Transparent Routing Bridges [8] concept, currently under discussion at the IETF [9], focuses on large campus networks with a single IP subnet prefix and zero node configuration. The technical focus is also on MAC based routing, trying to overcome the drawbacks of bridging (topology limited to the spanning tree, no hop count, slow reconfiguration and others) and routing (IP adresses are link-specific and vary when the host moves, routers need configuration of each link with a link prefix, the IP address range is not fully utilized due to the partition in subnets). The Spanning Tree Alternate Routing protocol (STAR) [10] uses alternate paths to tree paths between STAR bridges, with mechanisms for autodiscovery among the bridges that implement this protocol, to allow using shorter paths between them when available. It is not specifically addressed to backbones but to LANs, and it is compatible with 802.1D. Paths may be better than standard tree paths, but not necessarily minimum. A recent project that also uses multiple trees for optimum routing is [11]. It is oriented to both customer and provider-based VPNs and uses the VLAN tag in the frame for tag switching. This tag contains the MAC address of destination switch compressed into 12 bit.

5. Conclusions

A new protocol, AMSTP, has been discussed. It performs efficient frame forwarding through multiple source based spanning trees set up automatically, and uses tree instances rooted automatically at each Backbone Switch to avoid the complexity of configuring multiple spanning trees in a network. Packets are automatically encapsulated and subsequently assigned to backbone trees, ensuring that the minimum path is taken while traversing the backbone. AMSTP has similar performance to protocols based in MAC routing regarding backbone delay and infrastructure utilization, and better performance than Rapid Spanning Tree and Resilient Packet Ring. It can be applied efficiently to arbitrary topologies without restrictions on specific topologies like ring or tree. Main application is traffic distribution in optical cores or backbones of campus and metropolitan area networks. The protocol may coexist with legacy bridges running the RSTP or STP protocols.

6. References

[1] IEEE 802.17 Resilient Packet Ring Working Group. IEEE http://www.ieee.org/

[2] IEEE 802.1D.IEEE standard for local and metropolitan area networks--Common specifications--Media access control (MAC) Bridges

[3] IEEE 802.1D.IEEE standard for local and metropolitan area networks--Common specifications--Media access control (MAC) BridgesRapid Reconfiguration of Spanning Tree. http://www.ieee802.org/ 1/pages/ 802.1w. html

[4] IEEE 802.1s/D15. Draft standards for Local and Metropolitan Area Networks- Virtual Bridged Local Area Networks- Amendment 3 to 802.1Q virtual bridged local area networks: Multiple Spanning trees.

[5] R. García, J. Duato, F. Silla." LSOM: A Link State Protocol Over MAC Addresses for Metropolitan Backbones Using Optical Ethernet Switches". Proceedings c. Second IEEE NCA'03

[6] L. Zier ; W. Fischer; F. Brockners; “Ethernet-based Public Communication Services : Challenge and Opportunity”. IEEE Communications Magazine, vol. pp. 88-95, March 2004

[7] IEEE 802.1ad Provider Bridges Project. http://www. ieee802.org/1/ pages / 802.1ad.html

[8] R. Perlman, J. Touch, A. Yegin. Rbridges: Transparent Routing http://www.ietf.org/internet-drafts/draft-perlman-rbridge-00.txt April 2004

[9] The rbridge archives. http://www.postel.org/pipermail/ rbridge/

[10] K. Lui, W. C. Lee, K. Nahrstedt, “STAR: a transparent spanning tree bridge protocol with alternate routing,”. ACM SIGCOMM Computer Communication Review , vol. 3, pp. 33–46, July 2002.

[11] NEC Journal of Advanced Technology. July 2004 http://www.nec.co.jp/techrep/en/r_and_d/a04/a04_no2/ a0402p143.html.