Performance Evaluation of a Situation Aware Multipath Routing Solution

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Abstract – **The dynamics of modern communication networks, especially regarding the user's behavior, determine the necessity of an effective routing protocol that can ensure high performance. In this paper we present the implementation and performance evaluation of a new dynamic multipath routing solution, called Situation Aware Multipath (SAMP), using the OPNET Modeler. The main features of our solution are load balancing and congestion avoidance. To increase the scalability, the network is divided into multipath routing domains. We defined two types of routers: AR (Adaptive Router) and AMR (Adaptive Multipath Router), with different capabilities depending on their location inside the domain. SAMP offers network robustness and reliability by taking advantage of the path diversity. The performance of the proposed solution is evaluated and compared, in terms of throughput and network resource utilization, with three standard routing protocols: OSPF, ECMP and EIGRP. The simulation results demonstrate that the new proposed multipath routing algorithm can assure increased network resource utilization and also a high transmission quality, even in case of congestion.**

Keywords-congestion avoidance; load balancing; multipath routing; path diversity; situation awareness.

I. INTRODUCTION

Several applications (such as voice over IP, video conferencing, online games and high-definition video) have increased demands on throughput and robustness. Thus there is a need for a mechanism to offer a solution for fast recovery from failures and efficient network resource utilization. Even short disruption, caused for example by routing convergence, can lead to unacceptable degradation of the delivered quality.

One of the advantages of dynamic routing is the capacity to circumvent congested links, the effect being an improved quality of application. In many cases, the downside of this approach is the overhead introduced by new path activation, frequency of link-state updates and signaling overhead. For most of the existing dynamic routing protocols the information about the state of the network does not reflect the real situation.

If we consider the routing protocol OSPF [1] (or EIGRP [2]) the state of the link is tested through "Hello" messages. Thereby, if one out of four "Hello" packets reach the destination, the link is considered reliable. These solutions take into account the topology changes but not the bandwidth fluctuation. A high quality transmission can only be achieved if the routing protocol reacts to the real state of the network links.

Multipath routing is an effective solution to achieve load-balancing, congestion avoidance and end-to-end reliability. Furthermore it allows customized routing according to application performance requirements and it can ensure QoS requirements. There are two approaches for using multiple unequal cost paths between two nodes: source multipath forwarding schemes and hop-by-hop multipath forwarding. The authors in [3] propose a distributed forwarding scheme that computes a set of loop-free routes. They provide a general multipath forwarding method that combines load balancing and fast re-routing capabilities. Other solutions for handling the problems caused by link failure are the following: *1)* multiple routing configurations [4], *2)* failure intensive routing [5] and *3)* tunneling [6]. A solution for changing network topologies and link characteristics perturbation is described in [7]. This approach relies on the concentration of routing table entries to stochastically decide which path will be used for a given packet. A theoretical investigation of multipath routing is presented in [8]. The computational complexity for different methods is measured and the efficient solutions are established, according to the obtained results

One of the main stages of the development of a new routing method is the simulation phase. This is a reliable and low cost solution that has some advantages like: performance evaluation, parameter adjustment and a large test variety (different scenarios and network topologies).

In our previous work [9], using a practical implementation, we have demonstrated the capabilities of a situation aware multipath routing scheme called SAMP (Situation Aware MultiPath). This increases the network resource utilization and assures a reliable transmission by performing load balancing and congestion avoidance.

In this paper we present the implementation and performance evaluation of SAMP using the OPNET Modeler. The obtained results are compared with the performance of three of the most used routing protocols: OSPF, ECMP [10] and EIGRP.

The remainder of the paper is organized as follows. Section 2 presents an overview of SAMP's main functionalities, such as path computation, load balancing and congestion avoidance. In Section 3 we present the concept of multipath routing domains. The implementation and performance evaluation are presented in Section 4, followed by conclusions and future work in Section 5.

II. SAMP OVERVIEW

SAMP is a dynamic multipath routing protocol where the routing management functions are separate from the path discovery and the transmission process. The routing decision is based on statistical cross-layer QoS (Quality of services) information provided by a situation-aware network management application. One of the advantages of this approach is the increased information reutilization.

The solution has four main stages: *1)* computing loop-free paths; *2)* defining the load balancing policy depending on the type of the node; *3)* splitting the traffic among routes and *4)* changing the affected paths in case of congestion.

A. Path computation algorithm

SAMP takes full advantage of the diversity of the existing paths without taking into account the independence of the routes. In addition to the algorithm presented in [9], we introduce a new constraint, namely, we assure that the use of less *stressed* nodes is advantaged. If the number of interfaces of a node is higher, the probability that the router will be used more frequently is higher. Thereby, we define the *stress* factor depending on the number of interfaces. If for a destination there are two or more paths with identical parameters (length and metric), SAMP will chose the route with the less *stressed* gateway.

$$nNode_n = \left\{ dNode_i \in DN_n \mid \begin{array}{c} dNode_i \rightarrow metric = \max(dNode_k \rightarrow metric) \\ dNode_i \rightarrow length = \min(dNode_k \rightarrow length) \\ dNode_i \rightarrow uFactor = \min(dNode_k \rightarrow uFactor) \\ k = 1...m \end{array} \right\} \quad (1)$$

TABLE I. NOTATIONS

Notations	Definitions
$nNode_n$	*The gateway for the n-th destination*
$dNode_i$	*The i-th direct connected node of the current node*
DN_n	*Set of directly connected nodes of the current node*
$dirNode_i \rightarrow metric$	*The metric of the route that has $dirNode_i$ as gateway*
$dirNode_i \rightarrow length$	*The length of the route that has $dirNode_i$ as gateway*
$dirNode_i \rightarrow uFactor$	*The stress factor of $dirNode_i$*
m	*The number of directly connected nodes for the current node*

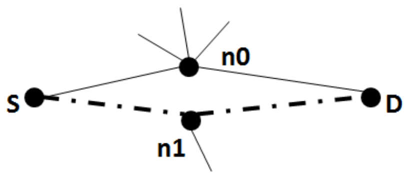

Figure 1. Next hop election

If we consider the network in the Fig. 1, the first choice regarding the next hop from source *S* to destination *D* will be n_1 because it has fewer interfaces as n_0.

B. Load balancing procedure

Load balancing is one of the key components of traffic engineering. The transmitted data is mapped on multiple paths and the share of each path is adapted in real-time to avoid congested areas. Each of these solutions uses a split method. The division granularity can be packet/flow-based. For the first variant, e.g. ECMP, the desired load share to each path is quickly achieved (fine granularity), but the reorder probability is high because the paths have different delays. Splitting at flow granularity eliminates the problems produced by out of order arriving, but the load on each route can be significantly different because the flows have different parameters. The solution FLARE [11] combines the two splitting solutions by dividing the traffic at burst (flowlets) granularity.

In case of SAMP, the load balancing is performed at flow granularity. Because the routing process is based on real information about the state of the network links, we assure that the flows will be transmitted on routes that can meet the application requirements. For each incoming packet we must identify to which flow it belongs. The identification process is based on the triplet: *destination IP address, source IP address* and *destination port*. The recognition of the existing active flows at a given moment in the network is performed by an external module. The main responsibility of the flow identification module is to maintain a valid list of the active flows in the network. Thereby, the tasks of this module are: *1)* add a new flow; *2)* for each flow update the time of the last incoming packet; *3)* delete the inactive flows. The collected flow information is delivered to the multipath routing module.

SAMP does not change the packets that cross the node, thus no supplementary overhead is introduced at the data level. The VRF (Virtual Routing Forwarding) [12] concept is used to divide the traffic between a source-destination pair on multiple paths. Each interface of a router will have a corresponding routing table with one entry represented by the default route to the direct connected node of that link. With this approach, the memory used by the routing tables is independent from the size of the network, which is important from the scalability point of view.

The flow management procedure allocates for each stream a path and a routing table. Depending on the arriving packet, the process can react in two ways. If the incoming packet belongs to a new flow, SAMP allocates a path for that stream and the packet is forwarded to the corresponding gateway. In the second case, if the packet belongs to an existing flow, the multipath routing algorithm identifies the assigned route and performs the forwarding process. For each new flow, SAMP will use an unused path from the existing routes. If the number of flows is greater than the number of paths, the allocation process resumes with the first used route.

The allocation process of a path for a new flow follows three steps: *1)* identifying the set of unused paths for a destination; *2)* determining the best metric of the selected set; *3)* determining the path with the minimum length and best metric.

$$flow_i = \left\{ path_j \in Path_D \mid \begin{array}{c} path_i \to metric = \max(path_k \to metric) \\ path_i \to length = \min(path_k \to length) \\ path_i \to used = false \\ k = 1...m \end{array} \right\} \quad (2)$$

TABLE II. NOTATIONS

Notations	Definitions
flow$_i$→path	*The path for the flow$_i$*
path$_j$	*The j-th path for the destionation D*
Path$_D$	*Set of paths for destination D*
path$_j$→metric	*The metric of the path j*
path$_j$ →length	*The length of the path j*
path$_j$→used	*The used indicator for the path j*
m	*The number of paths for destination D*

SAMP uses a composite metric defined in [13], which depends on three factors: the average available transfer rate (ATR), the delay and the bit error rate (BER) at the physical layer:

$$CM = \frac{k_0}{ATR[bps]} + \frac{OWD[s]}{k_1} + k_2 \times BER \quad (3)$$

where k_0, k_1 and k_2 allow to tune the composite metric for different environments. Thereby, the route selection process depends on information about the links, provided by the network management application, which collects the data from the Cross-Layer QoS (CLQ) measurement program module presented in [13].

C. Fast re-routing and congestion avoidance

SAMP provides a fast re-routing technique that improves network resiliency. Our solution offers alternative loop-free paths (if such paths exist) independently from the number of congested links or failures. The appearance of congestion is signaled by the management application. When the signal is received by the multipath routing solution, the metric of the used paths is recalculated. If the metric is below a threshold (fixed or variable) SAMP will restart the allocation process for that specific flow or destination.

The transmission is affected for a short period of time, from the moment the congestion occurs until the problem is acknowledged by SAMP. Thus, our solution can assure a high quality at the user's terminal.

III. MULIPATH ROUTING DOMAINS

Scalability is one of the major problems faced by multipath routing solutions. To overcome this difficulty, in this paper we propose a strategy for dividing the network into several multipath routing domains. This is possible because SAMP is a next-hop packet forwarding routing scheme.

Depending on the place of the node inside the domain, it has different capabilities. We define two types of routers that compose a domain: AR (Adaptive Router) and AMR (Adaptive Multipath Router). The first type of node is located inside the domain and performs situation aware routing, meaning, that in case of congestion, an alternative path will be used for the incoming traffic. The AMR nodes are at the edge of the domain. Beside congestion avoidance, this type of node also performs load balancing for the traffic coming from outside of the corresponding domain. If we consider the network composed out of the nodes N = {n_0, n_1 … n_m}, then *N* will be the union of the multipath routing domains:

$$N = DN_0 \cup DN_1 \cup .... \cup DN_p \quad (4)$$

where DN_i are the sets of nodes that compose a multipath routing domain and *p* is the number of domains.

Whenever the traffic is entering a new domain, it is dispersed in that domain. As a consequence, the higher the number of crossed domains, the greater the division factor of traffic among multiple paths. However, if the number of domains is very high, the complexity of the process increases. Because of this, it is important to have a balance between the number of multipath domains and the computational complexity.

The domain division process can be performed by the management application. Depending on the structure of the network, the domains will be defined in such a way that the load balancing process increases the utilization of network resources. The number of nodes that compose a multipath domain may vary from one node to all the routes in the network. Also, different domains can have different number of nodes. Besides the domains composed from the routers of the network, we defined also a special domain that includes the user's terminals. In this way, the traffic from each user will be dispersed in the network. Even if not all the nodes are multipath-capable, the simulations show that the percentage of used network resources is quite high compared to the others tested routing solutions.

IV. EVALUATION AND SIMULATION

OPNET Modeler [14] is among the most complex tools for modeling new communication technologies and protocols. The simulator is object oriented and supports the concept of model reuse. This simulator was used for the evaluation of the proposed situation aware multipath routing solution.

A. Implementation

To enable the situation aware multipath routing functionalities for a node, we have extended an already implemented router structure. Because each component in OPNET is composed by several modules, the newly created entity can be integrated, with some adjustments, in any routing structure. The development of the new routing solution implied three main steps: *1)* design; *2)* implementation and *3)* integration. First we defined the system context and determined the place of the new module. This implies the identification of the independent modules and choosing one of the available communication modes. After the first step, we created the STD (State Transition Diagram). This is a Proto-C (language for developing models of processes in OPNET) model composed of two basic component types: state and transition. The actions of the process corresponding to each state where implemented using C/C++. For the final step, the integration, we have made some changes in the source code of the *ip_dispatch* module in order to enable the communication between the existing modules which compose a routing node and the new module.

Besides SAMP, we also implemented an entity that performs the flow identification procedures. This communicates with a modified version of the *mac* module through packet stream objects.

B. Simulation setup

We implemented custom simulation scenarios to demonstrate the capabilities offered by SAMP: load balancing and congestion avoidance.

Simulation topology: SAMP is not dependent on a specific network topology. However, to be able to demonstrate the advantages brought by SAMP, the network should offer more than one path between a source and a destination node. The topology in Fig. 2 was used to demonstrate the facilities of SAMP. In this case, there are at least two routes between each source-destination pair.

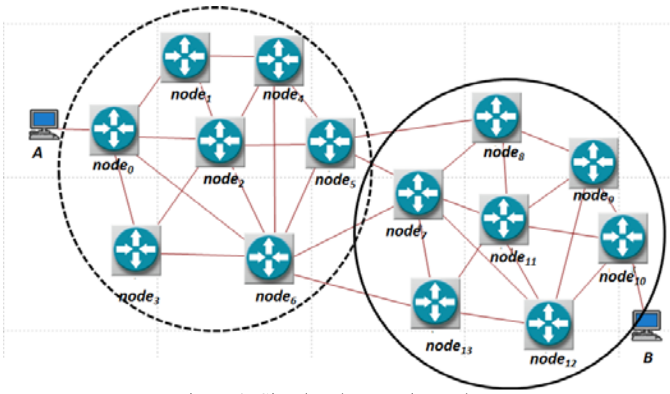

Figure 2. Simulated network topology

Another aspect that we wanted to highlight is the division of the network in multipath routing domains. The simulated network was split into two domains with equal number of routers, however, this is not a constraint, is just an example of division. The amount of nodes in each domain can vary from null to all the routers in the network. Each multipath domain is composed from the following AR and AMR routers:

- Domain 1: AR = {$node_1$, $node_2$, $node_3$, $node_4$}, AMR = { $node_0$, $node_5$, $node_6$};
- Domain 2: AR = {$node_9$, $node_{11}$, $node_{12}$}, AMR = { $node_7$, $node_8$, $node_{10}$, $node_{13}$}.

The network is composed out of 14 routing nodes and 2 user terminals. Each link has a capacity of 1Gbps. To make the working mode of SAMP more visible, we chose to introduce only two user terminals. In this way, the load balancing process can be traced easily.

Simulation traffic: The Internet traffic is composed of short-lived and small sized flows, and long-lived streams, especially video and voice traffic. To simulate these types of data, we transmitted two types of traffic: FTP (File Transfer Protocol) and video conferencing. To generate these types of traffic we used the standard applications offered by the OPNET Modeler. The generated traffic has the following characteristics: *1) FTP*: Inter-Request Time [sec] = exponential (360); File Size [bytes] = constant (5000); Type of Services = Best Effort; 2) *Video Conferencing*: Frame Interarrival Time Information = 10 [frames/sec]; Frame Size Information [bytes] = 128x129 pixels; Type of services = Best Effort.

We used TCP because it reacts to congestion by adapting the transfer rate to the condition of the network. The following TCP parameters were used: Received Buffer [bytes] = 8760; Maximum ACK Delay [sec] = 0.200; Maximum ACK Segments = 2; Fast Recovery = Reno. The throughput was monitored during the simulation.

To define the user's behavior we created a profile module with the following parameters: *1)* Supported Application: FTP, Voice Conference; *2)* Operation Mode: simultaneous; *3)* Start Time [sec]: uniform (100, 110); *4)* Duration: end of simulation.

For the composite metric we used the following values: $k_0 = 10^9$ [bps], $k_1 = 10^{-5}$ [s] and $k_2 = 0$. This means that we envisaged a maximum ATR of 1 Gbps and a minimum OWD of 10 microseconds. The BER was not involved because it was out of the scope of this paper.

C. Results

We compared the behavior of four routing solutions: *1)* SAMP, *2)* OSPF, *3)* ECMP and *4)* EIGRP. The performance evaluation was made with respect to: transfer rate, end-to-end delay and network resource utilization.

1) Case 1: Load balancing

In the first case we analyze the behavior of the tested routing solution in terms of network resource utilization, namely the percent of used paths from the total network links. During these simulations we consider that only the traffic between the two user terminals exists in the network.

OSPF and EIGRP are both single path routing protocols, thereby the used routes in this case are:

- ($node_0$-$node_6$-$node_7$-$node_{11}$-$node_{10}$) for OSPF in both ways;
- ($node_0$-$node_6$-$node_7$-$node_{12}$-$node_{10}$) and ($node_{10}$-$node_{11}$-$node_{13}$-$node_6$-$node_0$) for EIGRP.

The third tested protocol, ECMP, is the multipath variant of OSPF. In this case, the packets are transmitted on multiple paths with equal metrics. The division granularity is packet based, i.e. the packets are transmitted alternatively on the existing equal cost paths. The used routes are: (node$_0$-node$_6$-node$_7$-node$_{11}$-node$_{10}$) and (node$_0$-node$_6$-node$_{13}$-node$_{12}$- node$_{10}$) both ways.

In case of SAMP, there are two division points for the network traffic because in each direction the transmitted data is traversing two multipath routing domains. Depending on the direction of the traffic, the splitting nodes are:

- (node$_0$, node$_{13,}$ node$_7$ and node$_8$) for the direction *A* to *B*;
- (node$_{10}$, node$_6$ and node$_5$) for the direction *B* to *A*.

The routes used for the traffic from *A* to *B* are the following: (node$_0$-node$_6$-node$_{13}$-node$_{11}$-node$_{10}$), (node$_0$-node$_6$-node$_{13}$-node$_{12}$-node$_{10}$) and (node$_0$-node$_2$-node$_5$-node$_8$-node$_9$-node$_{10}$). The first two paths are node- and link-disjoint compared with the third path, i.e. no network resources are shared. As a consequence, there will be no influence between the two groups.

Fig. 3 presents the division process at *node$_6$* for the traffic coming from user *B*. In this case, the network traffic corresponds to several video conferencing and FTP applications. SAMP uses a flow based division granularity. Thus, at *node$_6$* the flows are split on four paths with the gateways: node$_2$, node$_4$, node$_0$ and node$_3$.

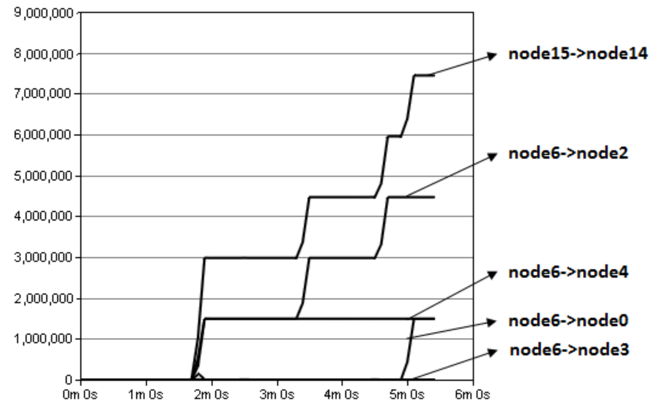

Figure 3. SAMP load balancing [bits/sec]

The results of the simulations demonstrate the advantages brought by SAMP in terms of network resource utilization. Fig. 4 illustrates the percentage of used paths from the total network links corresponding to the tested routing schemes.

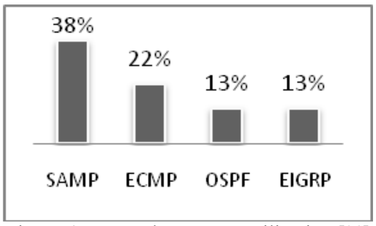

Figure 4. Network resource utilization [%]

A significant improvement brought by SAMP can be observed. Our solution provides resource utilization almost three times greater than OSPF (38% with respect to 13%), and compared to the multipath scheme ECMP, it procures more than 50% improvement.

2) Case 2: Congestion avoidance

To demonstrate the congestion avoidance capabilities of SAMP, we introduce congestion on one of the network links. After 190 seconds of transmission, link node$_{11}$-node$_{10}$ (node$_0$-node$_6$ for EIGRP) starts to be affected by congestion due to background traffic (1Gbps). As a result, ATR drops below a required rate necessary to transmit the video traffic. In this case, the first two routing solutions do not modify the path (paths) between the two nodes. In consequence, the video streams at the destination node are highly affected, the quality of experience being very poor.

Fig. 5 illustrates a representation of the entire global video transmission during the simulations. After 190 seconds, we can observe that in the case of OSPF, EIGRP and ECMP the network is affected by congestion and as a consequence the transfer rate drops. The single path routing solutions have a similar behavior in case of congestion, while the decrease of throughput in case of ECMP is smoother because a part of the packets are transmitted on an alternate route. In case of SAMP, the transmission is affected only for a short period of time, from the moment the congestion occurs until SAMP is informed by the management application that there is a problem in the network (~10 seconds). The problems caused by congestion are removed by avoiding the congested link and the traffic is re-routed trough link node$_{11}$-node$_9$. As we can observe in Fig. 5, the throughput in case of SAMP remains unchanged even after congestion occurs.

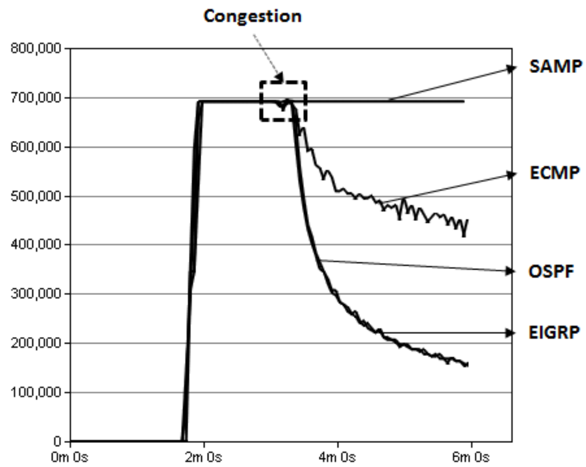

Figure 5. Transfer rate evolution [bytes/sec]

The degradation of the transfer rate continues to increase if the simulation time is longer. The approximate values obtained with the tested routing solutions for a video conferencing transmission are:

- (3Mbps→300Kbps) for OSPF;
- (3Mbps→300Kbsp) for EIGRP;
- (3Mbps→400Kbsp) for ECMP;
- (3Mbps→3Mbps) for SAMP.

Another indicator of the quality of the transmission is the end-to-end delay. Fig. 6 presents the evolution of this parameter in case of congestion. As in case of the data rate, the results obtained for OSPF and EIGRP are similar. An improvement can be observed in case of ECMP. SAMP ensures an end-to-end delay below 1 second (between 2.3 and 5.5 milliseconds) even in case of congestion. The value of this parameter is about 2.3 milliseconds for all the tested solution when no congestion occurs.

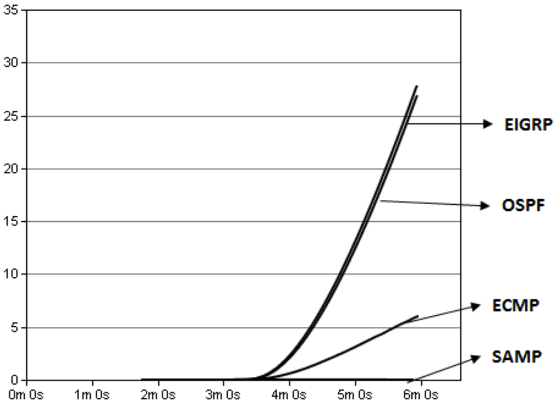

Figure 6. End-to-end delay [sec]

V. CONCLUSIONS AND FUTURE WORK

The simulation results demonstrate that the Situation Aware Multipath routing scheme described in this paper is a suitable solution to achieve load balancing and to solve the problems generated by congestion in Internet. Unlike legacy routing protocols that take into account the topology changes only and but not the bandwidth variation, SAMP takes the routing decisions based on the current state of the network links. This increases the processing and memory usage, but the overhead on a single link is in the order of tens of kbps which is negligible compared with the total traffic. The proposed solution can ensure a high quality transmission even in case of congestion. Some utilization domains for SAMP could be QoS-constraint and real-time multimedia applications.

As future work we intend to develop a load balancing formula that is based not only on the state of the network, but also on the single link utilization. In this manner we can reduce the disadvantage implied by flow based routing and obtain a more equal load sharing on each path.

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