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Network Performance Analysis of an Adaptive OSPF Routing Strategy – Effective Bandwidth Estimation

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Abstract – **Currently Open Shortest Path First (OSPF) is the most commonly used and promising intra-domain internet routing protocol where packets are routed along shortest paths to the destination. The shortest path computation is based on some static link costs and the change of the paths only happens when existing link components become unreachable or when new link components are added. In other words, the network congestion doesn't affect the routing decisions and, as a consequence, alternative paths, which could result in a better traffic performance, remain unused.**

This paper introduces and analyzes an adaptive OSPF routing strategy based on effective bandwidth estimation. Simulations carried out in the OPNET network simulator showed some preliminary, interesting results. Better network throughput (sometimes until 25,673 % better) can be reached using this adaptive routing other than the traditional OSPF, sacrificing an increase in network delay.

I. INTRODUCTION

Measurements from the Internet indicate that for almost 80% of the taken traffic paths, alternative paths exist which offer higher bandwidth and lower round-trip delay [1]. Possible reasons for these superior quality alternative paths being unused are the following: poor inter-domain routing policies and/or inadequate intra-domain routing protocols.

The main objectives of a routing protocol are to determine the network topology and the best route (according to some point of view) to a destination. The OSPF protocol is an efficient and commonly used link-state protocol that makes its routing decisions based on link costs.

The link costs, thereby the shortest path routes, can be changed by the network manager. These costs are normally set proportional to the link physical distance or according to the link priority. But often, the main goal of manager's intervention is to avoid traffic congestion and to obtain a better utilization of the network resources. The standard heuristic recommended by Cisco is to make the link costs inversely proportional to the link capacities [11].

All these attempts in choosing the best path based on static link costs assume link costs remain unchanged and therefore, the selected best paths remain the same all the time regardless network and link traffic conditions. A direct consequence frequently observed is that some paths are always overloaded and other paths that could offer a better performance remain unused.

A solution for this problem could be an adaptive routing protocol that allows dynamically associating the link costs to link congestion levels and establishing best paths in real time. It is a well-known fact that adaptive routing is capable of improving the network performance by increasing its throughput and possibly lowering the end-to-end packet delay [2] [3]. But, unfortunately this kind of routing has been largely abandoned in the Internet due to problems associated with routing oscillations (variation of best paths).

As an alternative approach, "online routing simulation" has been investigated. Network routing using online simulation can tune parameters (like the weights associated with the average link utilization, with the average buffer utilization and with the time period, over which the link utilization or buffer utilization is averaged and the link costs are updated) of the routing algorithm, achieving significantly better end-to-end throughput and delay performance and reaching stability [4]. However, the main drawback of online simulation is time consuming in routing decisions.

In this work we introduce the concept of *effective bandwidths for links* to define a new link cost for the proposed adaptive traffic routing strategy. More precisely, the effective bandwidth for links is a link utilization parameter, which allows us to introduce a new concept of "Network Quality", distinct to the quality of service (QoS) for connections. Effective bandwidth estimations used in the adaptive strategy adopted permit us to know the network load considering quality constraints desired for links.

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II – THE OSPF PROTOCOL

OSPF is a link-state routing protocol designed to be run internal to a single Autonomous System[1] [5]. Each OSPF router maintains an identical database describing the Autonomous System's topology. This database is referred to as the link-state database. Each single piece of this database is a particular router's local state (e.g., the router's usable interfaces and reachable neighbors).

Collections of contiguous networks and hosts frequently are grouped together in *areas*. Each area runs a separate copy of the basic link-state routing algorithm. Thus, it is no longer true that all routers in the AS follow an identical link-state database, therefore, the same copy of the link state routing algorithm.

The topology of an area is invisible from the outside of the area. This isolation of knowledge enables the protocol to effect a reduction in routing traffic as compared to treating the entire AS as a single link-state domain.

From the link-state database, a shortest-path tree is built. All routers run the exact same algorithm (the Dijkstra algorithm) simultaneously and each router constructs its own tree putting itself as the corresponding tree root. Each tree shows every path to any destination network or host, although only the next hop to a destination is used to the routing table construction.

A router periodically advertises its state, also called link state, by flooding[2] [5]. The flooding algorithm ensures that all routers in an area have exactly the same link-state database. Link state is also advertised whenever the state of a router changes. The unit of data describing the local state of a router or network is known as Link State Advertisement (LSA) [5].

RFC 2338 defines five types of LSAs: Router-LSA (type 1), Network-LSA (type 2), Summary-LSA (type 3 or 4) and AS-External-LSA (type 5). In this work, the Router-LSA was the LSA adopt in order to propagate the link cost actualizations. This LSA is originated by all routers and describes the collected states of the router's interfaces to an area.

Installing a new LSA in the link-state database, either as the result of flooding or a newly self-originated LSA, may provoke the updating of the OSPF routing table structure and consequently the change of best paths.

The contents of the new LSA should be compared to the old instance in the link-state database for updating purposes. If there is no difference, there is no need to recalculate the routing table. If the contents are different, pieces of the routing table must be recalculated, depending on the new LSA type.

For Router-LSAs, the entire routing table must be recalculated and reconfigured, starting with the shortest path calculations for each area (not just the area whose link-state database was changed) [5]. The reason that the shortest path calculation cannot be restricted to the single changed area has to do with the fact that AS boundary routers may belong to multiple areas. A change in the area currently providing the best route may force the router to use an intra-area route provided by a different area.

II – THE EFFECTIVE BANDWIDTH ESTIMATION METHOD

An effective bandwidth estimation method can be viewed as a method for obtaining the maximum bandwidth that could assure certain traffic/connection quality under the constraint of an admissible traffic loss probability. The objective of a bandwidth estimation method, together with an adaptive routing strategy, is to reflect the link loads on the routing and to permit that routing decisions follow different link qualities.

It is important to understand that, the routing strategy here proposed has nothing to do with any quality of service warranty, because no mechanism is used for bandwidth allocation/reservation. Instead, the use of the effective bandwidth concept permits us to adapt the routing to the network load and specify different, intended packet loss rates for the network links.

This intended link quality will be related and reflected in the link cost. If a link has a higher intended link quality than other, then this link will present a higher cost for the same or similar traffic load.

Existing methods for bandwidth estimation are mainly based on packet loss probability criteria, delay requirement and / or Gaussian approximation supposition over the self-similar process known as fractional Brownian Motion [9].

The bandwidth estimation method here used is based on a work developed by the LRPRC group [7, 8] that focuses their attention on the loss analysis approach based on the Large Deviation Theory and Gaussian Approximation. The effective bandwidth estimation method adapts Kesidis' Approach Motion [10] for the traffic with self-similarity characteristics, assuming an optimization function based on the buffer size and on the Hurst parameter and the following packet loss probability criteria:

$$P\{X > b\} \leq \exp\left(-\delta b^{2(1-H)}\right)$$

where,

X is a random variable representing the current number of packets in a buffer of size *b*; δ is a scaling constant and H is the self-similarity parameter (the Hurst parameter).

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[1] An Autonomous System is a group of routers exchanging routing information via a common routing protocol [5]. Abbreviated as AS.

[2] Flooding means that the router sends the LSA out of every interface and that every router that receives the LSA sends it out of every interface except the one from which it was received [6].

IV – THE ADAPTIVE OSPF-MODEL

The adaptive OSPF routing algorithm, developed in the OPNET network simulator, updates the link costs based on effective bandwidth estimates in each active router interface (Fig. 1).

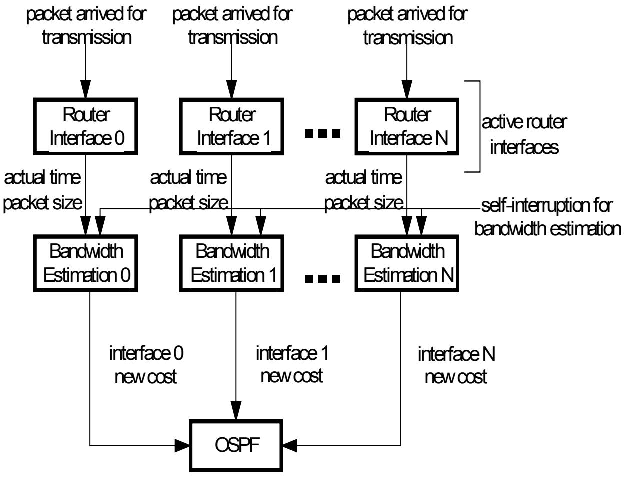

Fig. 1. The Bandwidth Estimation Based Adaptive OSPF Routing.

For each active router interface, there is a bandwidth estimation module that receives continuously the following traffic information: transmission time and output packet size. Based on this information, the estimation module calculates periodically, based on the *Bandwidth Estimation Period*, the bandwidth required for the current traffic and updates the link cost reported to OSPF. Therefore, periodically the new link cost is derived based on the newest effective bandwidth estimate. The adaptive link cost function adopted in this work is the following:

$$C_{l,t} = 1000 \times \exp\left(\frac{BE_{(t-BEP,t]}}{CT_l}\right)$$

where,

$C_{l,t}$	is the cost associated with link l at instant t.
BEP	is the bandwidth estimation period.
$BE_{(t-BEP,\, t]}$	is the bandwidth estimated since the last estimation time until the current time.
CT_l	is the transmission capacity of the link l.

This new cost $C_{l,t}$ is then passed to the OSPF module - from the bandwidth estimation module n, n ∈ {0, 1, …, N} - together with the corresponding interface number (n) via a *new cost message*.

The OSPF routing protocol behavior is specified in OPNET by a *state transition diagram* (STD). The adaptive OSPF model was constructed adding a new state (called, *New Cost Process*) to this STD. Figure 2 shows the STD of the proposed adaptive OSPF model.

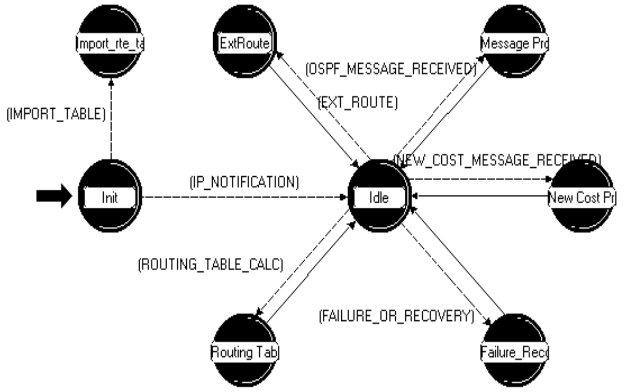

Fig. 2. The STD of the Adaptive OSPF Model.

Each time the OSPF module receives a new cost message from a bandwidth estimation module, the OSPF changes to the *New Cost Process* state. At this state the corresponding interface has its cost updated to $C_{l,t}$ and once all interfaces had their costs updated, OSPF module generates a Router-LSA, updates the area link-state database and floods the LSA.

V – SIMULATION RESULTS

The analysis of the proposed adaptive OSPF routing strategy was performed via simulations carried out under OPNET Modeler. In this work, the adaptive OSPF ran over IP layer and Frame-Relay was chosen for layer 2. Notice that the choice of Frame-Relay is only for convenience and independent of adopted routing strategy. The network topology chosen for this investigation is depicted in Figure 3, which has the goal of highlighting the major differences between the traditional OSPF and the proposed adaptive OSPF. For each router interface a FIFO (First In First Out) buffer of 50,000 bytes was implemented and a link capacity of 1,544,000 bps (T1) was adopted.

The generated packet traffic is specified by the following information: the source router, the destination router, the start time, the stop time and two functions, one for the packet inter-arrival time (called *delta time function*) and other for the packet size. Notice that the packet size refers to the size of the packet that has successfully passed to the IP layer, which is different to the size of the packet originally generated by the source. The notation *TRAFF_I_J* represents the traffic generated by the source router *node_I* to the destination router *node_J* (see Fig. 3).

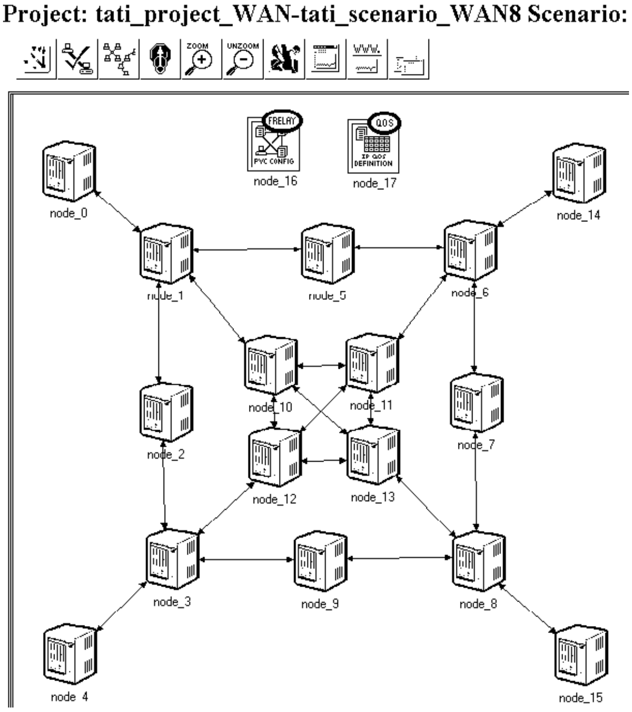

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Fig. 3. Chosen Network Topology in Simulation.

For the given network topology, we implemented several scenarios and analyzed the network performance in terms of network throughput and transmission delay. The simulation results are shown in Figure 4 to 11. More precisely, in Scenarios 1a, 2a and 3a the adaptive OSPF routing was implemented and in Scenarios 4a, 5a and 6a the traditional OSPF was investigated.

In Scenario 1a, we have: (a) single Poisson traffic, TRAFF_1_15, with start_time = 180 sec and stop_time = 2000 sec; (b) mean interarrival time = 700 µsec; (c) packet size is Poisson distributed with mean value 800 bits.

In Scenario 2a, we splits the same traffic of Scenario 1 into two traffic traces: (a) TRAFF_1_15 and TRAFF_8_0, both with start_time = 180 sec and stop_time = 2000 sec; (b) both with mean interarrival time = 700 µsec; (c) however, each trace having the Poisson distributed packet size with mean value 400 bits.

In Scenario 3a, each split traffic in the scenario 2a is again split into two traffic traces: (a) TRAFF_1_15, TRAFF_8_0, TRAFF_3_14 and TRAFF_6_4, all with the same start_time = 180 sec and stop_time = 2000 sec; (b) each trace has the mean interarrival time = 700 µsec; (c) however, each trace having the Poisson distributed packet size with the mean value 200 bits.

Scenarios 4a, 5a and 6a present the same traffic characteristics of scenarios 1a, 2a and 3a, respectively, but running the traditional OSPF routing strategy.

The objective of these six scenarios (Scenarios 1a to 6a) is to compare the network performance (throughput and delay) with the two routing strategies (adaptive OSPF with bandwidth estimation and traditional OSPF) using different arrangements of the same traffic trace. Figures 4 to 9 show the mean network throughput and delay for these six scenarios. And figures 10 and 11 show the average network throughput and delay for the same scenarios.

Comparing the scenarios 1a and 4a, the adaptive routing proposed presents better network throughput than the traditional routing during all time with an increase in the network delay. The network throughput in scenario 1a oscillates between values equals or until 1409189 bps (25,673 %) greater than the values of scenario 4a (Fig. 4). While the network delay in scenario 1a oscillates between values equals or until 0,000396 seconds (22,5137 %) greater than the scenario 4a (Fig. 5).

Comparing scenarios 2a and 5a, the network throughput in scenario 2a oscillates between values equals or until 25,534 % greater than the values of scenario 5a (Fig. 6). While the network delay in scenario 2a oscillates between values equals or until 20,4705 % greater than the scenario 5a (Fig. 7).

On the other hand, when comparing the scenarios 3a and 6a, we find that the network throughput and delay presented are almost the same for the two routing strategies (Fig. 8 and 9). Notice that these scenarios present a regular traffic disposition; consequently the adaptive routing decisions don’t have a great impact in the network performance. The network throughput in scenario 3a oscillates between values equals or until 0,4309 % greater than the values of scenario 6a (Fig. 8) while the network delay in scenario 3a oscillates between values equals or until 0,6106 % greater than the scenario 6a (Fig. 9).

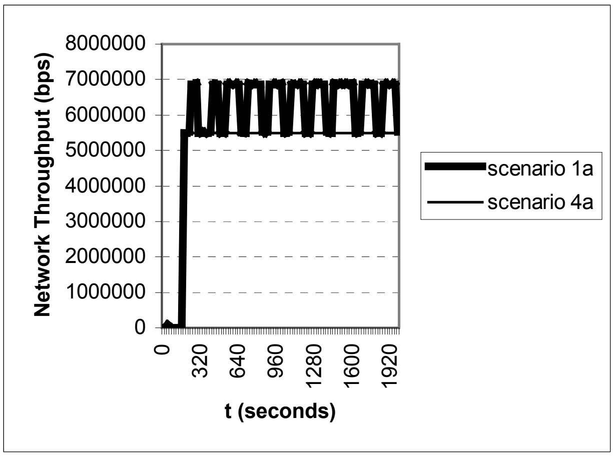

Fig. 4. Throughput for scenarios 1a and 4a.

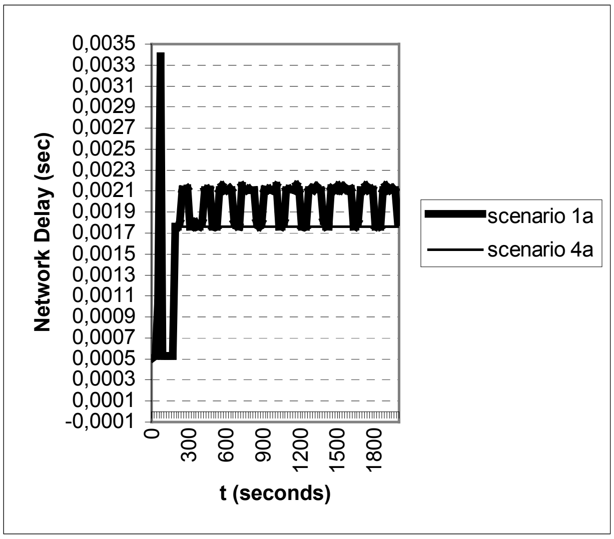

Fig. 5. Delay for scenarios 1a and 4a.

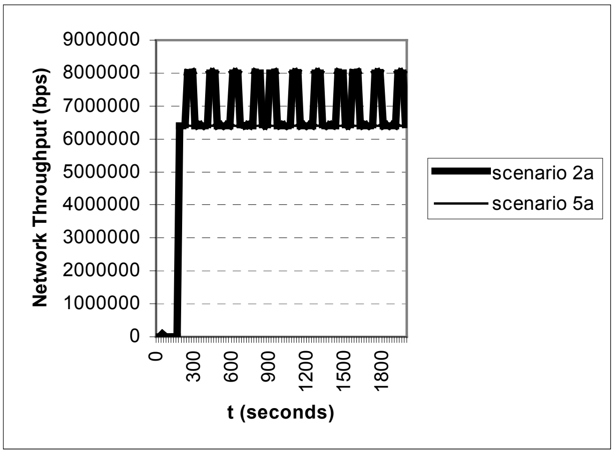

Fig. 6. Throughput for scenarios 2a and 5a.

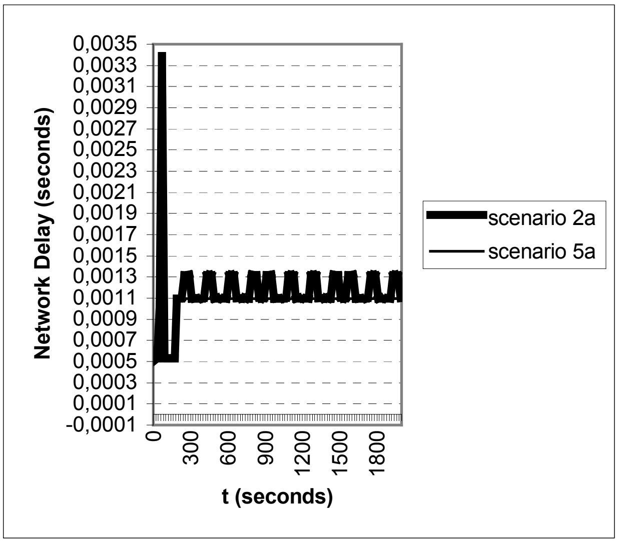

Fig. 7. Delay for scenarios 2a and 5a.

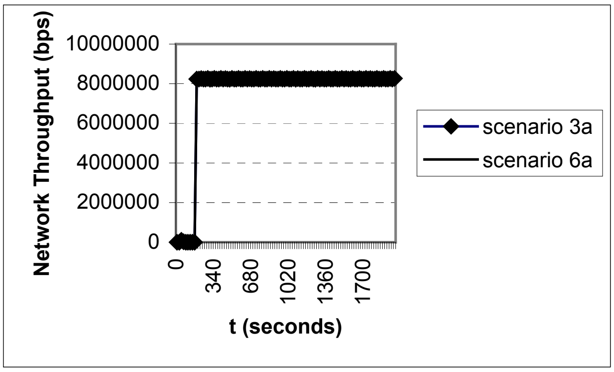

Fig. 8. Throughput for scenarios 3a and 6a.
(the two performance curves are almost overlapped)

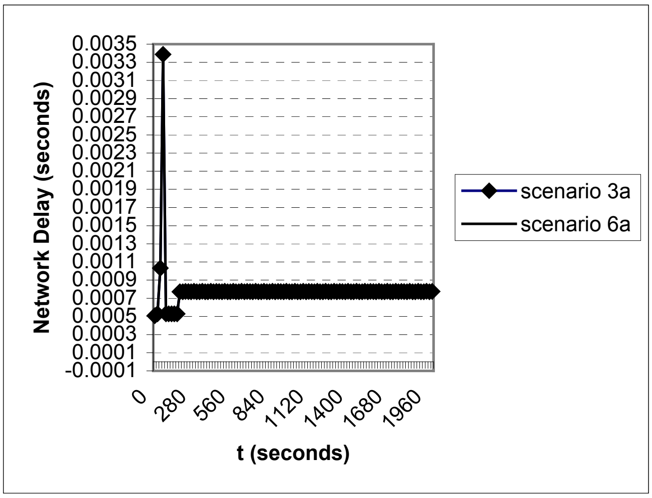

Fig. 9. Delay for scenarios 3a and 6a.
(the two performance curves are almost overlapped)

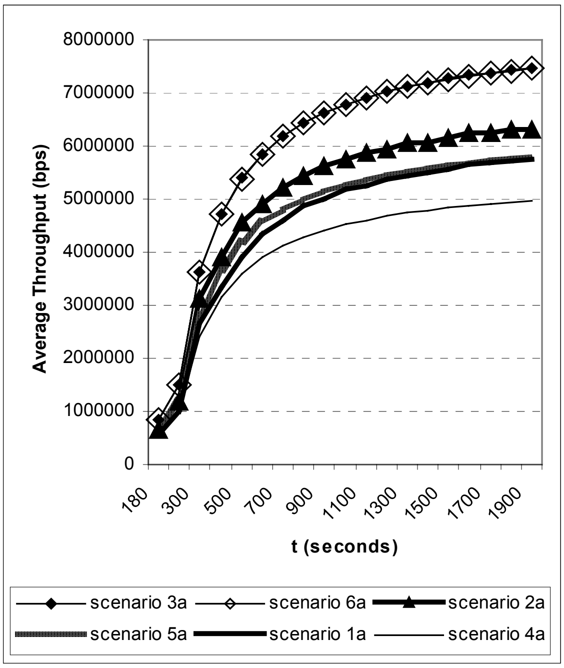

Fig. 10. Average Throughput for scenarios 1a to 6a. (scenarios 3a and 6a are almost overlapped)

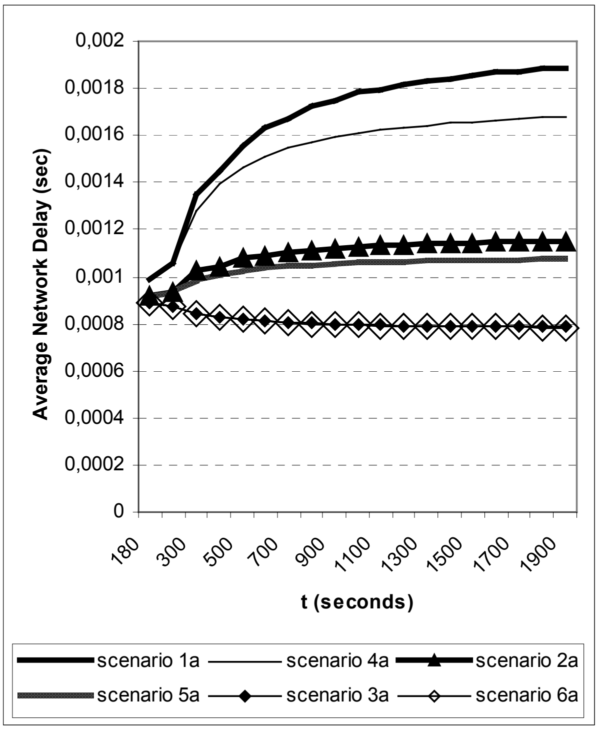

Fig. 11. Average Delay for scenarios 1a to 6a. (scenarios 3a and 6a are almost overlapped)

These plots show the following: less dispersion of traffic load (like scenarios 1a and 4a) result in, more increase in the throughput that the adaptive method is able to offer, what make the proposed adaptive routing method attractive. Although Scenario 4a presents the smallest network throughput among all analyzed scenarios, the gain in throughput is the biggest increase when adopting the adaptive method (see Figure 10). However, as expected, this scenario has the largest delay due to deviation from the shortest paths as well as the additional traffic load generated by OSPF updating.

In scenarios when the traffic load is well spread through the network (like scenarios 3a and 6a) the throughput and delay values for the two routing strategies are practically the same (see Figure 10 and 11).

VI – CONCLUSION

In this work, we investigated the network performance with an adaptive OSPF routing based on bandwidth estimation. The network performance was analyzed in terms of network throughput and delay under the OPNET network simulator. The results of this investigation show that the proposed adaptive OSPF routing may increase significantly network throughput (25,673 %) in scenarios where the traffic load is spatially highly concentrated, which proves the usefulness of this adaptive OSPF routing strategy. However, further analysis is needed, specially taking account of several factors simultaneously, such as throughput, delay and information loss rate.

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