AN OVERVIEW OF TODAY'S MULTIPATH ROUTING

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Abstract: The increased number of applications with strict demands regarding throughput and delay (e.g. video streaming, VoIP, video conferencing) determines the need for more efficient routing procedures in the Internet. Multipath routing is one solution that can assure a more reliable and robust transmission. This approach provides flexible load balancing and congestion avoidance by offering multiple alternative paths to a destination. This paper presents an overview of the design details of today's multipath routing solutions, with their advantages and disadvantages.

Keywords: *fast rerouting, load balancing, multipath routing, path diversity, split granularity.*

I. INTRODUCTION

The Internet is a global communication network with a large user community. Thus, the existence of a reliable and robust transmission system is mandatory. One of the major components of a communication environment is represented by the routing process. The performances of the forwarding method have a big influence on the quality of service delivered to the end user.

With the increasing number of Internet users, in order to satisfy their needs, more and more applications appear on the market, thereby the network must adapt to the new requirements. However, the protocols used in the current Internet did not have a significant evolution, mainly because of the rigidity of the existing architecture which makes the testing of new solutions difficult and expensive.

Routing is the process that ensures the delivery of the packets in a network from the source to the destination. The design of a new routing solution is a challenge because it must have a distributed nature and it also has to be able to adapt to changes that can occur in the network topology or traffic conditions.

Due to the dynamics of the Internet, the legacy routing solution based on finding a single path between a source and a destination cannot deal with all the challenges that arise, such as failure of nodes or links, congestion, increased delay, low throughput, etc. The result is a pronounced degradation of the transmission quality. Thus, to ensure the requirements of new applications, high efficiency and robustness, a new approach is needed. A suitable solution is represented by multipath routing. In this case, the forwarding process takes advantage of alternative paths that exist between a source and a destination node.

In case of multipath routing, depending on the application's communication needs, a corresponding path will be allocated. For example, VoIP (Voice over IP) and video conferencing traffic can use a low-delay path, while FTP (File Transfer Protocol) traffic uses a path with high throughput. Also the aggregation of path is possible, with the goal of increasing the total transfer rate.

The main advantages brought by a multipath routing solution are the following: a) increased global throughput; b) improved end-to-end reliability; c) congestion avoidance; d) customized routing in accordance with application performance requirements; e) load balancing, and f) quality of services assurance. However, these advantages come at a cost that consists in: 1) the computational overhead finding multiple paths; 2) additional path information required for multipath routing; 3) extra bandwidth; 4) the overhead introduced per packet which indicate the allocated path; 5) more memory, and 6) the router overhead of processing and forwarding data packets.

There is significant underlying path diversity in the Internet's network topology. A network is an ensemble of links and routers that are controlled by an Internet Service Provider (ISP) that offers connectivity to other networks or a stub network. There are studies that demonstrate that the existing path diversity in today's Internet is not exploited. Studies from more than ten years ago [1] show that although the Internet traffic traverses a single path, 30% to 80% of the time, an alternate path with lower loss or smaller delay exists, even so, the diversity of the existing paths is not exploit in the current Internet network. According to [2] the advantages of using path diversity are: 1) increased fault tolerance; 2) load balancing and smaller fluctuations in traffic load; 3) diverse routing, and 4) error reduction.

This survey is an overview of multipath routing

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techniques presenting the main characteristics of this approach. Section II describes the existing routing schemes with their limitations. Section III presents design concepts with their advantages and disadvantages, and concrete solutions that implement these ideas. The paper finishes with conclusion in section IV.

II. LEGACY INTERNET ROUTING

The routing process in today's internet is mainly based on single path routing, all the traffic between a source and a destination being sent on the same path. This is a primary end-to-end service with best effort reachability.

For the intra-domain, the mainly used routing protocols are OSPF (Open Shortest Path First) [3], IS-IS (Intermediate System to Intermediate System) [3], RIP (Routing Information Protocol) [3], and EIGRP (Enhanced Interior Gateway Routing Protocol) [4]. From these options, OSPF is the most common because RIP is not a suitable solution for an extended topology, and EIGRP is a Cisco proprietary routing protocol. OSPF is a routing link-state protocol that offers several advantages [3, 5]:

- *Simplicity*: routing is based only on a single link metric;
- *Reduced message-passing overhead*: routers only disseminate information when the topology changes;
- *Global view of the network*: each router has a complete view of the topology and the associated link weights.

The main disadvantage of single path routing protocol is that even when alternative paths have been computed, packets towards a destination are often forwarded on a single path; the existing path diversity is under-exploited. In case of failure the recovery period is long, thus the sensitive application, like video streaming, will be highly affected. In case of OSPF, because the state of the connections is tested through "Hello" messages, it can happen that the congestion is not detected in some situations because, if one of four "Hello" packets reaches the destination the link is considered reliable. Thereby, even if the throughput drops and the route can no longer satisfy the requirements of the applications, the path is not changed.

The disadvantages of the single path routing protocols are:

- *No load balancing option:* the traffic to a destinations follows only one path;
- *Inefficient resource utilization*: while some links are highly used, other connections remain unutilized;
- *Low convergence time*: in case of a failure the recovery period is long, thereby the transmission is interrupted;
- *Simple metric*: the metric of the links is not dependent on the real state of the network;
- *Limited QoS support*.

One of the most used protocols for inter-domain routing is BGP (Border Gateway Protocol) [6]. In this case, each router is limited to use a single path for each destination prefix. This means that in case of link failure or congestion the transmission process will be significantly affected, and as a result the quality of service at the end user will drop. The customers do not have a choice because only one path is advertised. Also because this is a path-vector protocol, the decisions are made based on local information, and thus it can happen that a path with a low bandwidth is chosen even if a better route exists.

A solution to increase the performance and robustness of the BGP protocol could be to enable multipath techniques. Such a solution would be possible only if an alignment of economic incentives between networks where achieved. The use of multihoming, where a stub network pays to connect to more than one ISP, is a solution for an enterprise to reduce the cost of Internet access and have a backup solution in the case the connection to one of the providers would encounter a failure.

III. MULTIPATH ROUTING STRATEGY

Multipath routing is one of the alternatives to the single path schemes. In today's Internet, the main routing method is a hop-by-hop forwarding scheme. At each node, based on the destination address, a certain gateway is used to transmit the packets. For the single path protocols, only a single entry in the routing table is needed for a destination, thus, the size of the routing table depends only on the number of destinations in the network. However, this approach cannot assure a flexible forwarding process because it does not offer any alternative variants. A solution is to use multipath techniques. At the moment there is only one multipath routing protocol that is supported by current IP routers, ECMP (Equal Cost Multipath) [7]. ECMP [8] is the multipath version of the single path routing solution OSPF. However the diversity of the paths offered by this method is limited because the traffic is divided only on paths with equal cost, if these paths exist. ECMP is a heuristic method that ensures load balancing using a round-robin distribution, but it does not consider the quality of the selected paths. This solution is not dependent on complex supplementary operations compared to OSPF; the validation of the paths is included in the path calculation process. The reaction to congestion is the same as for OSPF; thereby the routes are not changed even if the path cannot longer satisfy the applications throughput requirements.

A multipath solution for the inter-domain routing is MIRO (Multi-path Interdomain ROuting) [9]. This approach offers increased flexibility by assuring control over the traffic flows for the transit domain, it also avoids state explosion in disseminating reachability. BGP is used for the default routes. The two protocols are compatible; MIRO retains the BGP approach for most of the traffic. Even if BGP provides alternative routes, these are not advertised, thereby, there are scanty methods for one AS (Autonomous System) to influence the decisions of another AS. An AS can choose a specific path based on different needs. For example the selection can be made based on security or performance reasons so that a specific AS is avoided. The essential features of MIRO are: *1)* the path selection is implemented at the AS-level, *2)* bilateral negotiation for alternate route, *3)* compatibility with BGP, *4)* load balancing for incoming traffic and *5)* tunneling in the data plane to direct packets along the chosen routes. To assure the compatibility with a wide range of policies for inter-domain routing, where it is possible, MIRO separates the policy from the mechanism.

In the case of multipath routing the packets must be classified and the edge router takes the decision on which path the packet is forwarded. The packet classification can be made based on the requirements of the application (low delay, high throughput, etc.) or a secure path.

The process of mapping packets to multiple paths is made by the edge routers. These nodes measure the parameters of the paths and determine which route is best-suited for each class of traffic. Sometimes the measurement part can be difficult because it can introduce errors.

The main blocks of a multipath routing solution are:

- *the multiple paths computation block* (calculates the routes);
- *the load balancing block* (decides the way the traffic is split at each node);
- *the multipath forwarding block* (implements the method that can assure that traffic to the same destination follows different paths);
- *the update block* (dictates the reaction to the network conditions changes).

A. Multiple Paths Calculation Algorithm

An important step of a multipath routing solution is the computation of multiple paths. To accomplish this task graphs search algorithms are used, like BFS (Break First Search), DFS (Depth First Search) and Dijkstra. Because the main purpose of these solution is to find a single path between a source and a destination node, the multipath routing solution use a combination or a modified version of these algorithms. The authors of [7] propose a modified version, called DT (Dijkstra Transversal) where for each destination two alternatives routes are calculated with the property that these paths have different gateways. Other approaches that use combinations of the standard algorithms are presented in [10] (DFS+BFS) and [11] (Dijkstra+DFS).

Depending on the properties of the routes that compose a path set there are different approaches.

1) Disjoint paths

This type of algorithms calculates only a disjoint set of paths. In this case the number of routes is sometimes very limited. The advantages of this approach are: *1)* increased robustness in case of failure or congestion, e.g. if a path from the set is affected by congestion, the rest of the component routes will not be affected; *2)* no resources are shared, all routes and links are different for each path. Solutions derived from this approach are only link or node disjoint, thus the number of possible paths is higher. The authors of [12] propose a path calculation algorithm for disjoints path. The network is divided into two “colored trees”, namely red and blue using DFS algorithm. If there are two paths to a destination, and each path belongs to one of the trees, those routes will be node- or link- disjoint. Each router will maintain two gateways for each destination corresponding to one of the trees. The packets at the source node are marked with one of the two colors, and depending on the tag all, the nodes in the network will know which path should be used.

2) K-shortest paths

In this case the path independence property of the routes is not very important. The goal is to calculate all of paths or only a subset of the existing routes. In general the restriction for a subset consists in the maximum number of nodes that can compose a path. The amount of calculated routes is not a problem; depending on how large we want the set of paths to be, we increase the k parameter. A disadvantage of this approach is that the selected subset of paths could be using only a limited part of the network resources [13]. The authors in [14] propose a multiple calculation of the Dijkstra algorithm to obtain k shortest paths to a destination. The algorithm start the search in a graph with equal costs on all the edges, then the shortest path between the source and the destination is calculated. If the cost of the path is lower than a pre-established maxim, that path is saved, and the costs of the used edges are increased. The procedure repeats with the new costs, and a new shortest path is calculated.

Besides the path quantity and path independence, another parameter that can be considered in the path calculation process is the quality of the paths. There are two possible approaches [14]:

1) Multi-service paths: the calculated routes have different characteristics (like throughput or delay) and, depending on these parameters, a specific path is allocated for an application;

2) Multi-options paths: all the routes in a set have similar characteristics.

Depending on the chosen method the forwarding procedures also change.

B. Load Balancing Split Methods

There are three main splitting methods depending on the division granularity: *1)* packet granularity split, *2)* flow granularity split, and *3)* flowlets granularity split [15].

1) Packet granularity split

The traffic is switched at the granularity of packets and can achieve a very accurate splitting percentage. The main advantage of this method is that it adds a reduced extra overhead. The downside is the problem of out-of-order packets arrivals at the destination. This is the consequence that the used paths have different delays. In case of TCP

(Transmission Control Protocol) this situation would be interpreted as congestion. This type of load balancing is a good choice when the paths have similar delays. An example for this approach is ECMP: the division strategy is a simple round-robin split method, the packets being sent alternatively on the multiple paths.

2) Flow granularity split

Flow splitting granularity involves the identification of the packet, based on the header information. After this operation the packets are forwarded on the corresponding path. This solution ensures in-order delivery of most packets. The difficulty is to achieve accurate splitting percentages since flows vary drastically in their transmission rates. Also, in case of a high-speed links there is a significant additional memory consume at the nodes level, because of the high number of concurrent flows.

In [16] the traffic is divided into two classes based on the delay sensitivity and throughput restriction. The first type is *elastic flows*, characterized by a delay tolerant property and high throughput demand. The second type is *inelastic flows* having increased delay sensitivity and a fixed transfer rate demand. Depending on which class a flow belongs to, the packets are treated with a different priority through a two-stage queuing architecture.

3) Flowlets granularity split

The third solution, flowlets, combines the two splitting solutions by dividing the traffic at packet burst (flowlets) granularity. The propose method FLARE (Flowlet Aware Routing Engine) [15] assures the receptiveness and accuracy of the packet granularity split method, but it also eliminates the out-of-order packets problem at the destination. The main idea of this solution is that if the time between two successive packets is larger than the maximum delay difference between the multiple paths the second packet can be safely forwarded on any available path without the risk of packet reordering. Thereby, the traffic is split in packet bursts, called flowlets. Between the flowlets, the minimum time interval is chosen in such a way that it has a larger value than the delay difference between the routes that are considered.

There is also the question on how the flows will be handled at each node: one by one or in groups (route aggregation). If each flow is identified, there will be an increased processing and memory overhead. This method assures that the demands of the applications are satisfied and it can ensure fairness between flows, but it is not optimal in terms of resources allocation.

MITRO (Multi-path Iterative Routing Traffic Optimizer) [17] is a distributed multipath routing protocol based on the water-filling procedure of max-min fairness. It takes advantage of the existing path diversity by selecting the best route and it also offers flow control. The allocation of a specific transfer rate for the flows is assured by using different queuing approaches. The algorithm will use the routes in the decreasing order of performance. On each path the transfer rate is adapted periodically in accordance to the state of the network. After the system reaches a “steady state” (a low variation of the average throughput on all the paths) the overall rate over is reduced to avert sub-optimal allocation.

Other routing solutions that employ a similar approach are: TEXCP (Traffic Engineering with XCP) [18], where the load is balanced over multiple routes and is adapted periodically with the goal of minimizing the maximum link load, and TRUMP (TRaffic-management Using Multipath Protocol) [19], where the objective is to maximize the difference between the aggregate utility of all sources and the aggregated cost of all network links.

C. Forwarding Methods

The active block of a multipath routing solution is represented by the forwarding procedure. After the paths are calculated and a split method has been chosen, the router is ready to receive the traffic. To assure that different flows to the same destination will be routed on different paths, the nodes must have some additional information. There are two main approaches regarding the forwarding procedure: *1)* centralized solutions and *2)* distributed solutions.

1) Centralized solutions

In this case the main approach is to direct the packet on multiple paths from the source node. Thus, the source router has to have knowledge of the entire network and insert in the header of the packets the exact route that needs to be followed. A different path can be allocated for each flow. However, the scalability is reduced because of the global view requirement. For a large network the extra information added to the transmitted packets will be an important percent of the global throughput. Also, the system is fragile in case the centralized node encounters a failure.

In [20] the routing process is based on tags set by the end-systems, indicating that the routers should use a different path form the shortest path. These tags are used at each node to deflect the incoming traffic.

2) Distributed solutions

The distributed approach does not require a global view of the network. The forwarding decisions are based on the local information, available at each router in the network. The main advantages of this solution are increased scalability and flexibility. In case of node failure the system can still function. From the complexity point of view, these systems usually require increased control information.

The authors of [21] propose a distributed multipath routing solution for congestion minimization. It is considered a link-state environment where the forwarding decisions are made independently at each node based on local information about the neighbor nodes and links. The goal is to satisfy the requested throughput even in case of congestion. Another distributed multipath solution is presented in [7]. In this case each router computes for each destination at least two loop-free paths having the best parameters and different gateways (TBFH (Two Best First Hop) algorithm). The main advantages are a low complexity and a reduced overhead (no additional signaling messages).

D. Update Approaches

Another important feature of a routing solution is the reaction to changes in the network status, such as failure or congestion. Solutions for handling problems caused by link or node failure are the following: *1)* multiple routing configurations, *2)* failure intensive routing [23] and *3)* tunneling [24].

There are many routing schemes that approach the problem of link failure. For the first solution, to assure multiple routing configurations a routing algorithm can maintain backup routes for each destination, or entire backup routing table configurations. The solution presented in [22] is based on additional information that allows the nodes to deal with the problems caused by failure. The concept is to manipulate the link weights in such a way that it is possible to determine several backup graphs offering configurations that can be used by each node in order to safely forward packets in case of failure.

A proactive local rerouting method, called FIR (Failure Intensive Routing) method is described in [23]. In this case, if failure occurs, the link statement advertising (specific for OSPF) is blocked and the node reroutes the traffic using a backup table. For each input interface possible alternative outgoing paths are calculated for a specific destination. The process is performed in a distributed manner, and the decision of using an alternative path is made locally. Even if the other nodes are not explicitly informed of the failure, because the packets do not arrive on the normal input interface, the nodes will know that something has happened in the network. Another method is presented in [24]. Herein, the transmission is protected from link, router and shared risk group failure, regardless of the network topology and metrics. The idea is to use encapsulation in case of failure. Thereby, if a node is aware that for a destination the normal gateway node has failed, that router will encapsulate the corresponding traffic and send the packets to the next-next-hop. At this point the encapsulation is removed and the packets are transmitted on the normal path. Each node must calculate n-1 (n is the number of nodes in the network) SPFs (Shortest Path First) in order to calculate all the alternatives paths and identify the not-via address corresponding to the failure of each router in the network.

In [25] the authors propose a routing approach where in case of failure of two links, a node is capable to reroute the packet around the failed node without the knowledge of the second failure. A node must have three protection addresses, each corresponding to a protection graph of the network. In case of link failure, the packets are routed through IP-in-IP encapsulation-based tunneling, using one of the backup addresses. For this method, the graph of the network must be three-edge connected in order to overcome the problems caused by maximum two failures.

The development process of a new multipath routing algorithm can be difficult and entangled. In this paper we presented the main aspects that should be taken into account for the design phase, with some concrete implementation examples. A summary of this paper is exposed in Table 1, where the most significant routing solutions are presented.

TABLE 1. *Multipath Solution Overview*

Approach / *Routing Solution*		ECMP [8]	CT [12]	MIRO [9]	MITRO [17]	An efficient algorithm to enable path diversity in link state routing networks [7]	A Distributed Multipath Routing Algorithm to Minimize Congestion [21]	Source selectable path diversity via routing deflections [20]
Path Calculation Method	Disjoint paths		X			X		
	K-shortest paths	X		X	X		X	X
Load Balancing Method	Packet granularity	X	X					
	Flow granularity			X	X	X	X	X
	Flowlets granularity							
Forwarding Method	Centralized		X	X				X
	Distributed	X			X	X	X	
Update Approach	Multiple routing configurations		X			X		
	Failure intensive routing							
	Tunneling			X				

IV. CONCLUSIONS

Multipath routing is a key component of TE (Traffic Engineering). Multipath techniques are mainly developed for the wireless environment, but it has been demonstrated that the wired networks also offer an important path diversity that can be used to increase the robustness of the network. With the expansion of the Internet topology and the increasing number of users, the implementation of alternatives to single-path routing will become a necessity. The advantages of multipath routing over single-path are quite obvious. Forwarding traffic over multiple paths could improve the reliability of the network and assure better load balancing. Even so, multipath schemes are not widely spread because of scalability issues and economic challenges.

This paper tried to offer arguments to implement these techniques in the legacy Internet. It was important to find the solutions fulfilling the requirements for a given situation, scenario or topology. Based on the survey discussed within this paper, the authors proposed later on an original contribution called SAMP (Situation-Aware Multi-Path) [26]. Its main characteristics referred to simultaneous transmission on multiple routes, flow granularity, traffic split and packet forwarding according to the real status of the network.

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