Simulation model for evaluation of packet sequence changed order of stream in DiffServ network

M. Czarkowski and S. Kaczmarek

Abstract—**Current packet networks use a large variety of mechanisms which should support QoS (Quality of Service). One of those mechanisms is routing (calculating connection paths for incoming service requests). The most effective mechanism in QoS context is dynamic routing, based on the current network state described by the offered traffic matrix and link states. After switching between calculated available paths, connection path changes may cause received packets to change order within a single stream. This paper includes the problem definition and the analysis of all additional effects. A combined simulation/analytic model was proposed in order to answer whether the number of changed-order packets is significant and if it should be considered when calculating the end-to-end delay balance in analytical models for packet networks with differentiated services. Furthermore, the proposed model gave the answer on how often calculated paths may be switched to avoid the network beingout of tune.**

Index Terms—**IP, QoS, DiffServ, QoS routing**

I. INTRODUCTION

CURRENT telecommunications networks are based on a large variety of technologies. Many of those networks are packet based networks with focus on networks which use IP protocol (so called IP networks). If they are applied in a local scope (IP network connecting just neighbor devices), they work according to the provided design and they do not cause any additional problems with configuration and maintenance; however, when they are used in a global scope (IP network as a core network), they are the source of many problems and unexpected network behavior. Those problems are mostly combined with servicing requested QoS and, simultaneously, optimal network resources utilization. It is due to very strong dynamic traffic changes from multiple traffic sources. Those sources vary in their traffic characteristics. That is why any mechanism used should be resistant to such strong traffic dynamics. Unfortunately, current network control mechanisms provided for IP networks fail to solve this problem [1], [2]. One of network control mechanisms is connection path calculation process – routing. The important condition which should provide effective routing in these terms is to calculate paths to support requested QoS for differentiated services. Effective path calculation means also avoiding network congestion states and optimization of available resources. Current routing mechanisms do not meet those requirements [3], [4]. The key element to solve this problem is to use dynamic routing – the process of path calculation which follows the network changes and path selection decision, based solely on the current network state. In addition, the introduction of dynamic routing causes some consequences. One of them are incoming packets order changes within a single stream, which is due to the switching of available paths. Change of packets order is caused by switching from a path with longer delay into a path with shorter delay. The packet delay is directly combined with the number of transit nodes and traffic currently located in the network. Unfortunately, there is no scientific literature which considers the problem and no research results on the subject of reordered packets. Most authors dealing with dynamic routing mechanisms assume in their works that packet reordering during path switching is not significant. The authors who noticed the problem of packet reordering made initial assumption that reordering will be solved by upper layers and they just shift the responsibility. Other analyzed papers included the assumption that packet reordering due to path switching will not be considered because it is not an important issue. It seems to be a wrong assumption. In this paper we give the answer to the question whether the packet sequence changed order is a significant effect from the point of view of dynamic routing. The rest of the paper is organized as specified below. Section II describes the problem in general in terms of generated traffic relations and available system resources. Section III is a short description of the proposed simulation model used for problem evaluation and extended experiments. Section IV contains the research results and the analysis of those results. Some investigated relations are also identified. The final section V provides a short summary with focus on further work directions.

II. PROBLEM DEFINITION AND DECOMPOSITION

Some basic assumptions were made for further investigations. The analyzed network supports prioritized services. Packets come into/come out of the network via edge nodes. All core nodes support transit nodes functionality. Additionally, the service in the node is based on the non-preemptive priority model. The considered problem is illustrated in Fig. 1.

Packets come into the network into edge node A and are transferred via core node C to edge node B. The first calculated path1 from node A to node B is A→C→B. All packets with destination address B are transported using this path. After sudden traffic changes on path1, congestion state has been detected and the entire path had to be calculated again (dynamic routing). Let us assume that the new calculated path2 from A to B is: A→D→E→C→B. Packets sent before the path recalculation, which were being transported via path1 (and

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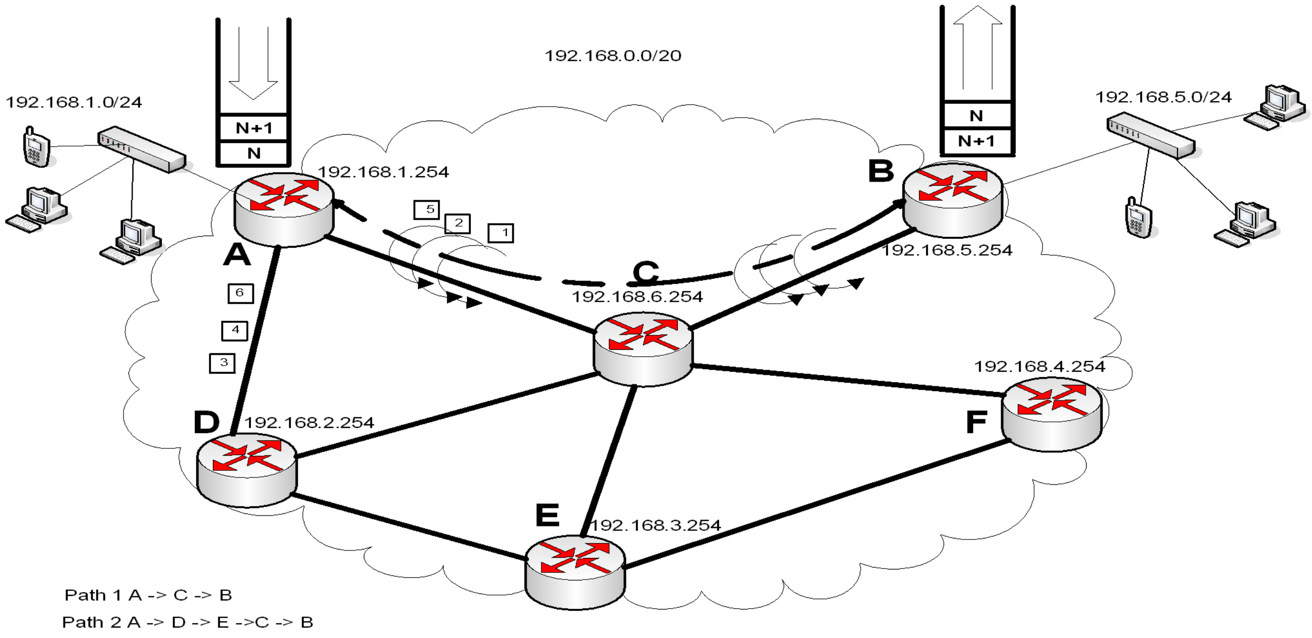

Fig. 1. Basic problem visualization.

have not reached the out-node yet), were not discarded and are processed in the network.

In Fig. 1 this one situation refers to packets with numbers 1 and 2. Packets with numbers 3 and 4 were sent through the new path2. After some time, the connection paths were transformed again into path1 A→C→B (packet 5) and again into path2 A→D→E→C→B (packet 6). Let us assume that each link in Fig. 1 introduces the same propagation time (the same medium and the same length for each corresponding link on the path). All links are one direction symmetric links with the same bandwidth. Moreover, each core node introduces the same waiting time (for service in the queue). Both paths from A to B differ only in the transit nodes number. Packets sent via path2 will be received later than they would be received from path1. This will cause switched packets order in node B (packet 5 will be received by node B before packets 3 and 4). The proposed model does not simulate delays on the path (the behavior of service systems). Therefore, an analytical part has been introduced for delays calculation (buffering delay, send delay and propagation delay). The end-to-end delay time may be described using the following equations when we assume PQ systems in nodes [5]:

$$E(t_{end-to-end}) = k \cdot (E(t_{wait}) + E(t_{send}) + t_{prop}) \qquad (1)$$

$$E(t_{wait}) = \frac{\sum_{i=1}^{R} \lambda_i m_i^{(2)}}{2\left(1 - \sum_{j=1}^{i-1} \rho_j\right)\left(1 - \sum_{j=1}^{i} \rho_j\right)} \qquad (2)$$

where: $R (= 3)$ – number of classes
ρ_j – offered traffic for class j
λ_i – packets intensity for class i
$m_i^{(2)}$ – second moment for class i
k – number of core node (=1 for a shorter path and =3 for a longer path)

$$E(t_{send}) = \frac{E(L_i)}{C_l} \qquad (3)$$

where: L_i – length of the packet for class i
C_l – link bandwidth in a given direction

$$t_{prop} = \alpha_m d_{u-v} \qquad (4)$$

where: α_m – delay factor for medium type m
d_{u-v} – length between nodes u and v

Three basic types of time (waiting time, send time and propagation time) may influence the problem under consideration. The end user connected to the edge node may generate several traffic classes (e.g. streaming, elastic, best effort). The time distribution between packets is assumed to be exponential. Packets generated from each user are transmitted through a common link to the in edge node. In the edge node routing a decision is made (path selection) and packets are forwarded to the path chosen from the two available paths. If they reach the out edge node, they are marked off from the aggregated DiffServ stream and forwarded to the destination end user.

III. SIMULATION MODEL

Based on the above delays model of events, a simulation model was proposed, i.e. a combination of simulation and analytical delay rules. A scheme of the proposed model is presented in Fig. 2 and demonstrated in omnet++ simulation tools [6]. The input in the model are traffic sources limited to three traffic classes: streaming services sensitive to delay and jitter – classified to EF; elastic services sensitive to loss probability – classified to AF; other services not sensitive to any factor – classified to BE. AF has been limited only to a single class

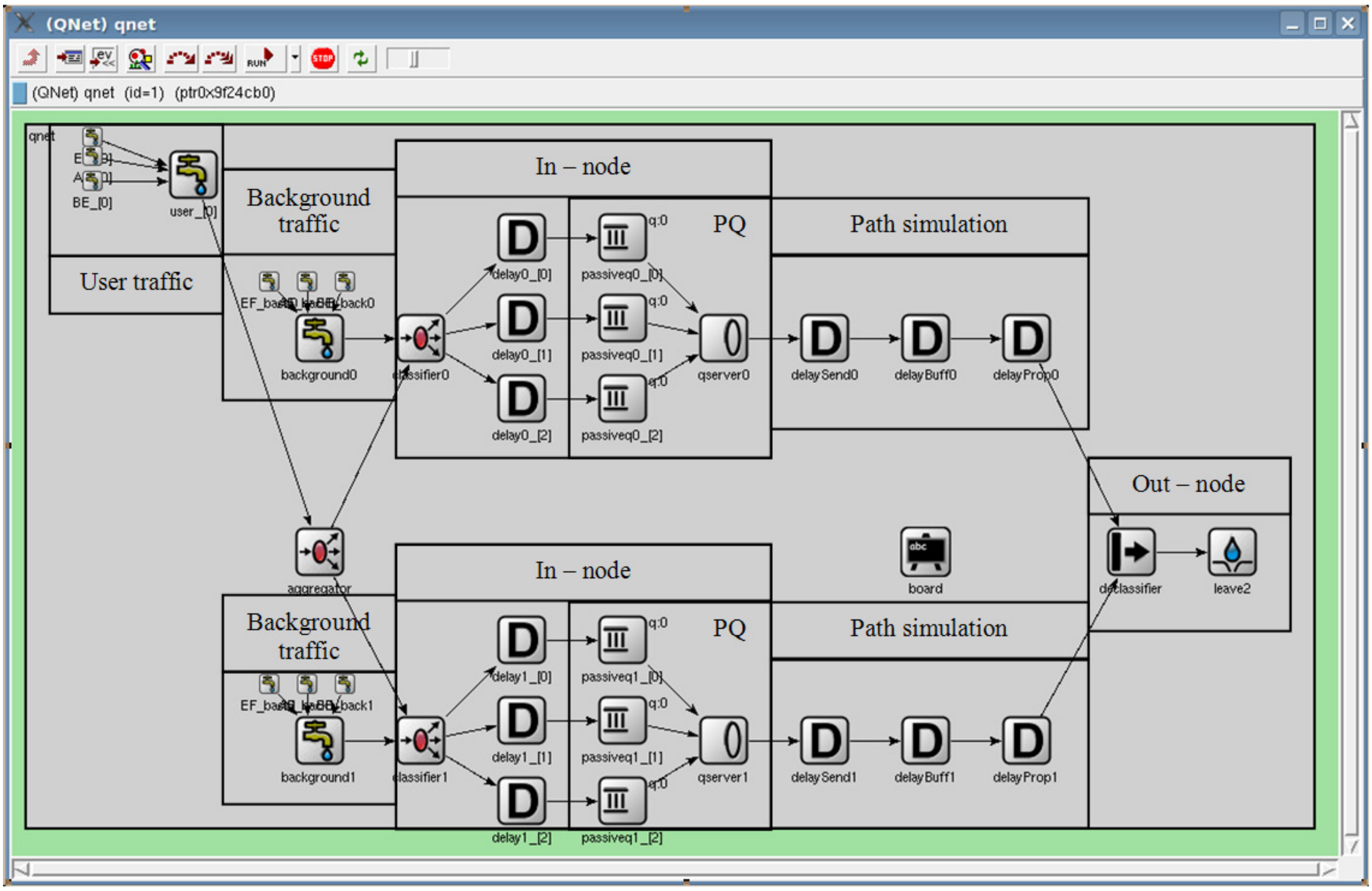

Fig. 2. Screenshot from omnet++ simulation model.

just to identify the problem. Those three service classes are generated by any user connected to the network. Each traffic class is defined by priority and packet intensity. Inter-arrival time between incoming packets is calculated on the basis of packet intensity within the class. Streaming services use short packets with 160 bytes length, elastic services use packets with 500 bytes length, other services – packets with 1,500 bytes length. Before simulation is run, traffic classes proportions are calculated. Users send their packets (User traffic) to the edge node which actually corresponds to the aggregating node (aggregator block connected to In-node block in Fig. 2). Connection paths are calculated in the edge node because we have source routing and packets are transmitted through the service system (in the edge node each path has its own service system). The remaining connection path (Path simulation) is calculated in block devices (D), which in fact are a chain of service systems present in the path.

Those devices simulate each type of delay, i.e. send delay, buffering delay and propagation delay, over the connection path. All global data used in the simulation are stored in the board object which is not linked to any block in the simulation model.

Given connection paths have varying delay values. Packets switched order is detected in the declassifier block (Out-node) and statistics are collected separately for each traffic source. Packets are deleted in the sink block (leave). The input parameters of simulation: the number of transit nodes present in the path, nodes distance, bandwidth between nodes, link load, packets interarrival time (given as exponential distribution), time values between successive routing table changes (paths recalculation). The following functional blocks have been defined:

A. *User traffic*

- EF_i – streaming class traffic generator for user i
- AF_i – elastic class traffic generator for user i
- BE_i – best effort traffic generator for user i
- User_i – aggregator of all available traffic classes

B. *Background traffic*

- EF_back_i – background traffic generator for streaming class for user i
- AF_back_i – background traffic generator for elastic class for user i
- BE_back_i - background traffic generator for best effort class for user i
- Background_i – aggregator of all available traffic classes for background traffic

C. Aggregator – switches the traffic onto the proper path

D. In node

- Classifier – separates aggregated traffic into separated class queues
- Delay_i – receiver processing delay (in this research set to zero)
- Qserver – PQ queue model

E. Path simulation

- delaySend_j – simulates sending delay dependent on link speed and packet length for path j
- delayBuff_j – simulates buffering delay dependent on non preemptive service model of path j
- dealyProp_j – simulates propagation delay of path j

F. Out node

- declassifier – splits packets received in aggregated stream into sub-streams and collects required statistics
- leave – sink for created packets

G. Board – global storage of simulation parameters and common data

IV. RESULTS ANALYSIS

A set of simulation results with confidence level of 0.95 have been collected for various configurations across many possibilities. The following charts represent some selected results. The figures outline the situation when background traffic is 80% and the rest (20% of the traffic) is being switched between paths. The background traffic has been introduced so that two service systems (for path 1 and path 2) are working in parallel while the paths are switched. Each of the charts shows different time values between routing tables recalculation.

The first one is when a routing table is updated every 5 seconds (Fig. 3), the second one when the table is updated every 20 seconds (Fig. 4), and finally every 40 seconds (Fig. 5). The results have been grouped in three parts: the first part (marked with EF on the x axis) collects EF class, the second one (marked with AF) collects AF class and the last one (marked with BE) collects BE class. The presented values are the ratio between switched packets within a single stream of class i to all packets sent for this stream class i. For all of the charts nine simulation series are presented.

Each series differs as far as proportions of traffic share for EF, AF and BE classes are concerned. Classes' shares are listed in TABLE I.

All charts show that for EF class a lower ratio of switched packets to all packets is when EF class has more shares within the overall traffic. It can be explained with the highest EF priority of all traffic classes and the fact that EF are short (160 bytes) – more share, will cause more intensity of EF, and less intensity within longer packets (AF and BE), so the residual time due to non-preemptive priorities, will not affect EF as strongly. No unexpected effect has been observed also for BE traffic class. The ratio of BE switched order packets was high for low BE share and high for EF and AF shares in the overall traffic. It may be explained by the meaning of BE priority (the weakest) as well as by the low intensity of BE. EF and AF have much higher intensity than BE.

TABLE I
CLASSES PROPORTIONS FOR EACH SIMULATION SERIES

Series	$EF[\%]$	$AF[\%]$	$BE[\%]$
1	10	10	80
2	10	45	45
3	10	70	20
4	20	10	70
5	20	40	40
6	20	60	20
7	30	10	60
8	30	35	35
9	30	50	20

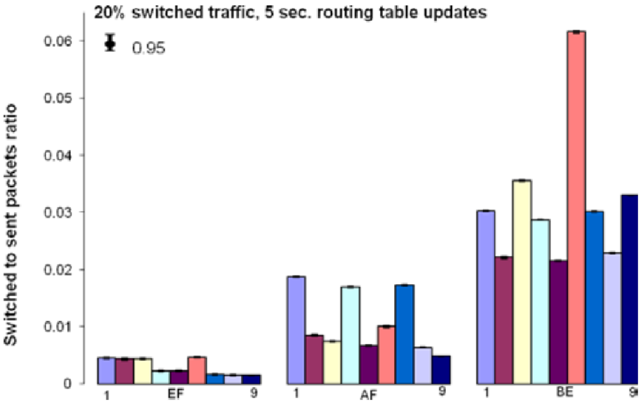

Fig. 3. Results chart for 20% traffic switched every 5 seconds.

A peculiar effect was observed for AF class in the case of some classes proportions. When EF class had the share above 40% and the remaining traffic (60%) was divided between AF and BE, AF had much higher switched sequence changed order packets ratio than usual. Although AF share was growing (within 60% of traffic for AF and BE), the ratio did not fall (though it should due to the priority higher than BE). It may be partially explained with the residual time of BE; but when BE share falls, the residual time shall not influence the AF class so strongly. The nature of the observed relations shows that they are influenced by many other factors which require further extended experiments. Only then will it be possible to identify all the relations and find the explanation of investigated effect. The current research stage allows us to confirm that the problem investigated in this work is significant in terms of dynamically controlled routing.

V. SUMMARY

Dynamic routing may introduce many additional problems. Some of them seem to be simple and their explanation should be obvious (they are already analyzed and solved). Unfortunately, sometimes they cause unexpected system behavior and introduce additional effects that have not been solved yet. Such effect is packet sequence changed order within a single stream caused by changes in the path transit node number

Fig. 4. Results chart for 20% traffic switched every 20 seconds.

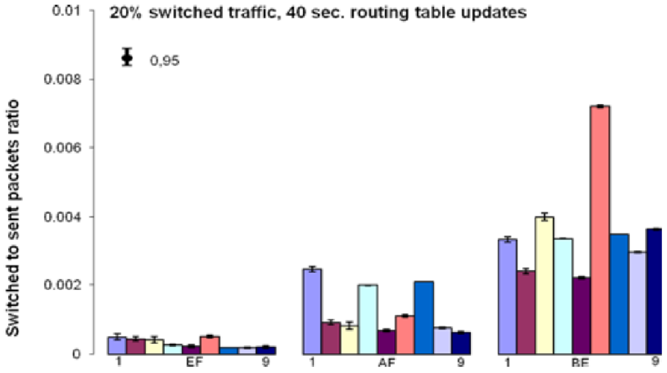

Fig. 5. Results chart for 20% traffic switched every 40 seconds.

(different delays on different paths). Further considerations gave several interesting answers on the meaning of dynamic routing mechanisms. The proposed simulation model made it possible to answer some questions and to shed light on the scope of other problems. Using some proportions between classes in differentiated services domain packets reordering caused by path switching should be marked in end-to-end balance. It may not be skipped and omitted in the system analysis. The AF switched sequence changed order packets to all AF send packets ratio may not be explained by applying the known analytical equations (for the non-preemptive priority system). The ratio value is significant for flexible services and should be taken into consideration. Furthermore, an important conclusion for EF traffic was found. The streaming services have lower switched sequence changed order than all EF sent packets ratio when EF share in the overall traffic amount is 20–40 %. Some additional remarks were also found for different time values between routing table recalculations. It turned out that the optimal time between routing table updates (in short term changes – seconds) was 35–40 seconds interval. This statement is based on simulation results but will not be discussed in this paper due to space limitation. For routing table switching time a local minimum of the 35–40 seconds was observed. For all analyzed situations residual time is important when packet length differs between given traffic classes (EF – 160 bytes, AF – 500 bytes, BE – 1,500 bytes). Further investigations will be aimed at finding the relations for AF traffic and explaining the issue using the newly developed analytical equations.

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