THE EFFICIENCY OF CONSTRAINT BASED ROUTING IN MPLS NETWORKS

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Abstract. *The paper presents the simulation results and evaluates the efficiency of constraint base routing algorithms used in MPLS network from the point of their usability in Next Generation Networks. The efficiency of constraint based routing is evaluated according following criteria: optimal path selection, routing priority of traffic flows selected for constraint routing and bandwidth allocation by MAM or RDM bandwidth constraints models.*

Keywords

Constraint routing, maximum allocation model, Russian Doll Model, MPLS, QoS.

1. Introduction

The MPLS (Multiprotocol Label Switching) [1] is a connection oriented packet network technology originally proposed to simplify and speed up a packet processing in broadband network nodes. Today the MPLS is considered as a core transport technology for NGN (Next Generation Network), therefore it should support real-time QoS sensitive services like voice, video, etc. Real time services have a strict QoS requirement on delay, jitter, packet loss etc [2]. There were no implicit QoS mechanisms proposed in MPLS, the quality of service can be achieved by a combination of several individual mechanisms. The proposed paper investigates the traffic routing methods as a one of the Quality of Service supporting mechanism.

There are three types of traffic routing used in MPLS:

- Hop-by-hop routing,
- Explicit routing,
- Constraint routing.

The hop-by-hop routing use a plain IP routing algorithms and does not provide adequate QoS quality due to impossibility to distinguish routing of packets through the network according to QoS constraints. The Label Switched Path (LSP) is established according the route selected by routing algorithms, usually a shortest path is selected, and in the fault state (congestion, connection breakdown, etc.) the guaranteed bandwidth is not available even for packets with highest priority.

Explicit routing uses LSPs explicitly selected by a network administrator. The routing can be considering QoS parameters and a real state of the network. The traffic can be classified into different QoS classis and for each Forwarding Equivalency Class (FEC) a different route can be selected. The explicit routing is not suitable for large networks.

Constraint routing is a more sophisticated type of explicit routing. Constraint-based routing use a new generation of routing algorithms (e.g. OSPF-TE) taking in account more link parameters than traditional routing algorithms. Unfortunately the existing constraint routing algorithms route only single flows and does not consider the other flows routing. The constraint routing can be affected by bandwidth allocations as well.

2. Bandwidth Constraints Models

There are three bandwidth constraints models proposed up today:

- Maximum Allocation Model (MAM) [3] - the maximum allowable bandwidth usage of each class type (CT) is explicitly specified,
- Russian Doll Model (RDM) [4] - the maximum allowable bandwidth usage is done cumulatively by grouping successive CTs according to priority

classes,

- Maximum Allocation with Reservation Model (MAR) [5] - it is similar to MAM in that a maximum bandwidth allocation is given to each CT. However, through the use of bandwidth reservation and protection mechanisms, CTs are allowed to exceed their bandwidth allocations under conditions of no congestion but revert to their allocated bandwidths when overload and congestion occurs.

Although the comparison of different routing technique in MPLS has been investigated in [6] the bandwidth allocation model has not be considered.

2.1. MAM Model

Maximum Allocation Bandwidth Constraints Model is defined in the following manner:

Assume that Maximum Number of Bandwidth Constraints Θ is equal to Maximum Number of Class-Types Ψ:

$$\Theta = \Psi = 8 . \quad (1)$$

For each value of n in the range $0 \leq n \leq (\Psi - 1)$:

$$B_{RCT_n} \leq BC_n \leq B_{MaxR} , \quad (2)$$

and

$$\sum_{n=0}^{\Psi-1} B_{RCT_n} \leq B_{MaxR} , \quad (3)$$

where B_{RCTn} is the Bandwidth Reserved for Class Type n, BC_n is the Bandwidth Constraint for Class Type n a B_{MaxR} is the Maximum Reservable Bandwidth. The sum of Bandwidth Constraints theoretically may exceed the B_{MaxR}, so that the following relationship may hold true:

$$\sum_{n=0}^{\Psi-1} BC_n > B_{MaxR} , \quad (4)$$

but usually the sum of Bandwidth Constraints will be equal to (or below) the Maximum Reservable Bandwidth

$$\sum_{n=0}^{\Psi-1} BC_n \leq B_{MaxR} , \quad (5)$$

2.2. RDM Model

RDM model is defined in a similar manner. We expect condition (1).

Then for each value of b in the range $0 \leq b \leq (\Psi - 1)$:

$$\sum_{n=b}^{\Psi-1} B_{RCT_n} \leq BC_b . \quad (6)$$

Let:

$$BC_0 = B_{MaxR} , \quad (7)$$

then

$$\sum_{n=0}^{\Psi-1} B_{RCT_n} \leq B_{MaxR} . \quad (8)$$

3. Simulation Experiments

To investigate a performance of constraint based routing in MPLS from the point of QoS provisioning for QoS sensitive telecommunication services and efficiency of bandwidth utilization the special simulation model was proposed. All simulations have been done using ns-2.

3.1. Simulation Model

All simulations use the same network architecture. A simulation network topology is shown in Fig. 1. All traffic flows are generated by Source node (node 0) and they are routed to four destination nodes (nodes 8 – 11). The MPLS network is composed of an Ingress Label Edge Router (I-LER), an Egress Label Edge Routers (E-LER) and five Label Switching Routers (LSRs). The MPLS routers are interconnected with 2 Mbps or 10 Mbps links. The external link between Source node (node 0) and I-LER (node 1) is 100 Mbps, the links between E-LER (node 7) and destination nodes (nodes 8 – 11) are 10 Mbps. Ingress and egress Label Edge Routers (node 1 and node 7) are interconnected by two different network segments. The shorter upper segment contains only two Label Switch Routers (LSR2 and LSR3) and it is preferred by classical hop-by-hop routing algorithms. Theoretically, in non congested situation, the packets routed through the upper segment have a smaller delay; therefore the upper segment should be preferred by real time services (e.g. voice). The upper segment throughput is 2 Mbps.

The longer bottom segment contains three LSRs (LSR4, LSR5 and LSR6) and one additional line leading to higher delay and therefore it is less suitable for real time services. The bottom segment throughput is 2 Mbps.

The LSRs in both segments are interconnected by intermediate 10 Mbps links that can be used to create an alternative path. This path has a throughput up to 10 Mbps.

As queue management algorithms a CBQ is applied on MPLS nodes and a drop-tail on external nodes.

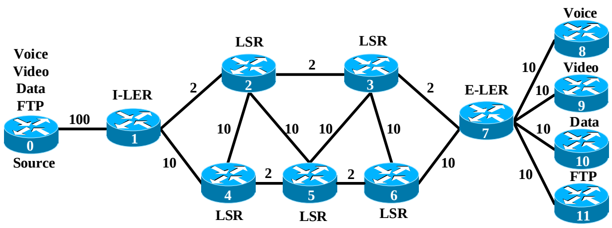


Fig. 1: Network topology (bit rates are in Mbps).

Tab.1: Traffic flows parameters.

Traffic	Bit Rate (kbps)	Packet Size (Bytes)	Traffic Type	Transport Protocol
Voice	952	238	CBR	RTP
Video	1200	250	CBR	RTP
Data	1800	1000	EXP	UDP
FTP	Unlimited	1500	TCP	FTP

There are four traffic flows generated in each simulation representing voice, video, raw data and FTP traffic. The traffic parameters are shown in Tab. 1.

3.2. Hop-by-Hop Routing

The hop-by-hop routing does not provide adequate QoS guaranty. All traffic flows are routed by hop-by-hop routing (shortest path selected). Even there is an available bandwidth on the network, it is not used. All traffic flows compete to 2 Mbps link LER1-LSR2. The link is congested and many packets from all flows are discarded (see Tab. 2).

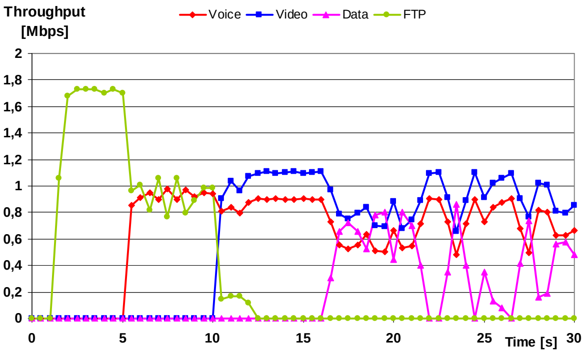
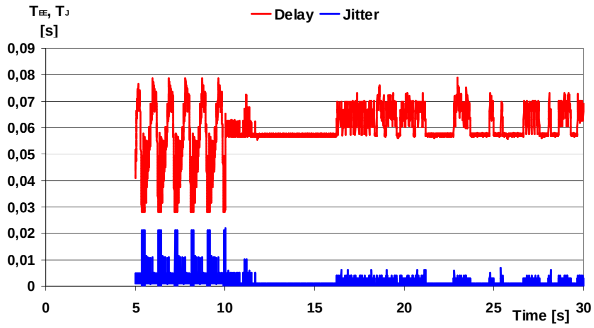
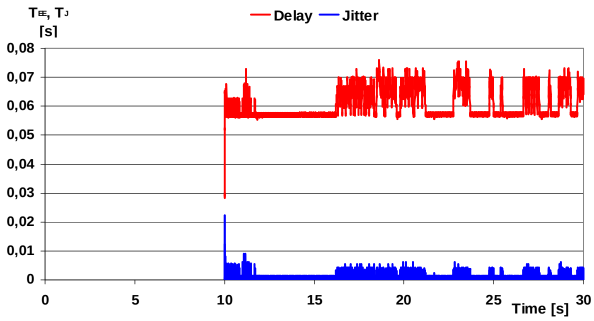


Fig. 2: Throughput of voice, video, data and FTP flows (hop-by-hop routing, WS=10).

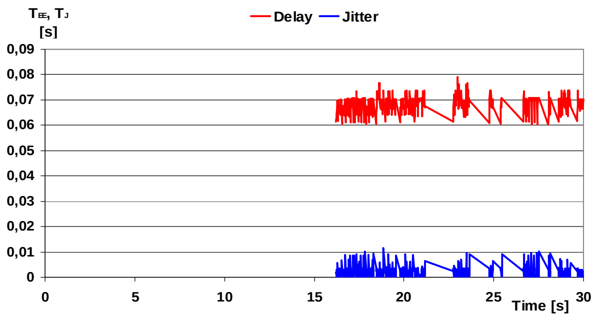
Figure 2 shows the throughput of voice, video, FTP and data flows. The FTP flow starts in time 1 second and up to 5 seconds uses the whole bandwidth. The voice flow starts in time 5 seconds and competes with FTP flow for bandwidth. Because the voice flow uses an UDP and the FTP flow uses a TCP the FTP flow slow down to the rest available bandwidth. The video flow starts in time 10 seconds. Because the voice and video flows require more bandwidth then the link capacity there is no available bandwidth for the FTP flow and the FTP flow slowdown to zero. As the last one starts the data flow in time 15 seconds. As can be seen all flows are affected by congestion and no flow got the required bandwidth. Figure 3 shows delays and jitters of voice, video, data and FTP flows. Because the traffic is not classified by QoS classes all flows have approximately the same delay and jitter (see Tab. 3).



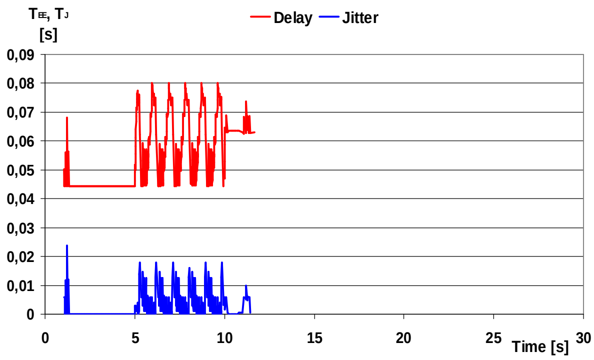
a) Voice



b) Video



c) Data



d) FTP

Fig. 3: Delay and jitter of voice, video, data and FTP flows (hop-by-hop routing, WS=10).

Tab.2: Packet loss (Hop-by-Hop Routing).

Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	2260	18,1 %
Video	12001	2590	21,6 %
Data	1713	951	55,5 %
FTP	984	7*	0,7 %*

Tab.3: Delay and jitter (Hop-by-Hop Routing).

Traffic Flow	Delay [ms]		Jitter [ms]	
	Mean	Max	Mean	Max
Voice	58,3	79,1	0,86	21,95
Video	59,74	76,60	0,76	22,28
Data	68,64	79,00	1,97	11,38
FTP	55,81	80,01	1,30	23,88

3.3. Explicit Routing

The explicit routing allows optimal flow distribution. In proposed example the voice flow is optimally routed via upper segment (shortest delay guaranteed), the video flow via bottom segment (with the second shortest delay) and data and FTP flows are routed via middle segment (the longest delay) marked as: I-LER_LSR4_LSR2_LSR5_LSR3_LSR6_E-LER (noted as 1_4_2_5_3_6_7 or 1425367). This path selection allows to reach required bandwidth, delay and jitter for all flows. Hence the same routing can be made by constraint routing (see Fig. 4) the values of throughput, delay and jitter shown in Fig. 5 and Fig. 6 and values of packet loss, delay and jitter in Tab. 4 and Tab. 5 are valid for explicit routing as well.

3.4. Constraint Routing

Constraint routing uses routing algorithms taking in account more link parameters than traditional routing algorithms. In optimal situation the constraint routing can select the same routes as optimal explicit routing.

The performance of constraint routing was investigated from the point of:

- optimal path selection,
- flow priority routing,
- bandwidth constraint allocation.

1) Optimal Path Selection

The optimal routing from the point of bandwidth allocation and delay is shown in Fig. 4. The voice, as the high sensitive service uses the shortest path (1_2_3_7), the video the longer path (1_4_5_6_7) and the data and FTP the longest path (1_4_2_5_3_6_7). This proposed path selection prevents link congestion, quarantine required bandwidth for all flows (zero packet loss) and shorter delay for time sensitive services (see Tab. 4 and Tab. 5).

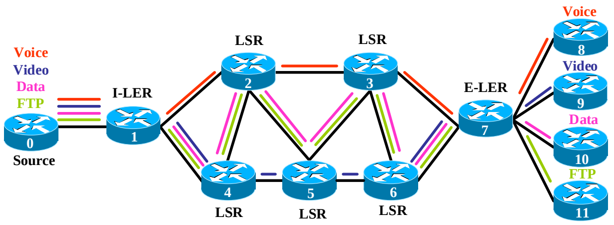


Fig. 4: Optimal traffic routing (constraint routing).

Figure 5 shows a throughput of voice, video, data and FTP flows with RDM constraints model implemented and FTP window size (WS) set to 10. In this case all flows have enough bandwidth, therefore the courses of constant bit rate voice and video flows are flat. The throughput of the data flow is vibrant, while it is generated as a variable bit rate flow with exponential packet distribution. The throughput of the FTP flow is oscillating due to TCP algorithm.

The Fig. 6 shows delay and jitter for a) voice b) video c) data and d) FTP flows. Figure 7 shows the number of transmitted FTP packets vs. FTP window size.

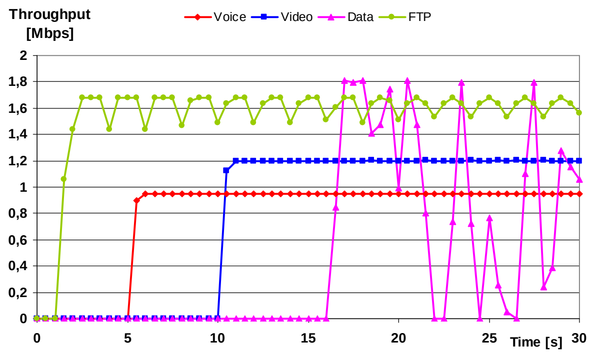


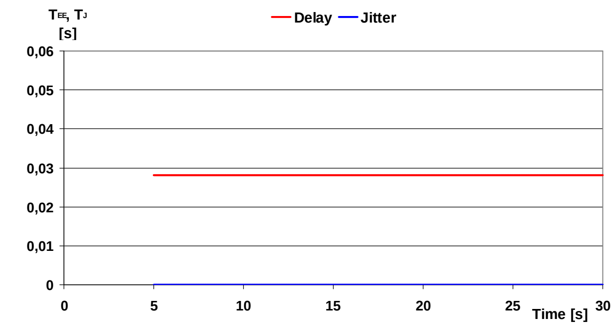
Fig. 5: Throughput of voice, video, data and FTP flows (constraint routing, RDM, WS=10).

Tab.4: Packet loss (constraint routing, RDM, WS=10).

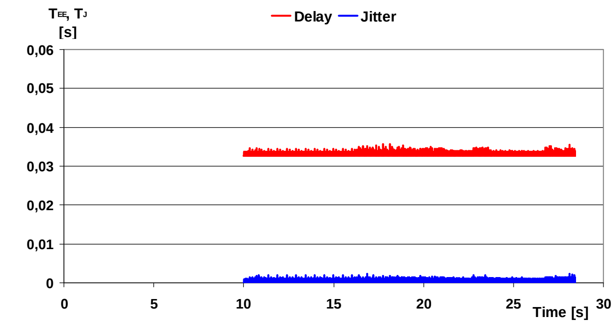
Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	0	0,0 %
Video	12001	0	0,0 %
Data	1713	0	0,0 %
FTP	3895	0*	0,0 %

Tab.5: Delay and jitter (constraint routing, RDM, WS=10).

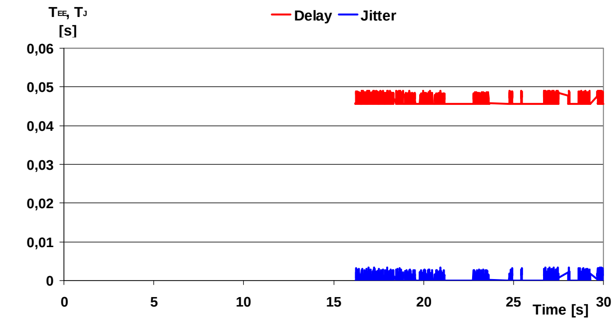
Traffic Flow	Delay [ms]		Jitter [ms]	
	Mean	Max	Mean	Max
Voice	28,06	28,07	0,00	0,006
Video	32,94	35,73	0,32	2,41
Data	46,46	50,35	0,66	3,44
FTP	48,57	53,20	0,06	4,68



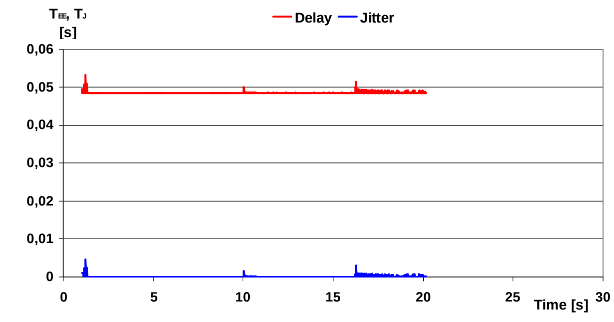
a) Voice



b) Video



c) Data



d) FTP

Fig. 6: Delay and jitter of voice, video, data and FTP flows (constraint routing, RDM, WS=10).

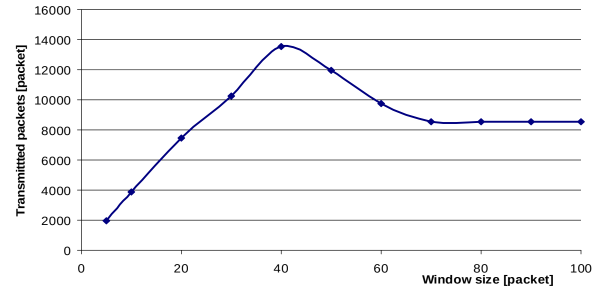


Fig. 7: Number of transmitted packets vs. windows size - FTP flow (constraint routing, RDM).

2) Flow Routing Priority

The results presented above have been achieved for optimal flow order routing i.e. Voice – Video - Data - FTP (Note: the flows start in different order). To show how the routing priority/order and constraint parameters impact the routing, the following simulations have been done.

The first simulation shows the selected path, packet loss, delay and jitter for reservation order Data – FTP – Voice - Video (Tab. 6). Although the low delay sensitive flows (data and FTP) are routed before a high delay sensitive flows (voice and video), due the setting of RDM and setting of bandwidth constraint for Data and FTP flows reasonably high (3 Mbps for FTP), the constraint routing select the same optimal routes as in previous experiment (see Fig. 8).

Figure 9 shows a throughput of voice, video, data and FTP flows with RDM constraints model implemented and FTP window size (WS) set to 40. The Fig. 10 shows delay and jitter for a) voice b) video c) data and d) FTP flows

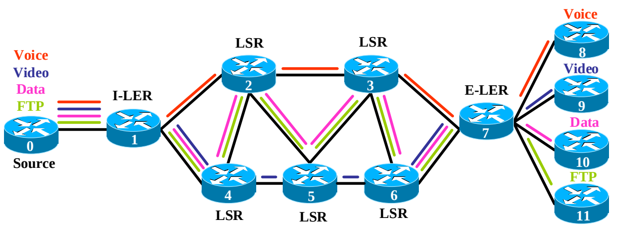


Fig. 8: Traffic routing (constraint routing, constraint bandwidth FTP = 3 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

Tab.6: Routing order Data-FTP-Voice-Video (constraint routing, constraint bandwidth for FTP = 3000 kbps, RDM, WS=40).

	Voice	**Video**	**Data**	**FTP**
Reservation order	3	4	1	2
Req. bandwidth [kbps]	952	1200	1800	Not lim.
Constraint bandw. [kbps]	1000	1200	1800	3000
Selected path [nodes]	1237	14567	1425367	1425367

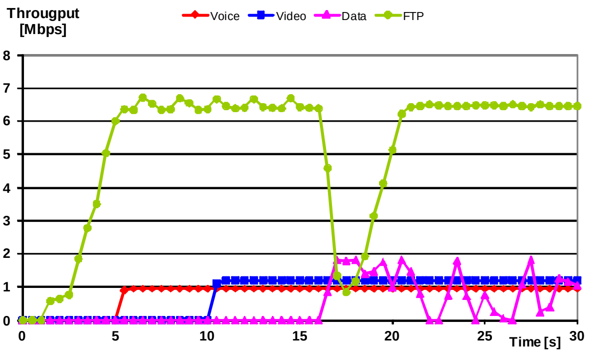


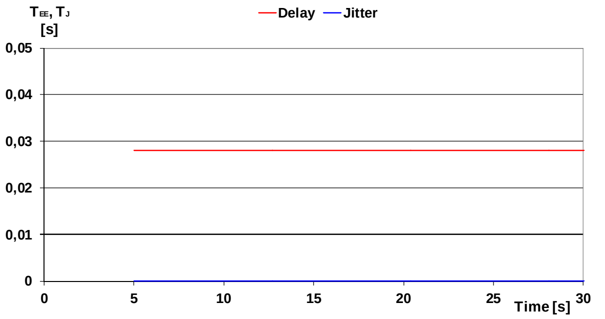
Fig. 9: Throughput of voice, video, data and FTP flows (constraint routing, constraint bandwidth FTP = 3 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

Tab.7: Packet loss (constraint routing, constraint bandwidth FTP = 3 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

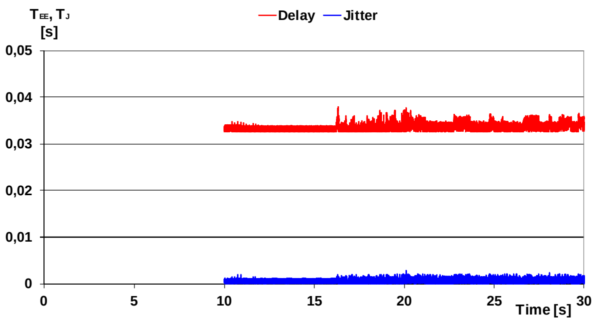
Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	0	0,0 %
Video	12001	0	0,0 %
Data	1713	0	0,0 %
FTP	13189	1*	0,0 %*

Tab.8: Delay and jitter (constraint routing, constraint bandwidth FTP = 3 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

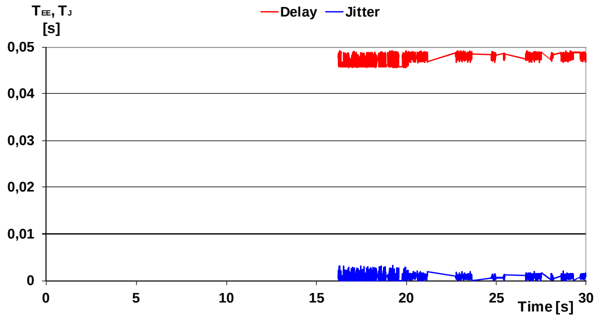
Traffic Flow	Delay [ms]		Jitter [ms]	
	Mean	Max	Mean	Max
Voice	28,06	28,07	0,000	0,006
Video	33,61	37,87	0,482	2,786
Data	47,43	49,09	0,694	3,245
FTP	48,73	55,60	0,126	6,521



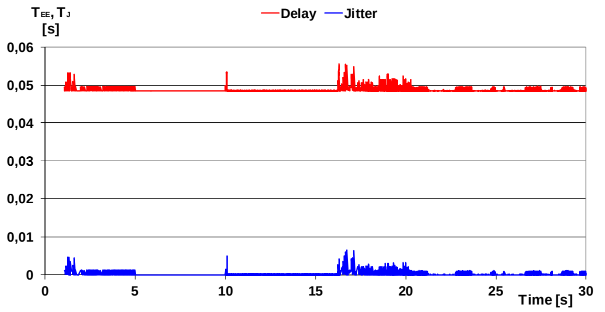
a) Voice



b) Video



c) Data



d) FTP

Fig. 10: Delay and jitter of voice, video, data and FTP flows (constraint routing, constraint bandwidth FTP = 3 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

In the next simulation the bandwidth constraint for FTP flow was decreased to 1 Mbps. This lead to situation that the FTP flow was routed through the shortest path 1_2_3_7, the delay sensitive voice flow through the longer path 1_4_5_6_7 and the video and data flows together via the longest path 1_4_2_5_3_6_7 (see Fig. 11 and Tab. 9).

Although the different route selection does not lead to packet dropping (see Tab. 10) it significantly decrease the throughput of TCP flow (from 13189 packets to 3671 packets – see Fig. 9 and Fig. 12 or/and Tab. 7 and Tab. 10) and increase the delay of voice and video flows. The throughputs of voice, video, data and FTP flows are shown in Fig. 12. The delays and jitters of a) voice b) video c) data and d) FTP flows are shown in Fig. 13.

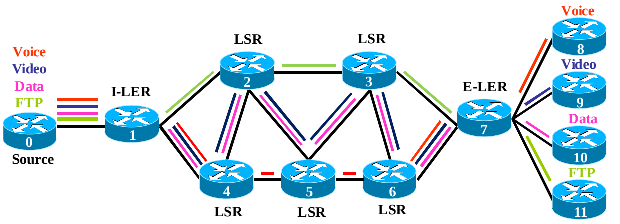


Fig. 11: Traffic routing (constraint routing, constraint bandwidth FTP = 1 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

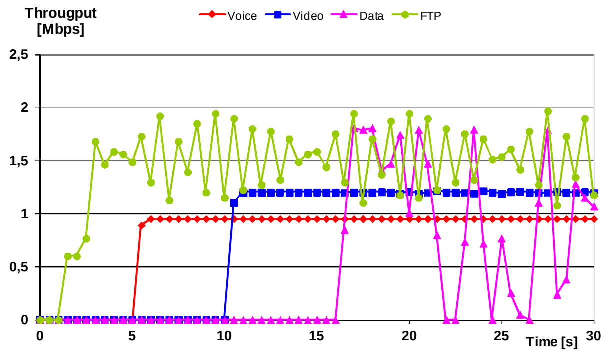


Fig. 12: Throughput of voice, video, data and FTP flows (constraint routing, constraint bandwidth FTP = 1 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

Tab.9: Routing order Data-FTP-Voice-Video (constraint routing, constraint bandwidth FTP = 1 Mbps, RDM, WS=40).

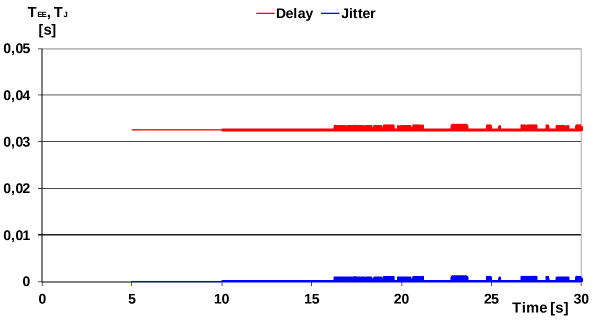
Parameter	Voice	Video	Data	FTP
Rezervation order	3	4	1	2
Req. bandwidth [kbps]	952	1200	1800	Not lim.
Constraint bandw. [kbps]	1000	1200	1800	1000
Selected path [nodes]	14567	1425367	1425367	1237

Tab.10: Packet loss (constraint routing, constraint bandwidth FTP = 1 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

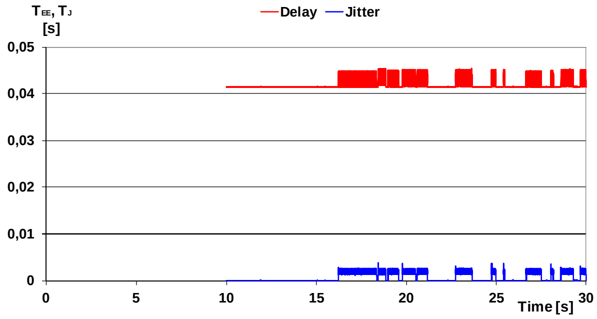
Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	0	0,0 %
Video	12001	0	0,0 %
Data	1713	0	0,0 %
FTP	3671	0*	0,0 %*

Tab.11: Delay and jitter (constraint routing, constraint bandwidth FTP = 1 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

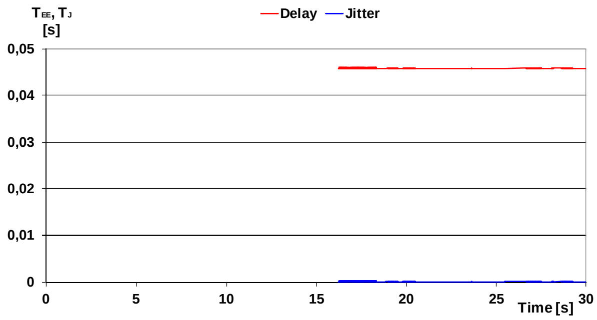
Traffic Flow	Delay [ms]		Jitter [ms]	
	Mean	Max	Mean	Max
Voice	32,59	33,61	0,185	1,122
Video	42,13	45,37	0,667	3,780
Data	45,70	45,97	0,042	0,291
FTP	54,19	68,32	1,298	24,000



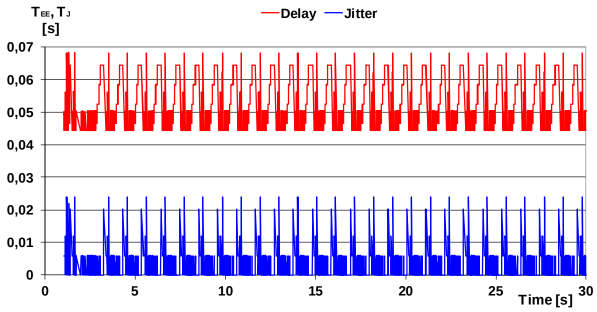
a) Voice



b) Video



c) Data



d) FTP

Fig. 13: Delay and jitter of voice, video, data and FTP flows (constraint routing, constraint bandwidth, FTP = 1 Mbps, Data-FTP-Voice-Video, RDM, WS=40).

In the last simulation the order and constraints were changed. The flows were routed in order FTP-Data-Voice-Video Due to the bandwidth constraints for FTP and Data flows were set only to 1,5 Mbps (see Tab. 12). The FTP flow was routed via the upper shortest path 1_2_3_7, data flow via the second shortest bottom path and delay sensitive voice and video via the longest path 1_4_2_5_3_6_7 (see Fig. 14). The throughputs of voice, video, data and FTP flows are shown in Fig. 15. The delays and jitters of a) voice b) video c) data and d) FTP flows are shown in Fig. 16 and Tab. 14.

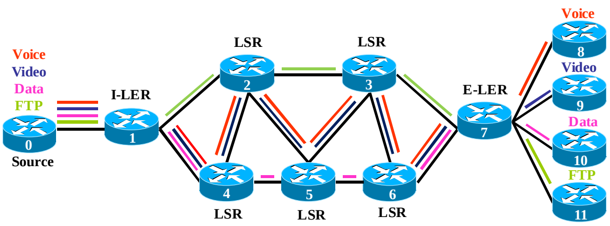


Fig. 14: Traffic routing (constraint routing, constraint bandwidth FTP = 1,5 Mbps, FTP-Data-Voice-Video, RDM, WS=40).

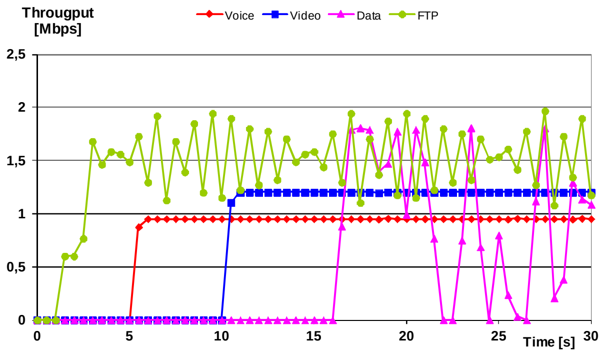


Fig. 15: Throughput of voice, video, data and FTP flows (constraint routing, constraint bandwidth, FTP = 1,5 Mbps, FTP-Data-Voice-Video, RDM, WS=40).

Tab.12: Routing order FTP-Data-Voice-Video (constraint routing, constraint bandwidth Data=1,5 Mbps, FTP = 1,5 Mbps, RDM, WS=40).

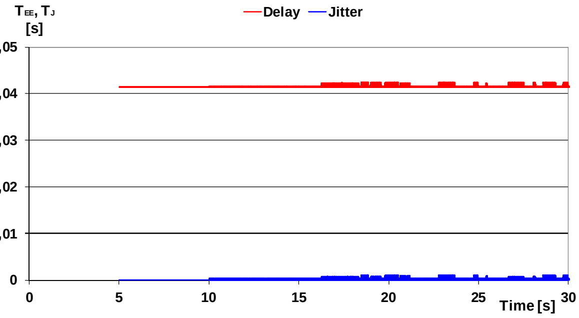
Parameter	Voice	Video	Data	FTP
Rezervation order	3	4	2	1
Req. bandwidth [kbps]	952	1200	1800	Not lim.
Constraint bandw. [kbps]	1000	1200	1500	1500
Selected path [nodes]	1425367	1425367	14567	1237

Tab.13: Packet loss (constraint routing, constraint bandwidth FTP = 1,5 Mbps, FTP-Data-Voice-Video, RDM, WS=40).

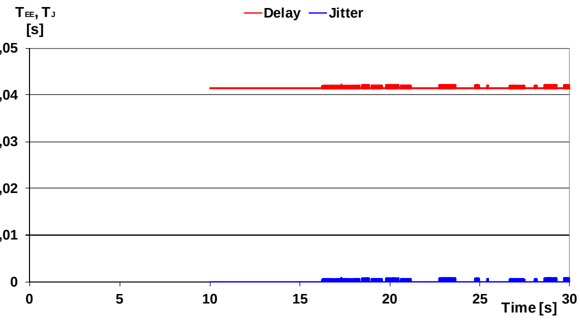
Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	0	0,0 %
Video	12001	0	0,0 %
Data	1713	0	0,0 %
FTP	3671	1*	0,0 %*

Tab.14: Delay and jitter (constraint routing, constraint bandwidth FTP = 1,5 Mbps, FTP-Data-Voice-Video, RDM, WS=40).

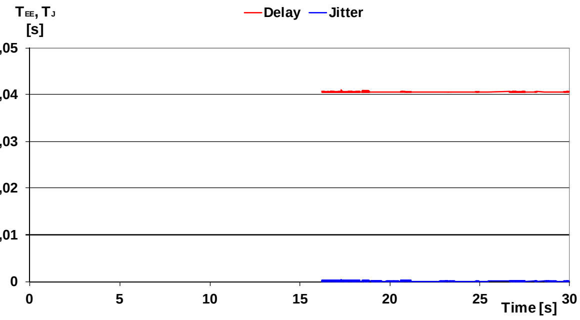
Traffic Flow	Delay [ms]		Jitter [ms]	
	Mean	Max	Mean	Max
Voice	41,44	42,38	0,105	1,029
Video	41,48	42,25	0,109	0,837
Data	40,52	40,92	0,071	0,442
FTP	54,17	68,32	1,298	24,000



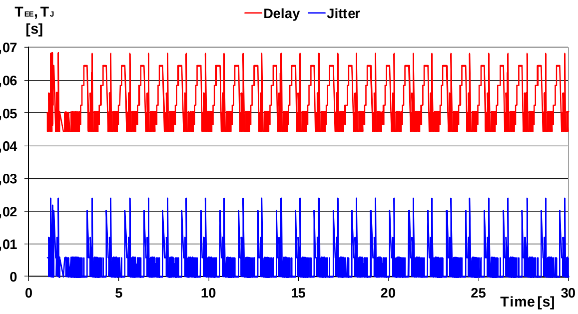
a) Voice



b) Video



c) Data



d) FTP

Fig. 16: Delay and jitter of voice, video, data and FTP flows (constraint routing, constraint bandwidth FTP = 1,5 Mbps, FTP-Data-Voice-Video, RDM, WS=40).

As can be seen from Fig. 16 and Tab. 14 the routing of voice traffic over the longest path lead to highest end-to-end delay and jitter. Even in this experiment delay and jitter for voice (and video) traffic are acceptable, the non optimal routing can in some situations lead to non acceptable high values of delay or jitter.

3) Bandwidth Constraints Models

The all previous simulations used a RDM bandwidth constraint model. RDM allows reuse of non allocated bandwidth from higher priority class types by traffic flow with lower priority class type. The disadvantage of RDM is a necessity to maintain preemption in all network nodes. MAM explicitly specify maximum allowable bandwidth usage of each class type and the bandwidth can not be shared among the different class types. This should be considered during network design process.

Table 15 shows the MPLS path allocation proposed by constraint routing algorithm for different bandwidth allocations for specified class type (CT). As can be seen, if not enough bandwidth is allocated to the CT on the link, the constraint routing algorithm chose the less preferable link. If the process fails on all links, the traffic flow is routed by hop-by-hop routing. This can lead to congestion on most preferable link usually used by the most time critical services.

Tab.15: Path selection (CR, MAM, WS=40).

CT Bandw. Allocation [%]	Voice	Video	Data	FTP
85	1237	14567	1425367	1425367
75	1237	14567	1425367	1425367
65	1237	14567	1425367	1425367
55	1237	1425367	1425367	Hop-by-hop
45	1425367	1425367	1425367	Hop-by-hop
35	1425367	1425367	Hop-by-hop	Hop-by-hop
25	1425367	1425367	Hop-by-hop	Hop-by-hop
15	1425367	Hop-by-hop	Hop-by-hop	Hop-by-hop

Figure 17 to Fig. 19 show the throughput of voice, video, data and FTP flows when the 85 %, 55 % or 35 % of the bandwidth is allocated to the CT used by traffic flows. As can be seen in Fig. 18, when the bandwidth constraint is set to 55 %, the FTP flow shares the 2 Mbps link with the voice flow (see Tab. 15) that degrades the QoS parameters of both of them. The number of loss packet is depicted in Tab. 16 to Tab. 18.

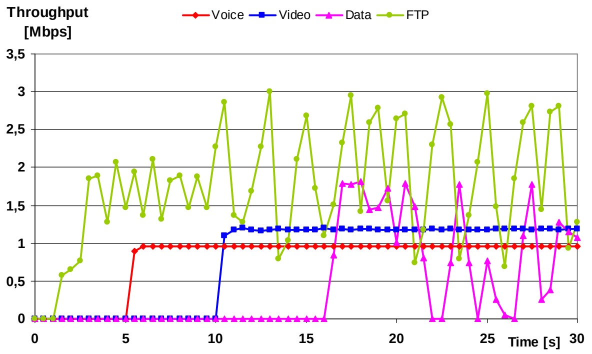


Fig. 17: Throughput of voice, video, data and FTP flows (constraint routing, MAM 85 %, WS=40).

Tab.16: Packet loss (CR, MAM 85 %, WS=40).

Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	0	0,0 %
Video	12001	191	1,6 %
Data	1713	0	0,0 %
FTP	4496	5*	0,1 %

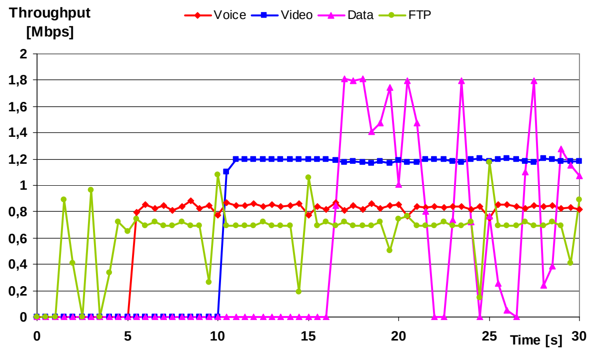


Fig. 18: Throughput of voice, video, data and FTP flows (constraint routing, MAM 55 %, WS=40).

Tab.17: Packet loss (CR, MAM 55 %, WS=40).

Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	1531	12,2 %
Video	12001	91	0,7 %
Data	1713	0	0,0 %
FTP	1675	3*	0,2 %

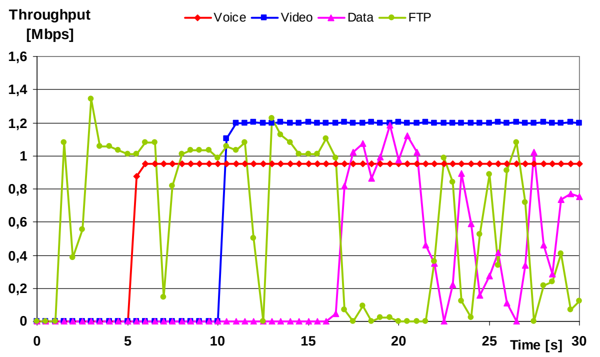


Fig. 19: Throughput of voice, video, data and FTP flows (constraint routing, MAM 35 %, WS=40).

Tab.18: Packet loss (CR, MAM 35 %, WS=40).

Traffic Flow	Packets		
	Sent	Dropped / Retransmissions*	
Voice	12501	0	0,0 %
Video	12001	0	0,0 %
Data	1682	618	36,7 %
FTP	1667	10*	0,6 %

4. Conclusion

The proposed experiments accomplished that constraints routing can be used as traffic engineering and QoS provisioning tool allowing providing QoS parameters for QoS sensitive services.

Even its good performance, it has been shown that in some situations such as non optimal order of the routed flows selected or inadequate bandwidth allocation with MAM bandwidth constraints model implemented the routing can fail or non optimal routes leading to QoS parameter degradation can be proposed.

Constraint-based routing should be implemented in conjunction with other QoS provisioning methods such as traffic flow differentiation according QoS requirements, different processing in network nodes (different Per-Hop Behaviors) or bandwidth reservation for different service classes.

Acknowledgements

This paper has been supported by the projects VEGA No. 1/0565/09 and ITMS 26240120029.

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