INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2022, VOL. 68, NO. 2, PP. 351-357
Manuscript received April 8, 2021; revised May, 2022. DOI: 10.24425/ijet.2022.139889

QoS Extensions for Flow-Awareness Networks

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***Abstract*—The paper contains a description and research results of the proposal for distributed QoS extensions for Flow-Based Networking. These QoS extensions let the network accept or reject flows based on current network load and QoS promises for each of the flows. Proposed solution consists of two distributed components, each of them performing in every node, measurement system and access control. The solution could be applied in any network architecture that is able to distinguish flows and routers in this architecture contains flow state table. Proposed approach was verified by simulation, in FSA architecture. Verification was done for six different network structures servicing two traffic classes (MRS, ARS). The results of the simulation tests have confirmed that the average time delay and packet loss ratio in the network with proposed extensions are below thresholds and meet the requirements recommended by ITU-T.**

***Keywords*—FSA; flow network; QoS; MBAC; simulation**

I. Introduction

DELIVERING appropriate Quality of Experience (QoE) lies within the research areas in the current packet networks [1]. One of the most important indicators of QoE is Quality of Service (QoS) [2]. There are plenty of solutions in packet networks to guarantee the proper QoS. In the control plane of the network we can list admission control, QoS routing and method of resource reservations [3]. In contrast, in the data plane there are classification and marking, packet queuing, shaping, policing etc.

To support different QoS for different traffic classes, proper design of the queening system and Admission Control (AC) function are required [4]. In this paper we focused on AC function which works on flow level [5]. Its importance lies in the fact that the role of this AC function is to accept or reject flow depending on whether the network has enough resources or not. Providing required QoS and resource utilization depends on valid AC function implementation.

There have been many studies in the last years in the field of Admission Control. AC algorithms can be divided into three categories [6]: Endpoint-based AC (EDAC), Parameter-Based AC (PBAC) [7] and Measurement-based AC (MBAC). In EDAC a decision is made on the user side, based on the probe packet. PBAC computes required network resources to handle the given set of flows, based on providing a priori characteristic of the flows [6]. MBAC measures traffic load and makes a decision based on the results of these measurements. It is worth emphasizing that the MBAC algorithm is perceived as the most promising category of AC algorithms, especially for high variable traffic, for example video transmission [8]. So far, plenty of researchers have worked on solutions linked with the MBAC function. Surveys are available for example in [9,10].

Flow-awareness networks are a new direction to achieve QoS [4,11,12]. This solution identifies a set of packets as a flow and applies QoS network policies for each particular flow. Every flow-awareness architecture has a flow-state table, which is a component to store information about service flows. MBAC solutions for flow-awareness networks are intensively researched [11,13,14]. However, we have to keep in mind that all solutions from [11,13,14] make admission decisions without using knowledge from the flow-state table.

In this paper, the concept of distributed MBAC for flow-awareness networks is proposed. Proposed solution uses data about currently serviced flows from a flow-state table to improve measurement quality. This approach consists of two units: flow-based measuring unit and flow access control function, which is based on measuring unit. Located in every service system, a measuring unit is responsible for measuring QoS parameters in a given node. Proposed measurement algorithm uses the flow-state table as a source of data to the MBAC function, located also in every service system. A decision about flow admission is made in every service system. Proposed solution was verified in a Flow-State-Aware (FSA) [15, 16] simulation network model.

This paper is structured as follows. Section II describes the proposed distributed MBAC algorithm. Section III describes the simulation environment used to evaluate the proposed solution. Section IV describes simulation results and discusses them. Section V summarizes this paper shortly.

II. QoS Extensions

To describe proposed QoS extensions, firstly the network model should be presented. Two network parts - core and border - are distinguished. Access to the first one, to the core network part, is possible only via border links between core node and border node. Simultaneously, the core nodes are connected by core links. Example structure with two border nodes and three core nodes is shown in fig. 1. Every link is connected to one of the service systems in node. This service system contains a proposed MBAC solution and queuing system.

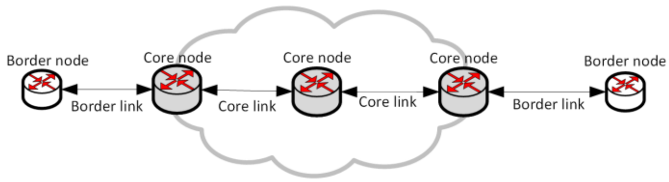

Fig. 1. Overall network architecture

In flow-awareness networks every packet is part of a flow. Flow is a set of packets localized in time with a distinguished flow identifier. For IPv4 it could be a tuple of five values: source

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IP address, destination IP address, transport layer protocol identifier, source port and destination port.

To introduce the proposed solution some assumptions about flow-awareness networks are required. Every node in the network must identify flow and calculate flow identifier. Simultaneously, every node in the network must identify and distinguish the first and last packet of every flow. In this paper the first packet is named INIT and last packet is named FINISH. INIT packet contains signalization data about coming flow and can also contain user data. Network node stores in the flow-state table all identifiers of accepted flows as well as data describing flow traffic for every flow. Wherein every flow is assigned to a traffic class. QoS requirements are defined per traffic class. All packets of a given flow are transported by the same network path.

Proposed solution requires adding some information to the INIT packet of every flow. Protocol stack must be expandable and must allow adding additional data to headers.

In this paper, particular flow is identified by symbol *f*. Path between two nodes is described by $p = (e_1, e_2 \dots e_w, \dots, e_W)$, where e_w is identifier of the service system in node *w* and the link connected to this service system, W is number of links on path p. Traffic class is marked as symbol *c*. To explain the concept of proposed solution and for simulation purposes MRS and ARS traffic classes from FSA recommendation [15,16] are used.

In the following subsections there is a description of the proposed solution's overall architecture. After that, the measurements and AC functions are more widely discussed.

A. Architecture of Proposed Solution

In the proposed solution, the MBAC function is distributed and is located in every network node. Moreover, the decision is made neither in the centralized element nor in the network border. Discussed approach is based on measurements of serviced flows, not on contract and flow properties provided by traffic source. In a distributed model every node on path makes an admission decision of flow *f* when the first INIT packet comes. MBAC function in service system e_w calculates state $S_{e_w} = aggregate(S_{e_{w-1}}, M_{e_w}(c))$, where state $S_{e_{w-1}}$ comes with INIT packet and $M_{e_w}(c)$ is local measurements for traffic class *c* of flow *f*. Based on the obtained value S_{e_w} and the traffic class *c*, MBAC makes an admission decision about coming flow *f*. When flow is rejected, INIT packet is dropped, and traffic source is informed about rejected flow. When flow is accepted, new state S_{e_w} is saved in INIT packet and INT packet is sent to the next node where it is processed by MBAC in the service system. State S_{e_w} contains two values: sum of loss ratio from subsequent service systems and sum of delay from subsequent service systems and links. Distributed algorithm of the MBAC function is presented in fig. 2. Functions $aggregate$ are described in section II.C.

Measurements $M_{e_w}(c)$ are made based on local flow-state tables stored in the service system. Three values are measured: loss ratio in service system e_w, delay in service system e_w and in attached link, bandwidth of all accepted flows in service system e_w. Measurement's algorithm is presented in section II.B.

For every not-INIT packet coming to the service system, this service system checks if the flow identifier of this packet is in the flow-state table. If yes, the packet is serviced by successive blocks, if not; it is immediately rejected.

For every FINISH packet coming to the service system, the row in the flow-state table about the flow of this packet is removed. Flows are also removed from flow-state tables in a given service system when this service system does not receive a new packet of this flow during time t_{fb}.

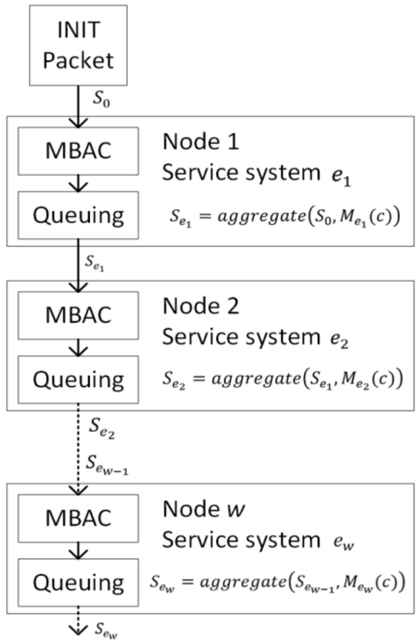

Fig. 2. QoS Extensions architecture

B. Measurement's Algorithm

Two goals for proposed measurement's algorithm were set:

- to limit memory effect and include only events related to currently serviced flows,
- to properly estimate the probability of rare events like loss ratio.

It is important to have the most accurate values about delay and loss ratio and not to include a packet of finished flows in calculation. To achieve these requirements measurement system that is based on a dynamic window has been proposed. Loss ratio and delay are measured based only on active and accepted flows ($F_A(e, c)$) in the service system *e* as well as for traffic class *c*. Data about flow are not included in measurements when given flow is finished.

For every accepted flow *f* following values are stored in a flow-state table of the service system *e*:

- traffic class *c* of given flow,
- number of received packets $P_r(f, e)$ – incremented for every received packet,
- number of rejected packets $P_l(f, e)$ – incremented when received packet is rejected,
- number of serviced packets $P_s(f, e)$ – incremented when packet leaves the node,
- sum of delay for every flow packet $T_T(f, e)$ – increased by sum of three values: how long the packet was in the service system, packet transmission time and packet propagation time on link,

- number of received bits $b_{win}(f,e)$ - incremented for every received packet by this packet's size, value is set as $b_{win}(f,e)=0$ for every T_{win} time,
- time of receiving last packet $T_l(f,e)$ – updated after receiving every packet.

For every request of AC function in service system *e* values of loss ratio ($l_r(e,c)$) and delay ($E[d_T(e,c)]$) for traffic class *c* are calculated by (1) and (2).

$$l_r(e,c)=\frac{\sum_{f\in F_A(e,c)}P_l(f,e)}{\sum_{f\in F_A(e,c)}P_r(f,e)} \tag{1}$$

$$E[d_T(e,c)]=\frac{\sum_{f\in F_A(e,c)}T_T(f,e)}{\sum_{f\in F_A(e,c)}P_s(f,e)} \tag{2}$$

Value of bandwidth of serviced flows ($C_s(e)$) is calculated every T_{win} time by (3). After calculation, all values $b_{win}(f,e)$ are set to 0.

$$C_s(e)=\frac{\sum_{c\in\{ARS,MRS\}}\sum_{f\in F_A(e,c)}b_{win}(f,e)}{T_{win}} \tag{3}$$

Example of flow-state table for service system e_w in node *w* is presented in Table I.

TABLE I
EXAMPLE OF FLOW STATE TABLE

Flow f	Traffic class c	$b_w(f,e)$ [bit]	$T_l(f,e)$ [s]	$P_r(f,e)$	$P_l(f,e)$	$P_s(f,e)$	$T_T(f,e)$ [s]
6893	ARS	94440	7,951	787	3	784	76,03
6907	ARS	92760	9,923	773	7	764	77,41
6911	ARS	92280	8,317	769	11	760	75,17
6931	MRS	980	9,929	71	0	70	7,523

Example of calculations for loss ratio, delay and bandwidth for data presented in Table I are following:

$$l_r(e,c=ARS)=\frac{3+7+11}{787+773+769}=\frac{21}{2329}\cong 0.009,$$

$$E[d_T(e,c=ARS)]=\frac{76{,}03+77{,}41+75{,}17}{784+764+760}=\frac{228{,}61}{2308}\cong 0.099\ [s],$$

$$C_s(e)=\frac{94440+92760+92280+980}{0.1}=2804600[\frac{bit}{s}].$$

Time value $T_l(f,e)$ from flow-state table is used to clean-up it from old flows. When sum of times $T_l(f,e)+t_{fb}$ is lower than current time, then flow is removed from the flow-state table. Assuming that the example from Table I is checked for current time equal to 10s and t_{fb}=2s then the first row of this table with flow identifier *f*=6893 will be removed.

Outcome of measurements is a set of values $M_{e_w}(c)$, which consist of: $l_r(e_w,c)$, $E[d_T(e_w,c)]$, $C_s(e_w)$. These values are used to make a decision about admission of new flows.

C. MBAC Function

MBAC in service system e_w takes two inputs: state $S_{e_{w-1}}$ and measurements values $M_{e_w}(c)$ from the measuring unit. MBAC checks if the coming flow *f* could be serviced based on these values and requirements for traffic class *c* of flow *f*. If the admission decision is to accept flow, new flow state is saved in INIT packet. Otherwise, if flow is rejected, INIT packet is dropped, and source of flow is informed about rejection.

MBAC function is located in the node service system and makes admission decisions about flow for every INIT packet. Every INIT packet is extended by two fields: $IPLR_{precursor}$ and $IPTD_{precursor}$. These fields store cumulated loss ratio and cumulated delay introduced in all previous nodes of packet flow path. INIT packet also contains a field with bandwidth C_f of flow *f*. For INIT packet coming to service system e_w, state $S_{e_{w-1}}$ contains $IPLR_{precursor}$, $IPTD_{precursor}$.

For every INIT packet of flow *f* coming to MBAC function, this function calculates two $aggregate$ functions in service system e_w by (4) and (5).

$$TD(f,e_w,c)=TD(f,e_{w-1},c)+E[d_T(e_w,c)] \tag{4}$$

$$LR(f,e_w,c)=LR(f,e_{w-1},c)+l_r(e_w,c) \tag{5}$$

Value $TD(f,e_{w-1},c)$ is read from $IPTD_{precursor}$ field and $LR(f,e_{w-1},c)$ is read from $IPLR_{precursor}$ field.

MBAC function calculates also $C_{fs}(e_w)$ value by (6).

$$C_{fs}(e_w)=C_f+C_s(e_w) \tag{6}$$

Values $E[d_T(e_w,c)]$ and $l_r(e_w,c)$, $C_s(e_w)$ are part of $M_{e_w}(c)$. $M_{e_w}(c)$ is requested from the measuring unit.

In the next step, calculated values $TD(f,e_w,c)$ and $LR(f,e_w,c)$ are compared to QoS requirements for flow traffic class *c* requirements. For loss ratio $IPLR_{threshold}(c)$ and for delay $IPTD_{Threshold}(c)$ requirements are defined. Capacity of link attached to service system in service system *e* is C_l. Value $C_{fs}(e_w)$ is compared with link capacity C_l. If $LR(f,e_w,c)\le IPLR_{threshold}(c)$ and $TD(f,e_w,c)\le IPTD_{Threshold}(c)$ and $C_{fs}(e_w)\le C_l$ then flow is accepted and flow identifier is added to flow-state table in given node. Otherwise, flow is rejected and INIT packet is dropped. If flow is accepted, new state S_{e_w} is set based on $TD(f,e_w,c)$ and $LR(f,e_w,c)$ values: $IPLR_{precursor}:=LR(f,e_w,c)$ and $IPTD_{precursor}:=TD(f,e_w,c)$.

III. SIMULATION

Proposed solutions were verified by simulation model of FSA network implemented in Omnet++. Network structures are taken from [17]. These structures represent network's core part (core nodes and core links). Border node is connected via border link to every core node. Goal of simulation is to show that in network's core part QoS promises are achieved. To limit the impact of border links capacity on the results, border links have much bigger capacity than core links. Capacity of core links is equal to 100 Mbit/s, while capacity of border links is equal to 1 Gbit/s. Length of the network link is always equal to 200km. Paths between border nodes are calculated using OSPF algorithm with number of hops as a metric. Border nodes are a source of and a destination for all traffic in the network. Every border node generates the same number of flows to destination border node set randomly with uniform distribution. Simulation was executed for two traffic classes from FSA specification – MRS and ARS. MRS definition is similar to CDBW traffic class, while ARS definition is similar to SBW traffic class from [18]. Traffic is generated by multiple ON-OFF sources in one border node. Every border node in a given network structure generates the same amount of traffic. All packets from one ON state from one ON-OFF source have the same flow identifier. When a given flow is rejected in the network, the traffic source is informed about this event and stops generating packets of this flow. Flows are generated with parameters provided in Table II. QoS requirements for ARS and MRS classes are also defined in Table II. Packets of MRS class are serviced with highest priority by FIFO buffer with size 10 packets, packets of ARS class are serviced with lower priority by WFQ with size 1000 packets.

TABLE II
TRAFFIC SOURCE PARAMETERS AND QOS REQUIREMENTS

Parameter	MRS class	ARS class
Traffic Source Parameters		
Packet length $L(c)$ [B]	160	1500
ON and OFF time length distribution	exponential	exponential
Avg ON time $E(T_{ON}(c))$ [s]	0.352	0.332
Avg OFF time $E(T_{OFF}(c))$ [s]	0.65	0.43
Distribution between ON packets	uniform	uniform
Avg time between packets $\frac{1}{\lambda(c)}$ [s]	0.02	0.00283
QoS Requirements		
$IPLR_{Threshold}(c)$	0.001	0.001
$IPTD_{Threshold}(c)$ [ms]	100	400

Packets of a given accepted flow are dropped when there is no place for them in the right queue. ON-OFF source parameters were set based on [19], lengths of packets were set based on [20] for ARS traffic class and [21] for MRS traffic class. Moreover, QoS thresholds are set based on [22] and they are provided in Table II. Value of t_{fb} is set to 2s.

Simulation was done for 13 quotas of ARS and MRS, offered traffic provided in Table III.

TABLE III
MRS AND ARS TRAFFIC QUOTA.

Quota identifier	ARS traffic quota (q) [%]	MRS traffic quota (1-q) [%]
1	40	60
2	45	55
3	50	50
4	55	45
5	60	40
6	65	35
7	70	30
8	75	25
9	80	20
10	85	15
11	90	10
12	95	5
13	100	0

Simulation was executed for 6 network structures pulled from [17]: Norway, France, TA1, India35, NewYork, Pdh. Number of links, number of nodes and ratio of links to nodes for all of these structures are presented in table IV.

TABLE IV
NETWORK STRUCTURES PROPERTIES AND OFFERED TRAFFIC

	Norway	France	TA1	India35	NewYork	Pdh
links	27	25	24	35	16	11
nodes	51	45	55	80	49	34
links/nodes ratio	1.89	1.8	2.29	2.28	3.06	3.09
$C_0[\frac{Mbit}{s}]$	70	70	90	90	210	270

The goal of the simulation is to show that the proposed MBAC solution works properly and rejects flows when there are not enough network resources. To achieve this, traffic sources need to offer enough traffic to overload service systems and MBAC starts to reject flows. It is achieved by setting offered traffic to value which leads to rejection of at least 2% of the total offered traffic in each network structure. Rejecting 2% of total offered flows that are distributed uniformly means that on some relations the network loses much more than 2% of the flows, but on some others, all offered flows are serviced. In table IV values of offered traffic from one border node are presented in last row.

Number of ON-OFF sources in one border node for every traffic quota q is calculated by (7).

$$N_s(c) = \begin{cases} \frac{C_0}{C_{AVG}(c)} * q, \ c = ARS \\ \frac{C_0}{C_{AVG}(c)} * (1-q), \ c = MRS \end{cases} \tag{7}$$

Value $C_{AVG}(c)$ is average bandwidth of one ON-OFF source calculated based on parameters provided in Table II:

$$C_{AVG}(c = MRS) \cong 22.48[\frac{Kbit}{s}],$$

$$C_{AVG}(c = ARS) \cong 1.85[\frac{Mbit}{s}].$$

Simulation is divided into stabilization phase with length $t_{P0} = 30s$ and five measurements sections with length $\Delta t_P = 30s$. Measurement sections are numbered with $i \in \{1, 2, 3, 4, 5\}$.

Goal of the simulation process is to show that QoS promises, loss ratio, and delay thresholds are achieved, so data required to estimate these values are gathered during simulation. Only for this purpose, some additional data are stored in packets and in nodes. These data are not used in any way by the proposed distributed MBAC solution. Every packet contains additional information of its generation time in the traffic source to calculate its delay in the network. This information is used by the destination border node to calculate time spend by a packet in the network and to sum such times for all packets of given traffic class c in Δt_P window. For the same purpose border node counts packets of given traffic class c received in Δt_P window. Moreover, every core node counts packets of traffic class c dropped in Δt_P window. Data about delay, received packets, and lost packets are gathered every Δt_P. This information is added up and dumped to the result file. This file contains number $P_R(c,i)$ of received packets in measurement section i, number $P_L(c,i)$ of dropped packets in measurement section i and sum $D_T(c,i)$ of delay of all received packets in measurement section i. Loss ratio $L(c,i)$ and average delay $D(c,i)$ of packets are calculated by (8) and (9).

$$L(c,i) = \frac{P_L(c,i)}{P_R(c,i)+P_L(c,i)} \tag{8}$$

$$D(c,i) = \frac{D_T(c,i)}{P_R(c,i)} \tag{9}$$

The last part of the results processing is using average mean to calculate expected values of loss ratio $L(c) = E[L(c,i)]$ and delay $D(c) = E[D(c,i)]$. Furthermore, confidence intervals for these averages are calculated based on t-student distribution with confidence level $1 - \alpha = 0.95$.

IV. RESULTS AND DISCUSSION

Results are shown on four charts, presented in figures 3-6. Each figure contains values for all six investigated structures. Wherein, respectively:

- in fig. 3 loss ratio for class MRS $L(c = MRS)$,
- in fig. 4 loss ratio for class ARS $L(c = ARS)$,
- in fig. 5 delay for class MRS $D(c = MRS)$,
- in fig. 6 delay for class ARS $D(c = ARS)$.

Each of these analyzed values, linked with the y-axe, has been compiled on the charts with the quota identifier from table III, linked with the x-axe. For the sake of simplicity, the legend has only been added to the fig. 3 and is appropriate also for other figures. Moreover, confidence intervals are presented on every chart. The purpose of the simulation was to show that expected values $L(c)$ and $D(c)$ are below QoS requirements and that the proposed solution works properly for all structures and offered traffic.

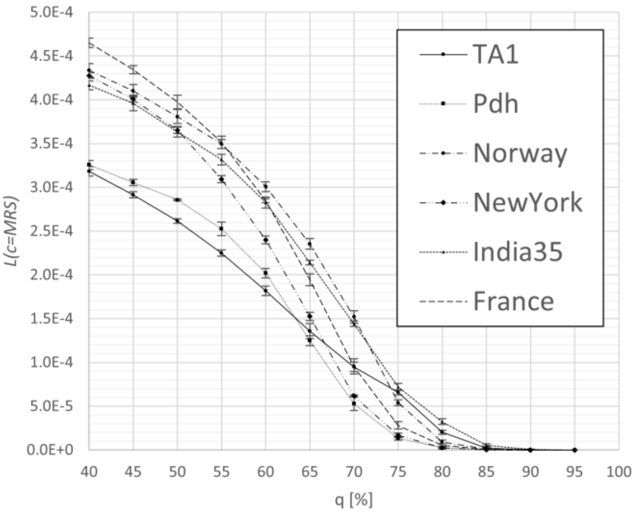

Fig. 3. Average loss ratio for MRS traffic class

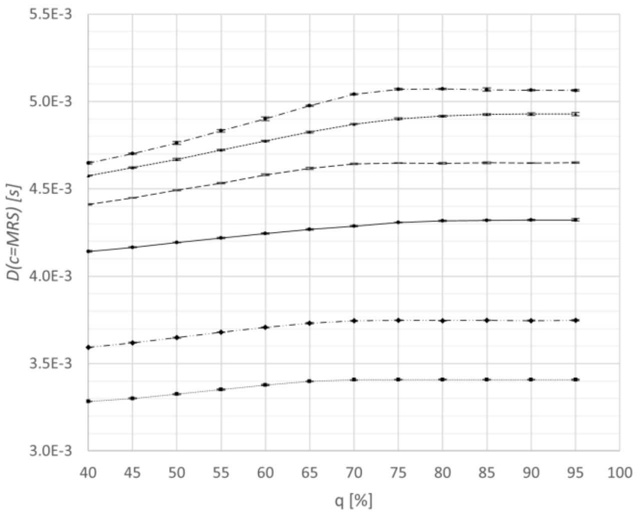

Fig. 4. Average delay for MRS traffic class

Proposed solution of distributed MBAC lets network accomplish QoS promises. Therefore, delay and loss ratio are below thresholds for all investigated network structures. When comparing results from figures 3 – 6 with QoS requirements from table II it can be observed that $L(\mathrm{c})$ and $D(\mathrm{c})$ are a few times lower than QoS requirements. To verify AC function condition about rejecting offered traffic is set to 2% of all flows offered uniformly to border nodes are rejected. This means that there are some more loaded relations, where values of delay and loss ratio are close to QoS requirements. In the meantime, there are also less loaded relations, where values of delay and loss ratio are much lower than QoS requirements. Values presented in figures 3 - 6 include all relations, so they are much below targets of QoS requirements. It is possible to be closer to QoS requirements. From a simulation point of view, applying a non-uniform distribution of traffic would lead to more links loaded. On the other hand, from a practical point of view, multipath routing would lead to a more uniform traffic distribution over links to load more of them [23-25].

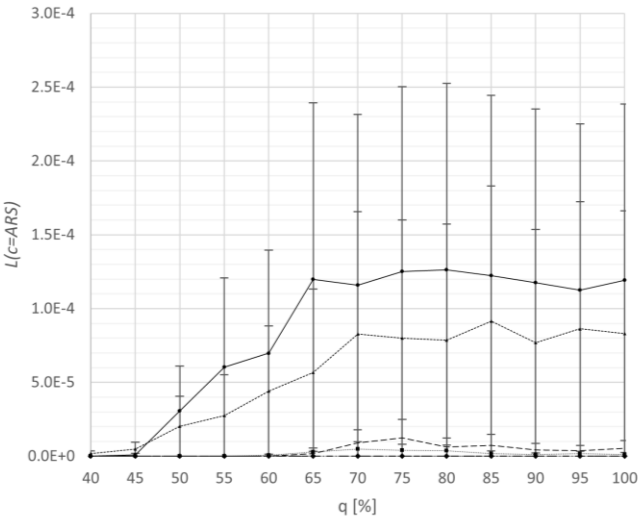

Fig. 5. Average loss ratio for ARS traffic class

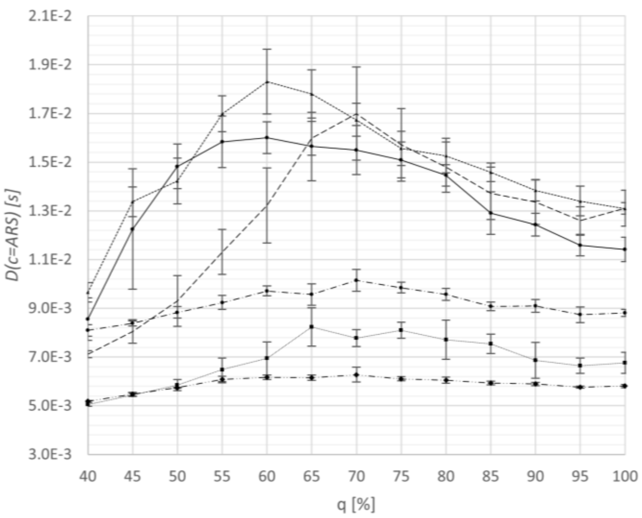

Fig. 6. Average delay for ARS traffic class

Analysis of results lets to see that there is some traffic quota q_p which changes how a given QoS parameter varies in function of q parameter. This means that for $q < q_p$ given QoS parameter changes differently in q function then for $q \geq q_p$. Value of q_p depends on the network structure, traffic class and QoS parameter. For Norway and NewYork structures there is no q_p value for $L(c = ARS)$ because there is no packet lost for these structures for all q values. Value of q_p is presented in table V.

TABLE V
VALUE OF q_p

	Norway	France	TA1	India35	NewYork	Pdh
$L(c = MRS)$	80%	80%	80%	85%	75%	75%
$D(c = MRS)$	75%	75%	70%	75%	70%	70%
$L(c = ARS)$	n/a	75%	65%	75%	n/a	70%
$D(c = ARS)$	70%	70%	60%	60%	60%	65%

Value of q_p is always higher for loss ratio $L(c)$ for a given traffic class and network structure then q_p value for $D(c)$. Value of q_p for MRS traffic class is lower for structures with higher ratio of number of links to number of nodes.

Value of q_p is lower for QoS parameters of MRS class for networks with higher links to nodes ratio. This means that for structures with more nodes between source and destination node, value of q_p is bigger. It is known that more aggregation and de-aggregation nodes on a given path affects QoS of serviced packets [26]. This means that for structures with higher link to nodes ratio it is easier to service more MRS traffic than in networks with lower ratio.

In the next paragraphs two QoS parameters for both MRS and ARS classes are described – firstly loss ratio $L(c)$ and then $D(c)$. At the end there is a discussion about confidence intervals for ARS class.

Value of loss ratio for MRS traffic class $L(c = MRS)$ for $q < q_p$ decreases with decreasing traffic of this class offered to the network. This is expected behavior. It is caused by the fact that the increase in offered traffic of MRS class leads to an increase in the average number of packets in priority queue in the service system. With increasing queue length there is a higher probability of packet drop. Moreover, loss ratio for MRS traffic class $L(c = MRS)$ for $q \geq q_p$ is on the same level, close to 0. Reason of existence of q_p value for $L(c = MRS)$ is that for $q \geq q_p$ offered traffic of MRS traffic is small enough to not overfill buffers for MRS class.

Loss ratio $L(c = ARS)$ for ARS traffic class is equal **to** zero for Norway and NewYork structures. For all other structures for $q < q_p$, focusing only on average values, ignoring confidence intervals, loss ratio increases with increasing ARS traffic class offered to the network. This could be explained similarly like changes of loss ratio for MRS class. The increase in offered traffic of ARS class leads to an increase in the average number of packets in WFQ in the service system. With an increasing number of packets in WFQ, there is a higher probability of packet drop. Simultaneously, for $q \geq q_p$ loss ratio $L(c = ARS)$ is on the same level. This is because AC functions limits to service more traffic of ARS class on over-loaded relations because of achieving threshold of $L(c = ARS)$ on these relations for $q \geq q_p$, so $L(c = ARS)$ is not increasing.

Delay of MRS traffic class $D(c = MRS)$ for $q < q_p$ increases with decreasing traffic of this traffic class offered to the network. Increase of delay $D(c = MRS)$ with decreasing of offered MRS traffic could be easily explained. With decreasing of MRS offered traffic, ARS offered traffic is increasing. With increasing ARS traffic, there is a higher probability that when MRS packet comes to the service system, ARS packet will be during servicing. When this happens, the MRS packet that is coming to the service system needs to wait to the end of ARS packet transmission before being handled. This is a property of the PQ system with non-preemptive priority. Simultaneously, for $q \geq q_p$ delay for MRS traffic class is on the same level. As it is described in the previous paragraph, AC function limits ARS traffic on over-loaded links because of achieving threshold for $L(c = ARS)$ for $q \geq q_p$. It should be assumed that achieving this limit for $L(c = ARS)$ impacts also increasing of $D(c = MRS)$ because the increase of this parameter is related to the growth of ARS serviced traffic.

For all investigated structures and for $q < q_p$ delay $D(c = ARS)$ for ARS traffic class increases with increasing traffic of this class offered to the network. Again, it is an expected observation. With increasing ARS traffic, there are more ARS packets queued in the service system, so these packets wait longer in a given service system before being serviced. For $q \geq q_p$ delay $D(c = ARS)$ decreases when ARS traffic increases. Reason of this could be that with ARS traffic increases, there is less MRS traffic with higher priority in the network. Because of that, this MRS traffic, which is serviced before ARS traffic, affects less ARS traffic which is serviced with lower priority. Existence of q_p value for $D(c = ARS)$ is the result of existence of q_p for $L(c = ARS)$. Until $q < q_p$ value $D(c = ARS)$ is increasing with increasing ARS offered flows. Simultaneously for $q \geq q_p$ the increase of ARS flows is limited by AC function on over-loaded relations because of losing too many packets. At the same time, the number of offered and serviced MRS flows is decreasing, so it is expected that waiting time for an empty MRS queue is decreasing with decrease of MRS traffic.

Above observations are summarized in table VI.

TABLE VI
RELATIONS BETWEEN QOS PARAMETERS AND QUOTA.

	$q < q_p$	$q \geq q_p$
$L(c = MRS)$	Decrease with MRS decreasing	Flat
$D(c = MRS)$	Increase with MRS decreasing	Flat
$L(c = ARS)$	Increase with ARS increasing; confidence intervals overlap	Flat
$D(c = ARS)$	Increase with ARS increasing	Decrease with ARS increasing

We can also note that confidence intervals are bigger for ARS class than for MRS class. Relatively high values of confidence intervals are not relevant to the purpose of this paper – upper interval boundaries are always below QoS requirements values. There is a simple explanation why these confidence intervals are bigger for ARS class. Packets of ARS class are serviced with lower priority than MRS packets, so servicing of MRS packets affects QoS parameters of ARS class. ARS packets always need to wait for the end of service of all queued MRS packets. It increases the delay and loss ratio of ARS packets. Simultaneously, some ARS packets come to the service system when the MRS queue is empty. These packets are serviced immediately by the service system. The ARS QoS packets are serviced immediately and there are some ARS packets which need to wait for an empty MRS buffer. To sum up, the distribution of ARS class QoS parameters is wider than for MRS class QoS parameters.

CONCLUSION

In this paper a distributed MBAC solution is discussed. The solution was implemented in an FSA network simulator and was tested on six network structures. The simulation's results demonstrate that the solution lets the network accomplish QoS promises. The paper contains a discussion about results and impact of the traffic offered on the delay and loss ratio result. Delay and loss ratio are below thresholds for all investigated network structures. These requirements are fulfilled with a big margin – this is an opportunity for potential improvements. The *q* parameter influences the changes of the curves describing the quality of services in various ways, but it can be relatively easily interpreted.

The obtained results also indicate the further direction of the research. Next work should focus on extracting traffic from the most loaded links and relations to get closer to the QoS parameters requirements. Moreover, the results show that there are relations and links which are not loaded enough. This is a space to improve and apply better traffic balancing in the network, for example by applying multipath routing with smart choice.

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