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Evaluation of Bandwidth Constraint models for MPLS networks

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Abstract – **The paper examines the two basic Bandwidth Constraint models for MPLS networks, called Maximum Allocation Model and Russian Dolls Model, from the point of view of Quality of Service guarantees and introduces the results of performance evaluation of these models in a simulation scenario. We evaluated the influence of the Bandwidth Constraint models on the most important transmission parameters such as throughput, packet loss, one-way delay and jitter.**

Keywords – **MPLS, Maximum Allocation Model**

I. INTRODUCTION

IP packet forwarding mechanisms are based on a hop-by-hop paradigm. When an IP packet arrives to a router, it examines the destination address, makes a route lookup, and forwards the packet to the corresponding next hop.

In an Multiprotocol Label Switching (MPLS) network the nodes also forward packets hop-by-hop, but this forwarding is based on the identifier with short, fixed length called label. The labels are assigned to the packets at the ingress node of an MPLS domain. Inside the MPLS domain, the labels attached to packets are used to control the forwarding decision. Thus, MPLS uses a kind of indexing instead of a long address matching as in conventional IP routing. The labels are finally removed from the packets when they leave the MPLS domain at the egress node. A router which supports MPLS is usually called Label Switching Router (LSR). An important difference between the MPLS and IP forwarding is that IP forwarding involves packet classification in every hop, whereas in MPLS forwarding, the classification is done only by the ingress LSR.

II. QUALITY OF SERVICE SUPPORT IN MPLS

A. MPLS Labels

RFC 3031 [1] defines a label as “a short fixed length physically contiguous identifier which is used to identify a Forwarding Equivalence Class (FEC), usually of local significance.” The label allows the decoupling of routing from forwarding paradigm as used in classical IP networks. The label is a value assigned to a packet tells the network where the packet should be sent.

The label is present in a header called the Shim Header. The Shim header is 32 bits in length. It resides between the layer 2 header and the layer 3 header. The shim header also contains the Exp field, S-bit field and Time to Live (TTL) field.

The 3-bit Exp field has been initially reserved for experimental use, but nowadays in most MPLS applications it is used to hold a QoS indicator. Often the copy of the IP precedence bits of an underlying IP packet is stored here.

The S-bit is the indicator of the bottom of the stack. It's common to have more than one label in a label-stack, therefore the bottommost label in a stack has the S-bit set to 1.

The TTL field is often a direct copy of the IP TTL bits. The value is decremented at every hop to prevent routing loops. It is also possible to set the TTL field to a value different from the TTL of the IP packet.

B. Differentiated Services with MPLS

As it was mentioned in the previous chapter the EXP field can be used to control packet scheduling and drop precedence. Other option how to implement QoS in an MPLS network is to use one label per class for each flow of traffic between two endpoints of the LSP. Therefore, the signalling protocol has to be able to signal different labels for the same LSP or prefix. In such a case the experimental bits still hold a part of QoS requirements, precisely the drop precedence, whereas the label indicates the traffic class [2].

C. DiffServ Tunneling Models

By default, the MPLS network preserves the IP precedence or Differentiated Services Code Point (DSCP) bits of the IP packet. The advantage of this is that the MPLS network can have different QoS scheme than the customer. IETF defines three models to tunnel the DiffServ information through MPLS network. These three models are Pipe model, Short Pipe Model and Uniform Model. The Tunnelled DiffServ information is the QoS requirement of the labelled packets, in the case of MPLS VPN, or the precedence/DSCP of the IP packets arriving into the ingress LSR of the MPLS network. The LSP DiffServ information is the QoS requirement of the MPLS packets transported on the LSP from the ingress LSR to the egress LSR. The Tunneled DiffServ information is the QoS information that needs to get across the MPLS network transparently, whereas the LSP DiffServ information is the QoS information that all LSRs in this MPLS network use when forwarding the labelled packet [2].

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D. DiffServ-Aware MPLS Traffic Engineering

The essential goal of DiffServ-aware MPLS traffic engineering (DS-TE) is to guarantee bandwidth separately for each class of traffic in order to improve and optimize its compliance with QoS requirements [3]. In the DS-TE model, the class of service-based bandwidth guarantee is achieved by two network functions:

- Separate bandwidth reservations for each set of traffic class,
- Admission-control procedures applied on a per-class basis.

To accomplish these two functions DS-TE introduces two new concepts:

- Class-type (CT) is a group of traffic trunks based on their QoS values so that they share the same bandwidth reservation, and a single class-type can represent one or more classes. CT is used for bandwidth allocation, constraint routing and admission control. According to IETF there are maximal 8 CTs (CT0 - CT7), and the best-effort service is mapped to CT0.
- Bandwidth Constraint (BC) is a limit on the percentage of a links bandwidth that a particular class-type can use.

The relationship between CTs and BCs are defined in the bandwidth constraint models (BC Models). There are two basic models defined:

- Maximum Allocation Model (MAM) assigns a bandwidth constraint to each class type, see
- Figure 1.
- Russian Dolls Model (RDM) assigns bandwidth constraint to the groups of class-types in such a way that a class-type with the strictest QoS requirement (e.g., CT7 for VoIP) receives its own bandwidth reservation - BC7. The class type with the less QoS requirements, CT6, shares its bandwidth reservation BC6 with CT7 and so on, up to CT0 (e.g., best effort traffic) which shares BC0 (the entire line bandwidth) with all other types of traffic as illustrated in
- Figure 2.

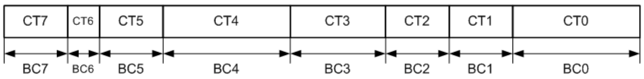


FIGURE 1. BANDWIDTH ALLOCATION IN THE MAXIMUM ALLOCATION MODEL

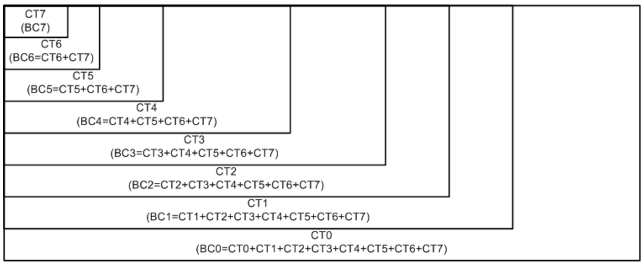


FIGURE 2. BANDWIDTH ALLOCATION IN THE RUSSIAN DOLLS MODEL

III. EVALUATION OF THE BANDWIDTH CONSTRAINT MODELS

In our work the BC models were analyzed from the point of view of QoS guarantees. For this purpose several MPLS simulation scenarios were built in the Network Simulator version 2 (NS-2) simulation environment extended with the MPLS capable MPLS Network Simulator (MNS) and with modules for label switching, CR-LDP routing and CBQ scheduling.

The topology of the test scenario is shown in Figure 3.6. This topology consists of three MPLS capable routers connected with 1 Mbit/s links. Other links have higher capacity to minimize the possibility of congestions and make the MPLS domain the bottleneck of the network. It is desired if we want to examine the differences of the BC models.

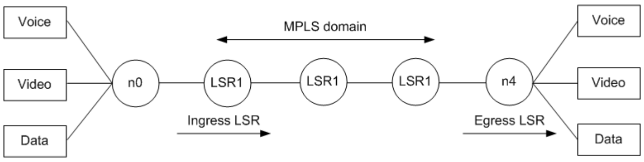
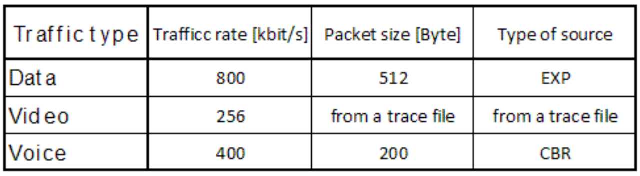


FIGURE 3. BANDWIDTH CONSTRAINT MODEL TEST TOPOLOGY

There are three types of traffic voice, video and data. These traffic types have different demands on QoS. The voice traffic has the strictest demands on QoS, so that it has the highest priority in the test scenario. On the other hand the data traffic has the lowest priority. There are Class-Based Queueing (CBQ) queues with DropTail used in the MPLS domain, and simple DropTail queues on other nodes. Table 1 shows the traffic parameters for these three traffic flows. The traffic rates have been chosen with the aim of overloading the ingress MPLS node, so that QoS implementation can take place. The voice traffic source is a model of four bundled VoIP flows. Each flow uses a G.711 codec with default packetization rate of 50 pps. The video traffic source is generated with the use of a trace file. It models a H.263 video stream.

The data traffic source is modelled as an exponential traffic source with idle and burst periods. The duration of the simulation was 40 s with 5 s pauses for each traffic type. In the 10th second there was a pause for voice traffic, in the 20th second for video traffic and in the 30th second for data traffic. The characteristics of throughput, oneway delay and delay-jitter for MAM and RDM models were measured and compared with the reference values obtained without the usage of any BC model.

TABLE 1. TRAFFIC SOURCES FOR THE BANDWIDTH CONSTRAINT MODEL TEST SCENARIO



Traffic type	Trafficc rate [kbit/s]	Packet size [Byte]	Type of source
Data	800	512	EXP
Video	256	from a trace file	from a trace file
Voice	400	200	CBR

A. Throughput evaluation

Figure. 4 shows the throughput of traffic classes without the implementation of any Bandwidth Constraint model. It is obvious, that the data traffic consumes the majority of the link's bandwidth. Other classes are suppressed by the data traffic and none of the classes can receive its full bandwidth requirement. As a consequence there is a considerable packet loss for each traffic class, what can be seen in Table 2. Such a treatment is not desirable especially for real time applications like voice and video transfer. Thus it is obvious, that we have to implement some QoS mechanism to improve the handling of real time traffic.

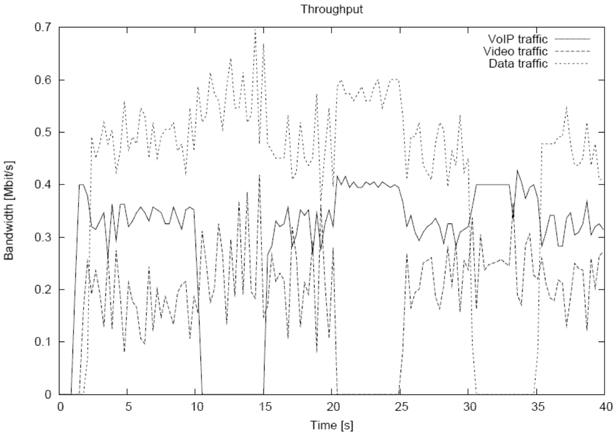


FIGURE. 4 TRAFFIC THROUGHPUT WITHOUT BANDWIDTH CONSTRAINT MODEL IMPLEMENTED

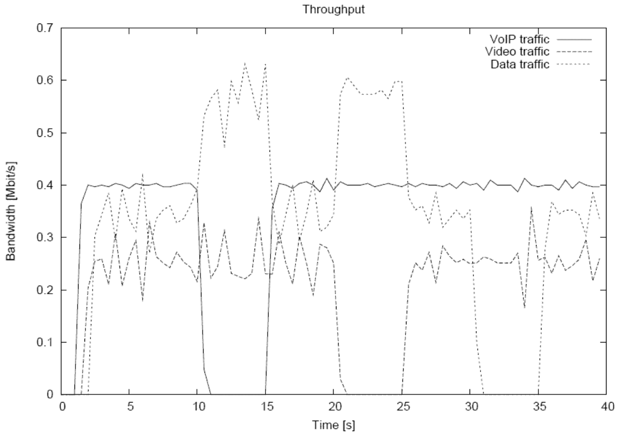


FIGURE 5. TRAFFIC THROUGHPUT WITH MAM MODEL IMPLEMENTED

In the case of the MAM model a reservation was made for both real time traffic flows. That means that a bandwidth of 400 kbit/s was reserved for the voice and 300 kbit/s for the video traffic. The data traffic was allowed to use only the remaining bandwidth according to principles of the MAM model. From the Figure 5 it can be seen that the MAM model can reserve the necessary capacity for the prioritized traffic classes. The disadvantage of the MAM model is that it is impossible to share the unused bandwidth reserved for another class. For example, in the 10th second of the simulation the link utilization is only about the half of the link capacity, which means that the MAM model is not very efficient. This behaviour causes high packet losses in the MAM model.

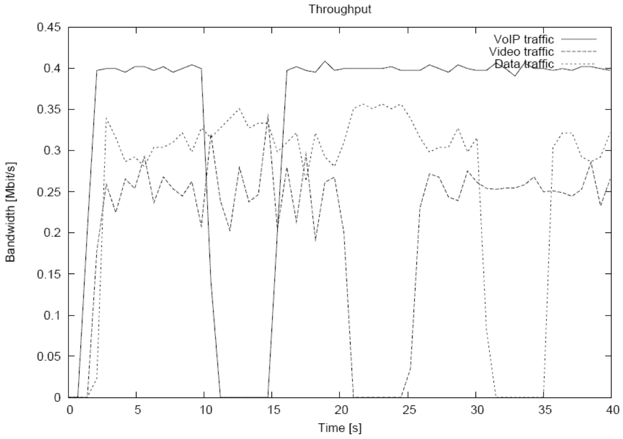


FIGURE 6. TRAFFIC THROUGHPUT WITH RDM MODEL IMPLEMENTED

Some improvements are introduced in RDM, where the traffic classes with lower priority can utilize the unused bandwidth of classes with higher priorities. The throughput of the RDM model implementation is shown in Figure 6. It can be seen that when the higher priority classes do not consume all of their allocated bandwidth, it can be occupied by lower priority traffic. For example in the 20th second of the simulation time, when the video traffic is turned off, the data traffic can use up to 600 kbit/s, in spite of the MAM model, where it was only 350 kbit/s. It can also be seen from Table 2 that the packet loss for data traffic is lower than in case of MAM model.

TABLE 2 PACKET LOSS FOR BANDWIDTH CONSTRAINT MODELS

Traffic type	Packet loss [%]		
	without BC	MAM model	RDM model
Data	12,84	44,58	27,89
Video	17,4	0	0
Voice	12,85	0	0

B. One-way delay and delay-jitter evaluation

Table 3 and Table 4 show that without the implementation of any Bandwidth Constraint model we obtain relatively similar values for one-way delay for all traffic classes. On the other hand if we consider that the real-time traffic is delay sensitive we have to choose another approach with a BC model implemented.

After the implementation of the MAM or the RDM model, it can be seen, that the delay and the jitter for data traffic has increased, but the impact of these BC models on the real time traffic is positive. When we compare the MAM and the RDM model it is obvious, that the RDM model represents a better solution. However the one-way delay and delay-jitter are nearly the same for real-time traffic as for both RDM and MAM models but there is a significant improvement in the case of data traffic when RDM is used.

TABLE 3 ONE-WAY DELAY FOR BANDWIDTH CONSTRAINT MODELS

Traffic type	Average delay [ms]		
	without BC	MAM model	RDM model
Data	60,2	240,83	112,22
Video	70,26	72,94	73,48
Voice	56,11	38,77	39,44
Traffic type	Maximal delay [ms]		
	without BC	MAM model	RDM model
Data	101,51	444,19	267,49
Video	101,92	153,53	152,67
Voice	104,41	48,61	48,94

TABLE 4 DELAY-JITTER FOR BANDWIDTH CONSTRAINT MODELS

Traffic type	Average jitter [ms]		
	without BC	MAM model	RDM model
Data	11,31	45,16	46,07
Video	12,77	20,14	20,29
Voice	12,5	4,16	3,83
Traffic type	Maximal jitter [ms]		
	without BC	MAM model	RDM model
Data	59,78	300,48	159,79
Video	55,12	106,73	105,9
Voice	69,61	13,65	13,63

IV. CONCLUSION

In our analysis we compared the two basic Bandwidth Constraint models for MPLS networks, called Maximum Allocation Model (MAM) and Russian Dolls Model (RDM), from the point of view of Quality of Service guarantees. As a result of our analysis we can conclude that the RDM model gives better results for both one-way delay and jitter. The main reason for achieving better results is the bandwidth sharing mechanism of RDM which allows low priority traffic classes consume the bandwidth of the higher priority traffic classes when it is unused.

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