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TITLE: Advanced Routing Algorithms on MPLS
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Summary:

In this paper, we will survey and classify researching advanced routing algorithms that take advantages of MPLS network to extent routing algorithms, supporting QoS services and traffic engineering. We also consider some recent projects that are researching and working with advanced routing algorithms .This paper include 5 parts. Part 1 presents Introduction. Part 2 presents QoS based routing, Classification of QoS routing. Part 3 Traffic based routing presents Based on information of current network such as: Minimum Interference Routing Algorithm (MIRA)[7], Dynamic On line Routing Algorithm (DORA)[9] and Based on profile information such as: Profile Based Routing (PBR)[8]. Part 4 presents Employing advanced routing algorithms .And last, Simulation with the combination of essential packages, we build simulate environment for MPLS based on ns2, setup some advanced routing algorithms, and evaluate them with old routing protocol.

1. Introduction

From the requirement of real network, must be a new protocol that is the combination between IP protocol and protocols on broadband networks such as Frame Relay, ATM, … .This protocol doesn't change entire existing architecture IP network and also not reduce the speed of broadband network. MPLS protocol is researched and developed. MPLS protocol is implemented by encapsulating a small header to IP package on MPLS domain, so that we don't have change so much. Each header has label, MPLS can use label for switching technique to reduce the time delay package on each router and remain the speed of broadband network. We introduce brief information about MPLS.[1][2][3]

In MPLS, packets are encapsulated MPLS header at ingress point. Each header has 4 bytes, and the important part is the label used to switch packets into the Label Switched Path (LSP) at each node. LSPs carry aggregate flows including packet flows that have common characteristics such as same source-destination address, destination address match a particular IP address prefix or have the same TCP port number… The set of these packets is called FEC, and an FEC will be associated with a LSP to forward packets. The labels of LSP from ingress to egress of MPLS domain are bound by signaling protocols such as RSVP-TE or CR-LDP.

When the MPLS network systems develop, many routing problems appear. The problem of QoS services is choosing the route that satisfies QoS request about bandwidth, delay, packet loss… The problem of traffic engineering is optimizing and using effectively network resources by controlling traffic flow. The requirement for developing advanced routing algorithms that can satisfy more LSP requests on dynamic routing in MPLS (IP routing protocol is only take care about optimal solution on present but doesn't care about the ability of blocking on future, so many LSP demands on future can't be satisfied). Administrator usually computes the optimal solution of these problems by himself and then configure static route on MPLS router. But this method isn't efficient for large network and not dynamic solution. For all above reasons, advanced routing algorithm is researched, developed and deployed on MPLS networks.

Besides, MPLS also has essential characteristics supporting for advanced routing algorithm. The LSPs can be setup independently with old routing algorithm (IP routing) because LSPs are routed by designed labels. So that, we can design LSPs with advanced routing algorithm to extent routing functions. Advanced routing protocol request that new extension distribution protocols distribute not only information such as metric, hop-count, delay… (used by old routing protocol such as OSPF, IS-IS…) but also information about reverse resource of network. Traffic engineering is a strong point of MPLS and MPLS completely support that information with extension protocols such as OSPF-TE, IS-IS-TE… because MPLS need them for building Traffic Engineering Database (TED).

There are many advanced routing algorithms on MPLS that are being researched. We classify advanced routing algorithms to two types. The one that support for constraint routing and QoS services is called QoS based routing algorithm. The other that support for finding solution satisfying many LSP demands and reducing blocking on future is called traffic based routing. In session 2, we discuss about QoS based routing algorithm, session 3 about Traffic based routing, session 4 about model and recent project and session 5 about simulation.

2. QoS based routing

Today, Internet supports only "best-effort" services, but does not have a mechanism to guard packet lost, bandwidth, delay, jitter… While old services such as FTP, mail… are working well with traditional Internet, the other services such as Internet Telephony, Video-On demand … request high bandwidth, low delay and small jitter.[4]

QoS is a set of requirement services for network when transferring data. In other words, QoS is level measurement of services for user, characterized by loss probabilities, bandwidth, end-to-end delay. QoS is a deal between user and network provider by Service Level Agreement (SLA).

QoS based Routing: Route the path satisfy the QoS services that is the agreement between user and network service provider about bandwidth, delay, loss probabilities, … Besides these constraints, other constraints that must be satisfied are optimizing network resources.

QoS Metric: SLA is expressed by QoS metrics. QoS metrics include bandwidth, jitter, cost, loss probability. Metric is classified to three kinds: additive, multiplicative, and concave

Set $m(n_1,n_2)$ is the metric of link (n_1,n_2). With any path P, $P= (n_1,n_2,n_3,\ldots n_i, n_j)$, metric m is:

- **additive**, if $m(P) = m(n_1,n_2) + m(n_2,n_3) + \ldots + m(n_i,n_j)$
- **multiplicative**, if $m(P) = m(n_1,n_2) * m(n_2,n_3) * \ldots * m(n_i,n_j)$
- **concave**, if $m(P) = \min\{ m(n_1,n_2), m(n_2,n_3), \ldots , m(n_i,n_j) \}$

Classification of QoS routing:

With some metrics, the path metric is affected by the links with minimum metrics (bandwidth, buffer space). We call these links the bottle links. We have link optimize routing (find the path which is optimized at bottle links) and link constrained routing (find the best path with bottle links satisfy some constraints)

With some metrics, the metric of the path is the combination of all metrics of all links along this path. We have path optimize routing (find the path with optimize path metric.) and path constrained routing (find the path satisfy some constraint metrics)

Routing algorithms can be solved with polynomial time

- Link-constrained, path-optimization routing
- Link-constrained, link-optimization routing
- Multi-link-constrained routing
- Link-constrained, path-constrained routing
- Path-constrained, link-optimization routing

For these problems, first we must solve the link-constrained or link-optimization routing problem, we will have limited set of result dependent on number of link, and then we solve path-constrained or path-optimization routing problems.

Routing algorithms can't be solved with polynomial time (NP problems)

- Path-Constrained, Path-Optimization (PCPO) routing
- Multi-Path-Constrained routing (MPC): If all metrics are depended on common metric, we can convert MPC problem to shortest path with polynomial time.

To find optimal solution for these problems, we must trace all paths from source to destination, but the time to trace all of them is exponential function of number of vertices, so it is NP problems. We can only find the solution near the optimal solution by using searching algorithm with heuristic to reduce searching space. Example: with Multi-path-constrained routing problem, we can choose the heuristic is a metric that is a function combining all metrics, and the minimum value of that combination metric induces nearly optimal solution.[6]

There are many QoS-based routing algorithms that are systematically classified on [5].

3. Traffic based routing

With shortest path algorithms, the drawback of these algorithms is that when an arc is good for many source-destination pairs, some source-destination pairs will choose this arc for their path and can induce the collision on this arc. Traffic based routing algorithm does not only optimize network resource for present time, but also for future demands. Traffic based routing algorithms will predict the links that will be blocked if we route many traffics through them and will reduce routing traffic going through these links.

Classify

- Based on information of current network, compute and choose the links that will minimize ability of block for future demands.
- Based on statistical information measured by server or router, we have approximate information about demands on future. We call this statistical information "profile". After having profiles, we solve linear programming to find optimal solution satisfying all profiles, that is, find optimal solution for future.

Following, we will show some traffic-based routing algorithms that support basic concept and suggest general ideals for traffic-based routing algorithms.

3.1. Based on information of current network

Minimum Interference Routing Algorithm (MIRA)[7] We know that to satisfy demand setup LSP, the less maxflow value we reduce of all ingress-egress pairs after choosing the path, the larger ability of network we have to satisfy for future demands. This problem can be described by math formulation: Set θ_{sd} is maxflow of ingress-egress *(s,d)* pair that is computed after satisfying setup LSP demand, solution of problem is maximize sum of θ_{sd} of all ingress-egress pairs. The optimization goal is:

$$Maximize \sum_{(s,d)\in P(a,b)} \theta_{sd}$$

Besides, we must find the traffic on each link of each ingress-egress pair, setup the path with bandwidth *D* and satisfy constraints: total bandwidth of all traffic going through each link is less than residual bandwidth of this link, and total traffic going in is equal traffic going out each node on networks.

Solving complete problem is NP problem. Author finds the approximate solution for solving problem and that can be described by MIRA algorithm: from the residual bandwidth information of all arcs, we can compute the maxflow of all ingress-egress pairs. With each ingress-egress pairs, we find *mincut* sets, and the arcs belonging to these sets are called critical links. The critical links have the properties that if we route the traffic of ingress-egress pairs going through them, the maxflow of the ingress-egress traffic pair will be reduced. So, the target of MIRA algorithm is maximizing avoiding routing through critical links.

Dynamic On line Routing Algorithm (DORA)[9] DORA algorithm also is based on current network information to anticipate links that have largely able collision to avoid routing through them. DORA is different from MIRA that MIRA is based on maxflow, while DORA consider about the number of path going through a link (Consider all ingress-egress pairs). Set *n* is the number of path (of all ingress-egress pairs) going through an arc, the larger value of *n*, the larger ability collision on this arc on future, so that DORA choose *n* is the weight of each arc, and run shortest path algorithm to find the shortest path having minimum weight value. Furthermore, combining *n* with another optimal constrained metric (example *m*), DORA algorithm build weigh value by formulation:

$$w = \alpha n' + (1-\alpha)m'$$

n', m' is normalized value of *n,m* that has the value in range *[0,100].*

$0 \le \alpha \le 1$, choose α value is based on experience.

3.2. Based on profile information

Profile Based Routing (PBR)[8] We assume that by using server or router, we measured the traffic going through network, and have the profiles of traffic flow. Each profile belongs to class, include B_i denotes aggregate bandwidth requirement of aggregated LSP setup requests between source s_i and destination d_i and is mapped to *classID*. We symbolize each profile by *(classID,* s_i*,* d_i*,* B_i*)* called commodity i^{th}. For approximately satisfying all requests on future, we must solve simultaneous equations to find the amount traffic of each ingress-egress pair distributed on each link (first step). If the problem has solution, we apply the solution to our network. For each LSP demand, we determine its class and use solution (on first step) for each class to initialize network topology, then use shortest path algorithm to find optimal solution (second step). On general case, not all profiles can be completely satisfied. PBR algorithm adds excess edges to the graph. Excess edge e_i is the edge that connect between ingress and egress pairs *(*s_i, d_i*)* of class *i*, and have infinite bandwidth (very large value). With adding excess edges, the simultaneous equations can always be solved and have many solutions. All PBR need is maximizing the number of satisfied LSP demands, so the target of PBR algorithm is minimizing the traffic routing through excess edges.

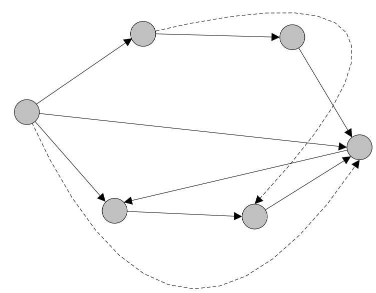

Figure 1: Excess edges are added to graph

Suppose we have *k* profile, let $x_i(e)$ is the amount traffic of commodity *i* route on edge *e*. The optimal goal is:

$$Minimize \sum \left(\cos t(e) \sum_{i=1}^{k} x_i(e) \right)$$

$\cos t(e) = \infty$ if *e* is excess edge, and $\cos t(e) = 1$ if *e* is normal edge.

And now, the simultaneous equations are changed to linear programming problem that can be solved with polynomial time. Its result is used for second step of PBR algorithm.

4. Employing advanced routing algorithms

Advanced routing algorithms are very difficult for implementing on router because router has limited memory, CPU speed and functions of operating system. So that, advanced routing algorithms are implemented on server with centralized model. Server get network information from distributed protocol such as OSPF-TE, IS-IS-TE,… then, server compute the optimal path, use the COPS,SNMP, telnet,… to control ingress-egress pairs setup new LSP.

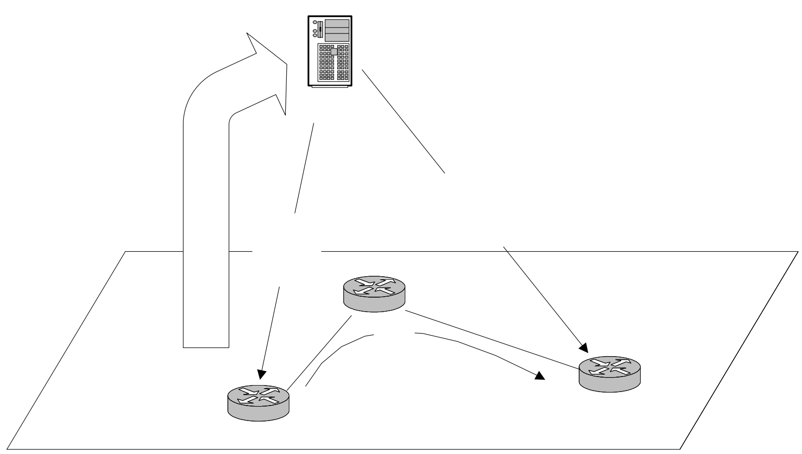

Figure 2: Centralized server model supports for advanced routing algorithm on MPLS

Some typical projects are working with advanced routing algorithms on MPLS with server

RATES (Traffic engineering server)[10] is developed by Bell laboratories, RATES uses TE-server to compute optimization paths based on MIRA, then COPS server setup paths by COPS protocol [15].RATES uses CORBA for distribution programming.

TEQUILA (Traffic Engineering for Quality of Service in the Internet at Large Scale)[17] is the project of European collaborative. It proposes an architecture providing QoS on Internet. TEQUILA has main components such as control plane, data plane, management plane…TEQUILA uses SLS for getting request of network users, and its modules communicate together with CORBA. Each router is configured by COPS protocols.

MATE (Traffic Engineering Automated Manager)[11] uses SPeCRA algorithm [12] for routing. This algorithm is simple than MIRA. This model was experimented on router Linux. MATE sends request message to router though SNMP/Telnet to configure routers, request router get information by TFTP, then router update its configuration by itself.

5. Simulation

Building an environment simulation is too important to evaluate the efficiency of routing algorithms and select the best options to these algorithms. *ns2* [19] is open source simulation on *linuz OS,* and is usually used to implement new package for research. Originally, *ns2* don't have MPLS module, we use module MNS [20] for MPLS. To distribute extensive network information, we use package QOSPF [13][14][18] because IS-IS-TE, OSPF-TE… is not completely built on *ns2*. Some advanced routing need a package to solve linear programming problems, we use PPRN package [16]. And last, we edit and repair the different version of these packages, combine them with our module together, and have complete MPLS environment for testing and simulating advanced routing algorithm.

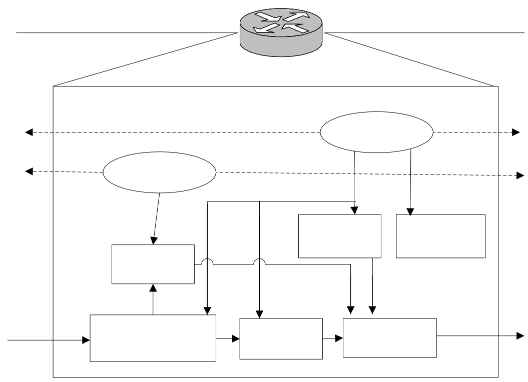

Figure 3: Original conceptual model of MNS on *ns2*

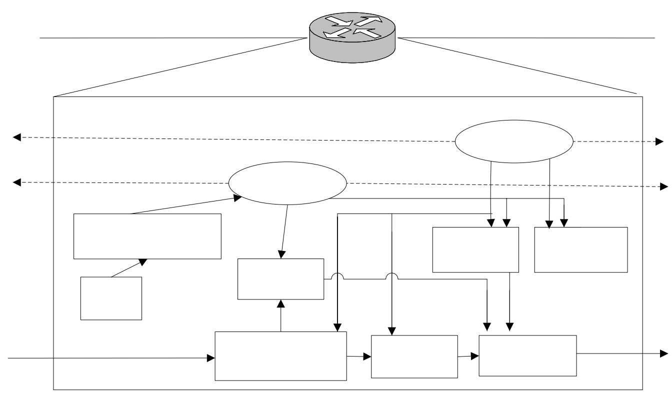

Figure 4: Our conceptual model to deploy advanced routing algorithms on *ns2* with MNS

There are a large number of the QoS based routing algorithms. It is the result of the combination of many constraints and optimization problems, the combination of many types of metrics such as bandwidth, delay, jitter… and the combination of many proposal heuristics to solve QoS NP problems. We didn't go deep into QoS-based routing, and to see clear result of comparison between advanced routing algorithm and traditional routing algorithms, we implement some traffic-based routing algorithms. The considered traditional routing algorithm is MHA, min-hop algorithm. MHA will choose the route with minimum hop-count. If the route satisfies bandwidth demand, it will be chosen to setup LSP. If not, the demand will be rejected. The comparison result is on the graph with the number of satisfied requests (axis Y) and the total number of requests (axis X), and showed by *xgraph (on ns2)*.

Topology is similar to the topology used on [7]. On this topology, the thin edges have capacity 1200 unit, and the thick edges have capacity 4800 unit. There are four ingress-egress pairs *(S0,D0) (S1,D1) (S2,D2) (S3,D3).*Correlatively, the PBR use four commodities, each commodity has 2700 unit. We use uniform random function supported by *ns2* to create random bandwidth and random ingress-egress pairs. DORA algorithm use $\alpha = 0.5$.

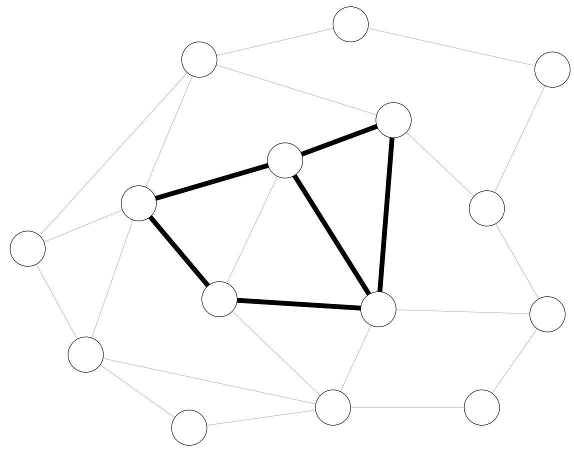

Figure 5: Topology is used in our experiments

On experiment 1, we have 500 LSP demands, each demand randomly chooses ingress-egress pairs and demanded bandwidth from 100 to 400 unit. On experiment 2, we have 1000 LSP demands, each demand randomly chooses ingress-egress pairs and demanded bandwidth from 10 to 40 unit. We can see on the figure 6 that DORA and MIRA algorithm satisfy the number of demands more than PBR and MHA on these cases, and especially with large number demands, the distinction is so clear. On two these experiments, PBR doesn't have right profile because its profiles predict that each commodity (ingress-egress pair) has total 2700 unit bandwidth, but it is not true. So the PBR algorithm is not efficiency.

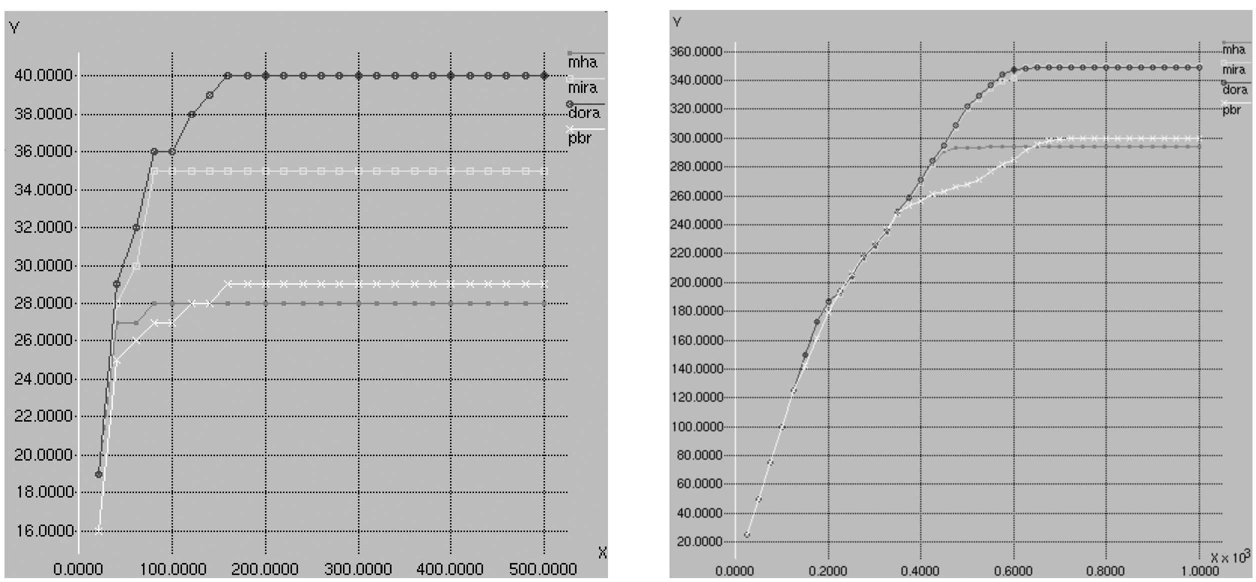

Figure 6: Number of requested LSP is satisfied on experiment 1 and 2

On experiment 3, we create simple conditions to PBR having right profile. We define a profile and force the traffic of network to follow this profile. The profile that although each demand randomly chooses ingress-egress pair and bandwidth, the total demanded bandwidth of each ingress-egress pair doesn't exceed 2700 unit is imposed to network. We have 1000 LSP demands, each demands randomly choose ingress-egress pairs and demand bandwidth from 10 to 40 unit. With suitable profile, PBR prove its efficiency than two first experiments. Because demanded bandwidth of all ingress-egress pairs doesn't exceeds 2700 unit, actually we have approximately 420 LSP demands for each ingress-egress pair (<1000) as we see on figure 7.

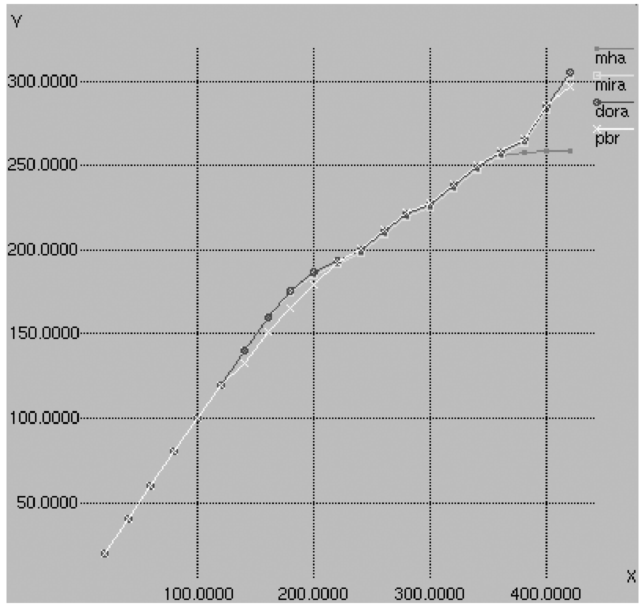

Figure 7: Number of requested LSP is satisfied on experiment 3

From three these experiments, we proved the efficiency of advanced routing algorithms (traffic-based routing algorithm) with traditional routing algorithm (MHA) on MPLS for satisfying LSP demands (so express the ability to reduce collision) on dynamic networks and also showed the difference between profile and non-profile traffic-based routing algorithms (on simulation environment).

6. Conclusion

Nowadays, with the appearance of new services and constraints for MPLS network of users, providers and administrators, it is necessary to build new advanced routing algorithms on MPLS. MPLS supports infrastructure and potential environment to developing these algorithms. On this paper, we presented main characteristic and classified advanced routing algorithms on MPLS. We also simulated some algorithms to see their efficiency and mention about some project with advanced routing algorithm. On future, many projects will be built for supporting advanced routing algorithm, not only on servers but also for routers that now only support IP routing protocols and CSPF (constrained shortest path first) (for traffic engineering). If we want to develop advanced routing algorithm on MPLS routers, the algorithm must be simplified and improved to fit with router devices. And this is our future research plans for advanced routing algorithm on MPLS.

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