NEXT-GENERATION SWITCHING NETWORK TECHNOLOGIES: A SURVEY

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ABSTRACT

New technologies based on Label Switching, recently proposed, have been developed as a result of various motives. These approaches represent the next generation switching networks. The most popular ones are the Cell Switching Router (CSR) from Toshiba, IP Switching from Ipsilon, Tag Switching from Cisco and Aggregate Route Based IP Switching (ARIS) from IBM. All of them are based on the switching mechanism called Label Swapping, but each implementation is quite different from the others. They all enable Network Service Providers to solve many of the issues that they struggle today. These issues include the explosive growth of the Internet and the requisite scalability of service provider networks, the ability to offer Quality of Service (QoS) to enable voice, video, and multimedia applications over IP, and to offer differentiated services such as Virtual Private Networks (VPNs). This paper aims to show some of the main characteristics of Label Switching, in addition, it presents a global view of all approaches mentioned above, differences and comparisons among their key aspects.

1. INTRODUCTION

Since the Internet was opened to commercial traffic, it has grown rapidly from an experimental research network to an extensive public data network [1]. Demand is pushing the capabilities of today's Internet in several dimensions including, but not limited to, transmission bandwidth, number of hosts, QoS, geographic size and traffic volume [4]. At the same time, the Internet is evolving from best-effort service towards a service framework with QoS assurances, which will be necessary for many new applications such as voice over IP (VoIP), videoconferencing, and multimedia, adapting to the needs of its users and incorporating new technologies as it has been developed.

There is a continually demand for an increased number of routing functionalities, and also for a bigger flexibility related to the delivery of the routing services, and hence, for the development of new protocols according to these goals [2].

The integration between IP (Internet Protocol) and ATM (Asynchronous Transfer Mode), trying to combine the best of ATM - fast and simple forwarding, with the best of IP - ubiquity, scalability and flexibility, is one of the challenging factors, among others mentioned above, which allowed the development, by many companies, of approaches whose basic concepts came from Label Switching.

This paper is organized as follows: Section 2 shows some characteristics of Label Switching like the use of the label swapping technique as the forwarding algorithm and its subsections presents features of the most popular Label Switching approaches that are CSR from Toshiba, IP Switching from Ipsilon, Tag Switching from Cisco and ARIS from IBM; Section 3 discuss the principal comparison points and differences among the technologies mentioned before. It shows some fundamental design decisions and some characteristics and functionalities supported by the Label Switching approaches mentioned before; Section 4 presents the standard in this area, called MPLS, that has been standardized by the IETF. And finally, concluding remarks are given in Section 5.

2. LABEL SWITCHING

It is called label, a relatively short and fixed length value, considered a simply entity and with no internal structure which is used to make forward decisions during the forwarding of packets through a network that uses the Label Switching technology.

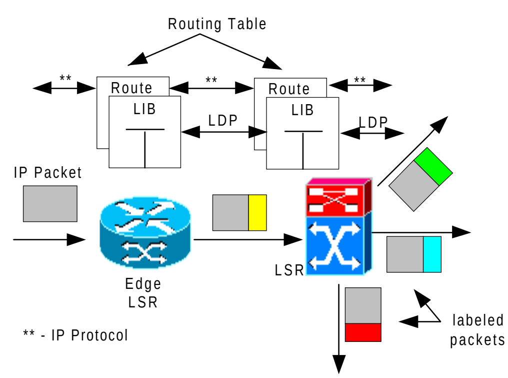

Figure 1 – Simplified Label Switching function.

The value of the label is normally local to a single link. It is forwarded across the network by the packets, and as the packets are been forwarded in the core nodes of the network, these ones replace the label by a new value before forwarding them to the next hop. For this reason, the forwarding algorithm is called

Label Swapping, the same technique that, not coincidentally, is used to forward data in ATM switches.

Unlike ATM, all Label Switching techniques strive to maintain the control paradigm of the IP (Figure 1). They use the IP addresses and standard Internet routing protocols. Thus, in many aspects, they combine the best of ATM with the best of IP, like it was mentioned above. There are also many significant differences among the approaches, such as the use of either data or control traffic to drive the establishment of forwarding state.

The standard in this area, which has been defined by the IETF, is called MPLS (MultiProtocol Label Switching). It is a neutral term to refer to these techniques.

2.1 CSR – Cell Switching Router

CSR is a Label Switching approach from Toshiba, which predated the MPLS initiative by several years. Its ideas were first presented to the IETF IP over ATM Working Group in the beginning of 1994 and to the ATM Forum's Service Aspects and Applications Working Group in the same year. When the effort to charter the MPLS Working Group began in the late 1996, the CSR was presented as one of the candidates approaches to Label Switching (along with Tag Switching and ARIS) [2].

The CSR architecture introduced the idea that an ATM switching fabric could be controlled by IP protocols rather than ATM signaling protocols. The fundamental architecture intent is that procedures and protocols that work in the normal IP environment should work transparently on CSR networks.

2.2 IP Switching

IP Switching, which was announced in the beginning of 1996, is a Label Switching technology proposed by Ipsilon, which gained significant attention in the marketplace rather than the CSR.

This approach uses just the IP component plus a label binding protocol to allow forwarding of IP on ATM switch hardware. IP Switching relies on IP routing protocols to establish a routing information base from which the next hop for a packet can be determined, and only after the next hop has been identified, does the separate process of negotiating label bindings with that next hop takes place.

2.3 Tag Switching

Tag Switching, a Label Switching approach proposed by Cisco, is a high-performance technology that can deal with high traffic rates, applications that require a large bandwidth, multimedia applications, and also a great number of users. It also allows the internetworking between IP and ATM technologies in the same network environment.

This approach aim is to label the packets from multiples protocols that are supposed to be sent through a Tag Switching network.

2.3 ARIS – Aggregate Route Based IP Switching

ARIS is a Label Switching approach proposed by IBM that was developed in parallel with Tag Switching because the announcement of ARIS followed the Tag Switching announcement by only a few weeks. Like the name suggests, ARIS binds labels to aggregate routes, rather than to flows.

One of the key concepts of ARIS is the egress identifier (egress ID). In the simplest case, an egress ID represents the identity of the ISR at the egress end of a label switched path [7]. However, the term is more of a catchall for anything that might have a label switched path associated with it.

3. COMPARISON AMONG THE TECHNOLOGIES

All Label Switching approaches have specific characteristics in common like the use of the IP protocol and the ability to run on standard ATM hardware. Each technology, proposed by a different company, uses a certain sort of binding distribution protocol between labels. However, there are many significant differences and some of them are really crucial when designing an architecture, and others just interfere on the scheme priorities.

The most important difference between schemes is the choice between a data-driven or a control-driven approach. Table 1 shows a classification of the approaches, already presented, describing in terms of the fundamental design decisions and some characteristics and functionalities supported by all the Label Switching approaches.

3.1 Components

In a CSR domain, the router capable to implement this technology is called CSR (Cell Switching Router). On the other hand the one that is capable to implement the ARIS approach is called ISR (Integrated Switch Router). A specific device that implements the IP Switching architecture is called IP switching router. It consists of two parts: (1) an ATM switch; (2) an IP Switch Controller. A Tag Switching network is composed by two devices: (1) TSR - Tag Switching Router; (2) Edge TSR.

3.2 Characteristics of Label Distribution Protocols

Like all Label Switching approaches, CSR requires a Label Swapping forwarding and a label distribution mechanism to realize the packets forwarding. The label distribution protocol used is the Flow Attribute Notification Protocol (FANP). It is a data-driven protocol and an independent approach to label binding establishment.

IP Switching defined not only a label distribution protocol - IFMP (Ipsilon Flow Management Protocol), but also a switch management protocol - GSMP (General Switch Management Protocol).

Tag Switching views piggybacking tag binding information on top of routing protocols as the preferred way of distributing tag binding information. However, because this option may not always be viable, Tag Switching provides its own mechanism to distribute tag binding information, the TDP (Tag Distribution Protocol).

The ARIS protocol is a peer-to-peer protocol that runs between ISRs directly over IP. The protocol includes an initialization phase followed by the active phase.

3.3 Control-driven x Data-driven

A control-driven approach creates label bindings in response to the arrival of control traffic, such as routing updates or research reservation requests. By contrast, data-driven approaches look at the arriving patterns of data and decide based on that traffic whether to establish a label binding for some class of data packets or not. The choice between these two methods for establishing bindings will clearly have some impact on performance and scalability.

One attractive property of data-driven label binding is that it creates a binding only when there is a data traffic that could utilize this binding. But a data-driven binding also has some drawbacks compared to control-driven label binding. First of all, the amount of control traffic needed to distribute label binding information may be higher and the difficulty in predicting performance because it depends so much on the detailed characteristics of the offered traffic. A small change in the length or number of flows may cause a large change in the percentage of traffic that can be switched, resulting in overload of the control processor [2].

CSR and Tag Switching are control-driven approaches and on the other hand, IP Switching and ARIS are data-driven ones. There are some advantages of control-driven to data-driven approaches as follow: (1) control-driven approaches provide a more efficient use of labels than traffic-driven. This yields the scalability required for public Internet service networks, where the number of flows is enormous, and the rate of change of flows is very high; (2) the control-driven approaches switches establish label mapping at the same time that they populate their routing tables; (3) these approaches can be used both on short-lived flows and on the initial packets of long-lived flows, avoiding bottlenecks in high-performance applications; (4) control-driven method minimizes the amount of additional control traffic needed to distribute label binding information, because this is distributed only in response to control traffic, independent of data traffic; (5) control-driven method makes the overall scheme independent of and insensitive to the profile data traffic. Forwarding performance is improved because labels are bound before data traffic arrives rather than being created as data traffic arrives; (6) control-driven method simplifies overall system behavior, because the control plane is controlled solely by control traffic rather than by a mixture of control and data traffic.

3.4 Upstream Versus Downstream Label Binding

The label switching control component uses both local and remote bindings to populate its forwarding table with incoming and outgoing labels. This can be done in two ways. The first method is called downstream label binding and the second method is called upstream label binding.

In the CSR network model, label binding follows the upstream method. Upstream CSRs identify candidate IP flows that should benefit from cut-through in the network. In IP Switching, like in ARIS, labels are allocated by the downstream label switching router. The upstream node is informed by a LDP message to use that label for the flow specified. In Tag Switching, there are two allocation schemes: downstream and upstream. But if the Tag Switching is used over ATM, a scheme called downstream-on-demand, like the downstream scheme but the process is realized after a request only, is used.

3.5 Performance

The first thing to notice about performance of various label switching schemes is that, under ideal conditions, all of the schemes can forward data at whatever speed label switching runs. The key phrase is “under ideal condition”. But how close to ideal will the real the network environment be? This question is quite difficult to be answered, especially for data-driven schemes, because the ideal conditions for this scheme are when all flows are infinitely long-lived [2].

So, it is easier to reach the best performance with control-driven scheme rather than data-driven one, because the last depends on the data traffic, which does not have the same characteristics all the time.

3.6 Soft and Hard State

The two data-driven approaches, IP Switching and CSR, use soft state, as does ARIS, whereas Tag Switching uses a mixture of hard and soft state, depending on the type of FEC to which labels are being bound.

Both data-driven approaches made the same design choice. This seems eminently sensible when one considers the difficulty of deciding exactly what a flow is and especially, when it has ended. Thus, soft state seems like a natural choice for data-driven schemes.

Tag Switching, for cases where TDP is used, is a hard state approach. The reason for this is primarily efficiency.

3.7 Ordered x Independent Binding

Use of ordered versus independent creation of forwarding table entries has certain implications on the overall system behavior. First of all, the ordered creation adds latency to the construction of forwarding entries by LSRs, because it serializes the creation of such entries among a set of LSRs. With the independent creation a LSR may establish its forwarding entries in parallel with other LSRs. Second, the ordered creation creates additional interdependencies among LSRs, which in turn brings robustness and scalability problems. In contrast, the independent creation minimizes such interdependencies.

ARIS uses ordered label distribution and Tag Switching uses an independent approach, even been two control-driven technologies. The result of these choices is that there are more situations where ARIS cannot label switch packets for some period of time and must either resort to layer 3 forwarding or dropping. However, ARIS can create label switched paths through points of routing aggregation, at the cost of loss of scalability.

3.8 Encapsulations

Tag Switching approach uses different tag encapsulations so that it can be used with a variety of technologies. With some link layer technologies (e.g. ATM), the link layer header has adequate semantics to carry tag information. However, there are other link layer technologies (e.g. Ethernet, FDDI, Token Ring, etc), whose link layer headers don't have semantics adequate to carry tag information. When Tag Switching is used over subnetworks built out of such technologies, tag information is carried in a small shim inserted between the link layer and the network layer headers.

In addition to the obvious label encapsulation for ATM, in which labels are carried in the VCI or VPI field, the ARIS team has developed a LAN encapsulation that places labels in the destination field on the MAC header. Although it avoids fragmentation issues, the approach raises some problems of label space allocation and the need to operate LAN interfaces in promiscuous mode.

3.9 Hierarchical Switching

One of the key innovations of Tag Switching is the use of a hierarchy of tags, organized as a tag stack, each of them is used in a different environment. In this case, TSR within a domain only need to know the route information within that domain, which is much less than the route information about the whole Internet. This is a good feature in terms of scalability. But the TSR at the border of the domain need to know all the route information and must add (or remove) tags to packets entering (or leaving) its domain. This support exists for ARIS too and there is no such support for CSR and IP switching.

3.10 Packet TTL Decrement and Loop Prevention

IP Switching uses the TTL field and because of this performs the loop prevention. CSR, like IP Switching, is a data-driven approach, but it doesn't perform the TTL decrement, therefore it doesn't have loop prevention. Tag Switching provides exactly the same degree of protection from loops that IP provides. Looping paths may be set up, but the TTL field in the tag header causes

Table 1 - Classification of the Label Switching approaches in terms of the fundamental design decisions, main characteristics and functionalities.

	MPLS	CSR	IP Switching	Tag Switching	ARIS
Data- or Control-driven	control-driven.	data-driven.	data-driven.	Control-driven.	control-driven.
Link Layer	ATM, FR, LAN.	ATM, FR, etc.	ATM.	ATM, FR, LAN.	ATM, FR, etc.
Network Layer	Ipv4, others.	Ipv4, others.	Ipv4, Ipv6.	Ipv4, others.	Ipv4, Ipv6, others.
Loop Prevention	supported.	unspecified.	supported.	Supported (on ATM only).	supported on all media.
Binding Distributions	upstream and downstream.	upstream.	downstream.	Upstream and downstream.	Downstream.
Binding Creation	independent.	independent.	independent.	Independent.	ordered (from egress).
Label Distribution Protocol	separate – LDP.	separate – FANP.	Separate – IFMP.	Piggybacking / separate –TDP.	separate - ARIS protocol (except RSVP).
Components	LSR and edge LSR.	CSR edge devices.	switch and IP gateway.	TSR and edge TSR.	ISR
Soft or hard state	soft/hard	soft	soft	soft/hard	soft
Explicit Route Support	yes.	no.	no.	yes.	yes.
Multicast	yes.	unspecified.	yes.	yes.	partial.
Hierarchy of labels	yes.	no.	no.	yes.	yes.
RSVP	yes.	yes.	yes.	yes.	yes.

packets to be discarded if they are stuck in a loop. ARIS actually prevents the establishment of looping paths in the first place, by carrying a list of LSRs in the message that establishes the path. If a LSR sees its own identifier in this list, it knows that the ESTABLISH message has followed a loop, and thus it aborts the attempt to create a label switched path.

3.11 Multicast Support

Supporting multicast forwarding with label switching places certain requirements. Multicast routing uses spanning trees (multicast distribution trees) for forwarding of multicast packets, where a tree could be associated with either a combination of a particular source and multicast group, or just with a particular group.

To provide consistent forwarding of multicast packets with label switching, when an LSR receives a packet, it must be able to unambiguously identify a particular multicast distribution tree that the LSR should use to forward the packet. To identify a particular multicast distribution tree, the only information provided by a packet to a LSR is (1) a label carried in a packet and (2) the interface that the packet arrived on. Relying on just a combination for identifying a particular tree requires that a LSR maintains its label switching table on a per-interface basis.

With IP Switching, receivers use the IGMP (Internet Group Management Protocol) to join a multicast group. At an IP switching router, a multicast flow is replicated by the ATM switch into a number of branches. Flows for branches of a multicast tree are identified and redirected by the downstream nodes in exactly the same manner as for unicast traffic. The IP Switching router can also send a copy of the multicast flow to the switch controller, so that branches that have not yet established flows can receive their copies through the default channel.

To support multicast with Tag Switching, a TSR should be able to select a particular multicast distribution tree based solely on (a) the tag carried in a packet and (b) the interface on which the packet was received. This requires a TSR to maintain its TFIB (Tag Forwarding Information Base) on a per-interface basis.

ARIS supports multicast by defining another type of "egress identifier" and binding labels to those identifiers. An egress ID in no way represents an egress router in this case, since the multicast trees to which labels are bound have multiple egress from the ISR region.

4. MPLS – MULTIPROTOCOL LABEL SWITCHING

It has been standardized by the IETF and it has the best characteristics of the prior work. But it has many features in common with Tag Switching, because Cisco sent its Label Switching approach to the IETF to get the standardization and because this technology is considered one of the best technologies among the others.

The MPLS consists of two components (Figure 2): (1) Forwarding Component – uses the generated labels to send the packets across the label switched domain; (2) Control Component – ensures that the label switches maintain correct forwarding information via Label Distribution Protocol (LDP).

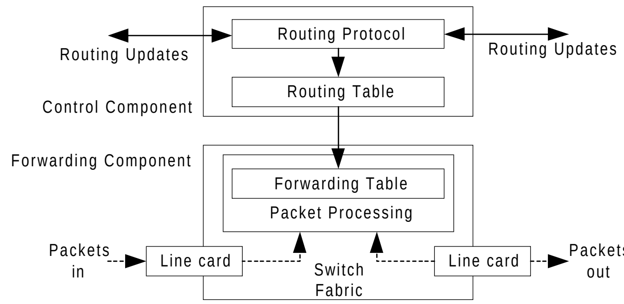

Figure 2 – MPLS Components

By completely separating the control component from the forwarding component, each component can be independently developed and modified. The only requirement is that the control component continues to communicate with the forwarding component by managing the packet-forwarding table.

There are two operation stages in a network that uses MPLS. The first one occurs before the entrance of the packets into the domain and, the second one when the packets arrive at the Edge Label Switching Router (Edge LSR) so they can be forwarded through the Label Switching domain [3]. All the LSRs, including the ATM switches, implement IP routing protocols such as OSPF and BGP, and each LSR uses the result of these protocols to build the LIB (Label Information Base), a database that is maintained by an LSR.

The MPLS works basically as follows (Figure 3): a packet that arrives at the ingress point of a MPLS network is labeled. This packet is forwarded to the next hop in the core of the network according to the label value that was attributed to it. This is done by the edge LSR.

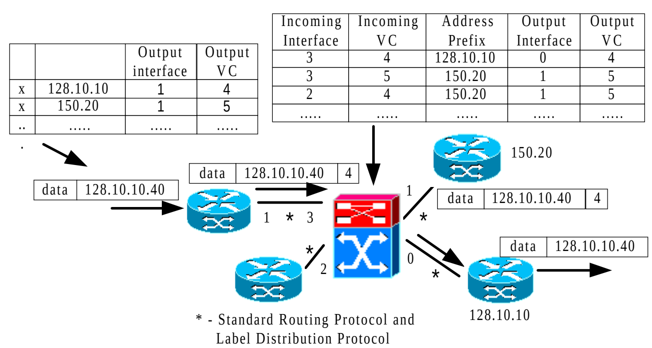

Figure 3 – Simplified Function of a MPLS Network.

When the labeled packet arrives at the next hop LSR, in the core of the network, it swaps the label value for a new appropriate one so that the packet can be successfully switched to the next downstream LSR. The label value is exchanged because the label is local to a single link. This procedure is repeated until the labeled packet reaches the edge LSR at the egress of the MPLS network. The egress device strips off the packet's label so that it can be delivered [9].

5. CONCLUSIONS

A brief comparison among the most important technologies based on Label Switching was presented. The main features of each mentioned approach were outlined, including the common characteristics and also the differences among them.

From this study it could be noticed that no approach is universally better or worse than the others are. Depending on the application that is been used, Internet, LAN, WAN etc, the most adequate approach can be chosen. Each technology has its advantages and disadvantages to a specific application if compared with the others. But it is possible to notice that if it is consider as a whole, Tag Switching presents the majority of the advantages of each characteristic analyzed.

To enable more exactly comparisons, a deeper performance study among the Label Switching approaches, is needed. At present, there are some of these technologies which have already been developed and are on the marketplace; others exist only in theory. Therefore, it is a little difficult to develop this kind of study. The next step of this work is a comparative study, based on simulations to be realized, so that more accurate results, related to the technologies can be obtained.

However, an important point in this study is the real advantages offered by the new technology called Label Switching, compared with the conventional routing techniques. It may be hard to justify label switching from a performance or a cost standpoint alone, but the label switching offers real advantages in routing functionality, IP/ATM integration and scalability.

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