Flow-Aware Networking as an Architecture for the IPv6 QoS Parallel Internet

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***Abstract*—The IPv6 QoS is one of the Parallel Internets proposed as a part of the IIP System researched and developed under the Future Internet Engineering Project. IIP System assumes that it is possible and reasonable to virtually divide current Internet into three Parallel Internets. In this way three architectures may co-exist over one physical topology. Three Parallel Internets have been defined under the Future Internet Engineering project: IPv6 QoS, CAN (Content Aware Network) and DSS (Data Stream Switching). The main goal of the IPv6 QoS Parallel Internet is to support applications which need QoS guarantees. In this paper, the FAN (Flow-Aware Networking) concept is proposed for a possible implementation to meet the requirements of the IPv6 QoS architecture. The main goals and assumptions of such implementation are presented. Moreover, the simulation results show the usefulness of using FAN in this Parallel Internet.**

***Index Terms*—IIP System; Flow-Aware Networks; Quality of Service**

I. Introduction

The Internet has changed radically since the first messages were sent between two nodes years ago. Currently it is used not only to search web pages or to send e-mails. Applications like VoD (Video on Demand), VoIP (Voice over IP), real time transmissions, P2P (Peer-to-Peer) and other along with fast progress in optical networks changed end-user devices into multimedia, multi-functional and smart machines. It is a real challenge to ensure the required QoS (Quality of Service) for all such different traffic in current Internet.

The IIP System developed under the Future Internet Engineering project [1] assumes that currently existing Internet should be virtually divided into three Parallel Internets dedicated to serve a selected type of traffic with expected QoS. Three types of the Parallel Internets have been defined: IPv6 QoS, CAN (Content Aware Network) and DSS (Data Stream Switching). The first one is dedicated to serve traffic with dedicated QoS based on the IPv6 protocol. It should consider different types of traffic which may be grouped in classes similar to those defined for DiffServ. The main goal of CAN is to allow for efficient transmission of data in a network based on the type of transmitted content. In this way, a new routing rules should be defined. In DSS, streaming transmissions ought to be served. In this case, fixed bandwidth and acceptable values of parameters like delay, jitter or drops must be ensured. Moreover, also in this concept new routing rules need to be defined.

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In this paper, the FAN (Flow-Aware Networking) architecture is presented as a possible solution to be used in the IPv6 QoS Parallel Internet. FAN was first proposed in [2], [3] and, further presented as a complete system in 2004 [4], [5]. This is a simple architecture to ensure QoS in IP networks based on the minimum information from a network. There is no need for signalling in FAN. The architecture have been developed for several years since it was proposed. New congestion control mechanisms, improvement of packet scheduling or fairness and multi-layer-based extensions are only a part of recently presented in literature new solutions for FAN. It is also worth to know that FAN architecture conforms to the net neutrality rules [6].

The paper is organized as follows. Section II presents the main assumptions and a brief description of the IIP System. In Section III, the FAN architecture is presented. The possible implementation of FAN in the IPv6 QoS Parallel Internet is described in Section IV. In Section V, the results of carefully selected simulation experiments are discussed. Section VI concludes the paper.

II. IIP System

The IIP System have been introduced and developed as a proposal for implementation in the Future Internet. The main motivation to work on it was to design a system which will be able to change current Internet into an user-friendly environment where new possibilities and services are offered with the satisfactory quality. It was assumed that thanks to virtualization possibilities a network device may operate in several different ways. For example, routers may be virtually divided into several independent machines which serve different types of traffic. Based on this assumption a new network model was proposed, realized and tested under the Future Internet Engineering project.

In the IIP System three Parallel Internets have been defined: IPv6 QoS, CAN and DSS. They operate over one physical topology from which the available resources are virtually allocated based on the management module decision. Each Parallel Internet works independently and consumes the allocated resources, like part of the outgoing interface capacity, buffer space, CPU power and others.

The IPv6 QoS Parallel Internet was proposed to handle the traffic which needs proper transmission quality. It operates on the IPv6 protocol stack. It was assumed to use the DiffServ PHB (Per Hop Behavior) mechanisms, NGN transport and service stratum functionalities. The goal is to maintain the architecture which is able to ensure the QoS guarantees in

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the IPv6-based environment. The proposed solution is similar in concept to the IPv6 autonomous system [7]. Four types of processes have been defined for the IPv6 QoS Parallel Internet:

- management process to create or remove and provision of network (long time scale),
- management process to create or remove and provision of virtual network (long time scale),
- signalling process to call for set-up or release paths inside virtual network (short time scale),
- data transmission process for packet handling (very short time scale).

The IPv6 QoS assumes that it is necessary to guarantee QoS parameters like packet losses, packet delay, and jitter at the network level. In paper [8] the signalling system for the IPv6 QoS Parallel Internet is proposed. It should work along with the admission control block. Moreover, the dedicated virtual networks were defined to serve traffic of a specific Class of Service.

CAN Internet is a post-IP architecture designed and developed to ensure access to multimedia content in a large scale environment [9]. The motivation to work on CAN is quite simple – there is a need for new transport system which will be able to efficiently transport segmented multimedia data without global naming scheme. The multimedia data generate now the majority of traffic in the Internet [10]. It is a real challenge for network operators to ensure a proper QoS for such traffic. The goal of the CAN Parallel Internet is to deliver a content in a most efficient way. The transport protocol of CAN should take into account location of the content, possible replicas and also network conditions, like link occupation. The control and management planes for CAN provide:

- unified content naming and addressing scheme – thanks to this scheme consumers have access to the content independently from its location and distribution mode,
- algorithms for content search which are able to find available content replicas and select preferred server,
- routing based on content and responsible for discovering and enforcing content delivery paths,
- content management algorithms.

Data plane for CAN ensures efficient transfer of multimedia data units as well as control and management messages. Different types of connections have been defined for CAN:

- anycast,
- multicast,
- unicast.

Moreover, it is possible to cache content at edge network nodes.

The DSS network is dedicated to serve traffic which is transmitted with constant rate as flows. Such traffic is usually constituted by real time streaming transmissions. In the IIP System it is assumed that the best way to implement such a solution is to base on the traditional circuit switching. However, due to the needs of synchronization in the circuit switching, which is hard to achieve, the modification of the Rate Envelope Multiplexing scheme was proposed for the DSS Parallel Internet [11]. In this modification, it is assumed that each connection in DSS has its own short buffer. It allows for more strict control of quality of transmitted traffic. The transmission in DSS is based mostly on three parameters: bandwidth, transmission delay and jitter. It is necessary to allocate such bandwidth for each connection that the buffering of packets will be limited. The acceptance of connections is managed by the centralized Network Controller. Connections are set-up before transmission. As a result, the signalling is needed. A specific data format is used in DSS. It contains a DSS header with the stream identifier value and payload.

An incoming packet to the physical routers must be classified and served by the proper Parallel Internet. The model of the scheduler for the IIP System is presented in Fig. 1. As we can see, traffic is sent by using Ethernet. After the Ethernet header, the PI header (Parallel Internet header) is placed in each packet. It tells the router to which virtual device it should be sent for transmission. Next, packets are scheduled under the particular Parallel Internet needs and sent to the outgoing link.

III. Flow-Aware Networks

Flow-Aware Networks have been proposed as an architecture to ensure QoS guarantees in IP networks. Traffic in FAN is implicitly classified to one of two types:

- streaming – flows which transmit with rate lower than min_FR; usually VoIP or VoD flows,
- elastic – flows which transmit with rate higher than min_FR; usually data transmission.

The min_FR parameter means a bandwidth available for each flow in a link. This value is set statically by an administrator.

The cross-protect router (also known as XP-router) is a main element of the FAN architecture. There are two main blocks of the XP-router:

- admission control – decides on acceptance of new flows,
- scheduler – queues packets and decides which should be sent.

Flows may be accepted in the admission control block only when the outgoing link is not congested. In such cases their IDs are written to the PFL (Protected Flow List). The values of two parameters are periodically estimated in the scheduler block:

- FR – the maximum rate that is or may be realized by a flow,
- PL – the ratio, which represents the rate of incoming priority packets with reference to the link capacity.

If the estimated value of any of these parameters exceeds the border value (min_FR or max_PL) the congestion is noticed.

Three scheduling algorithms have been proposed for FAN. The PFQ (Priority Fair Queuing) is based on the Start-time Fair Queuing. The PDRR (Priority Deficit Round Robin) is a modification of the Deficit Round Robin Algorithm. The third, the most promising one, is based on the AFD (Approximate Fair Dropping) and called AFAN (Approximate FAN) [12]. All simulation results presented in this paper have

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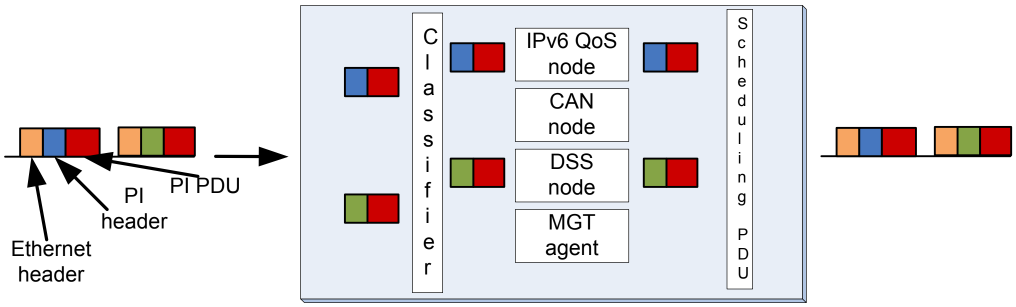

Fig. 1. The Scheduler for IIP System

been obtained for this architecture, which is less complex than its predecessors.

Many researchers in the world provide the research work on FAN. Several important new solutions have been recently proposed for this architecture. In this paper, two of them are shortly described: the MFAN (Multi-layer FAN) and the Intelligent Routing for FAN, because such mechanisms may be implemented in FAN adjusted to the IPv6 QoS Parallel Internet needs.

A. Multi-layer FAN

MFAN was proposed in [13]. It assumes that traffic which cannot be served at the IP layer may be redirected to the optical layer and transmitted using only the optical resources. Three polices have been defined to select flows which should be redirected to the optical layer. In the "Most-active flow" policy the flow which has the most bytes in the queue is selected for redirection in congestion. The "Oldest-flow" policy assumes that flow which began transmission first is served by the optical layer in congestion. In the "Newest-flow" policy traffic of all new (already not accepted in the admission control block) flows in congestion is transmitted by using only the optical resources. In MFAN, it is assumed that new lambda is called when needed and when the resources are available. Moreover, new flows at the optical layer are accepted until the optical buffer becomes congested (buffer free space is lower than the available threshold).

B. Intelligent Routing for FAN

The new method for intelligent routing for FAN was proposed in [14]. In this solution it is assumed that paths are selected for flows based only on the uncongested links. If a link becomes congested the routing protocol does not consider it in routing tables. When a new flow is accepted in the admission control block, its ID is written to the PFL. Moreover, the ID of the outgoing interface for this flow is also added to the PFL. Further packets of such a flow are transmitted through the selected outgoing interfaces based on the content of the PFL (not based on the routing table). The results presented in [14] show that it is possible to significantly increase the total amount of traffic transmitted in a network when using the Intelligent Routing for FAN.

IV. FAN in IPv6 QoS

Flow-Aware Networks may be used in the IPv6 QoS Parallel Internet to ensure quality of transmission for different types of flows. Flow ID in FAN is calculated based on five fields of a packet header: source and destination addresses, source and destination ports' numbers and the ID of the transport protocol. This value may be calculated as a simple sum or as a hash, however it can be done for both IPv4 and IPv6.

FAN, modified to meet the IPv6 QoS Parallel Internet needs, can serve different classes of traffic. For each class of traffic several parameters may be defined, e.g., minimum throughput, maximum delay, priority, etc. The identifier of traffic class should be written in packets' headers. Each router in the network knows how packets of a particular class should be served. The XP-router for the IPv6 QoS Parallel Internet is presented in Fig. 2.

The pseudo-code for realizing packet service in the IPv6 QoS Parallel Internet is presented in Fig. 3.

Instead of FR and PL only the values of $spare\_C$ are estimated each time a new flow wants to begin transmission (line 12 in Fig. 3). This value is calculated as a difference between total capacity of the link and the sum of throughputs assigned to active flows (flows which are registered in the PFL). A new flow may be accepted if its declared maximum throughput is lower than the current value of the $spare\_C$ parameter (line 13). In this case its ID is added to the PFL (line 15). The other transmission parameters are guaranteed based on the features of FAN.

Once accepted flow may continue transmission until its ID is removed from the PFL. The ID of a flow is removed from the PFL after its inactive longer than time given by the $flow\_timeout$ parameter. Each traffic class has its own queue in the scheduler. Fairness among flows of the same type is ensured by using one of the scheduling algorithms used in FAN. On the other hand, packets are selected for sending according to the weights assigned to the queues within the deficit round-robin regime (line 25). Moreover, a part of available capacity in the link may be reserved for the emergency flows, e.g., emergency calls. Such flows are always accepted and served first (line 13 and lines 22-23).

There are several advantages of using FAN in the IPv6 QoS Parallel Internet. The signalling is not needed. Only the packet marking (to check for traffic class) is necessary. Paths do not

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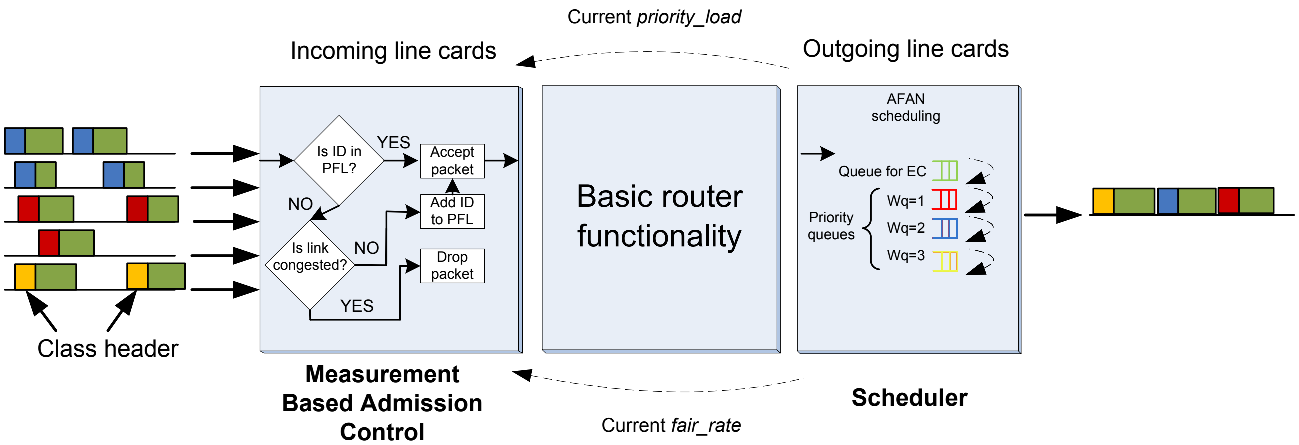

Fig. 2. Scheduling in IPv6 QoS PI based on FAN

```
################## queuing #################
on a packet p of flow i arrival to a router
current_time = Scheduler :: instance().clock()
if ID(i) is in the PFL then
begin
    accept p
    update flow_timeout(i) in the PFL
    send p to the proper queue
end
if ID(i) is not in the PFL then
begin
    calculate spare_C
    if spare_C ≥ C(i) or i is an emergency flow then
    begin
        add ID(i) to the PFL
        flow_timeout(i) = current_time
        send p to the proper queue
    end
    else drop p
end
################# dequeuing ################
if emergency queue is not empty then
    send first packet from emergency queue
else
send packets according to the weighted DRR
```

Fig. 3. Pseudo-code for realizing packet service in the IPv6 QoS Parallel Internet

need to be created or removed. FAN work independently in virtual networks created in the IPv6 QoS Parallel Internet. Moreover, FAN conforms to the net neutrality rules [6].

FAN may be implemented in the IPv6 QoS Parallel Internet in the multi-layer environment (based on MFAN). In this case, flows which cannot be accepted due to congestion may be redirected to the optical layer. In such a case we have to maintain the additional PFLλ list and to compute the value of the $spare\_C\lambda$ parameter. As an effect the optical path is treated as an additional link between source and destination. Moreover, the Intelligent Routing concept may be used to increase the total amount of traffic sent in the network. A router may look for new paths when the optical resources are not available and the primary path (calculated based on the routing protocol when all links in the network are not congested) is overloaded.

V. Simulation Experiments

In this section, the results of the simulation experiments provided in the ns-2 simulator are presented. The goal of them is to show the effectiveness of FAN (also with extensions) implemented in the IPv6 QoS Parallel Internet.

60 simulation runs were provided in topology presented in Fig. 4. The goal of the experiments was to show how the volume of total traffic and mean flow rates in basic FAN, MFAN and MFAN with Intelligent Routing in the IPv6 QoS Parallel Internet changes. For MFAN the "Newest-flow" policy was used. The simulated topology is simple, yet adequate to analyze FAN. The reason behind such a statement is that all nodes in FAN operate independently and all the decisions are taken without any information from the network. Therefore, the topology is sufficient to demonstrate the operation of the analyzed algorithms. Moreover, FAN is a scalable solution, which was proved by presenting the results for 100 Mbit/s and 1 Gbit/s links.

As AFAN is the most promising proposal for FAN, it was decided to provide the simulation analysis for this architecture. Firstly, it was assumed that the capacity of each AFAN link was set to 100 Mbit/s. The capacity of access links was set to 1 Gbit/s. The simulations were repeated at least 10 times for each experiment. 95% confidence intervals were calculated by using the Student's t-distribution. The traffic pattern with Pareto distribution for calculating the volume of traffic to be sent by the elastic flows from node S to D was provided. 1000 TCP flows with the maximum rate of 1 Mbit/s (class 3), 1000 TCP flows with the maximum rate of 5 Mbit/s (class 2), and 1000 TCP flows with the maximum rate of 10 Mbit/s (class 1) were generated. In each case the shape parameter was set to 1.5 and the mean flow size was 150 Mbit. The exponential distribution for generating the time intervals between beginnings of the transmissions of flows (the mean value of the inter-arrival time was set to 0.2 s) was used.

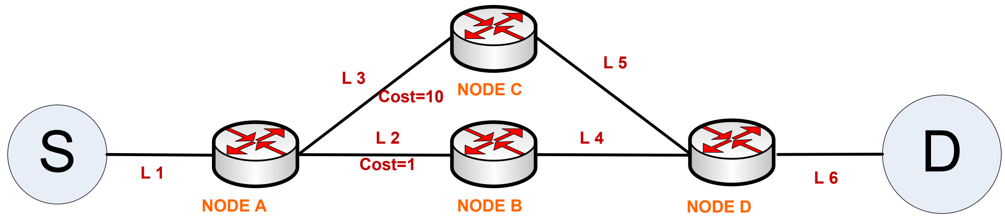

Fig. 4. The network topology

The duration of each simulation run was set to 300 s. The warm-up period was set to 50 s. For AFAN, min_th was set to 4000 packets and max_th to 9000 packets. In MFAN, it was assumed that it is possible to set-up one additional path at the optical layer with the same capacity as link at the IP layer. Secondly, to show the scalability of the analyzed proposal, I changed the capacity of the FAN links to 1 Gbit/s and the capacity of access links to 10 Gbit/s, and multiplied the number of generated flows and buffers' size by 10. The simulation parameters are summarized in Tab. I.

The simulation results are presented in Tab. II and Tab. III. We may see that FAN can be implemented as an architecture for the IPv6 QoS Parallel Internet. It is possible to ensure proper quality of service for different types of flows. In each analyzed case, the mean flow rate values were only slightly lower than the assumed values (maximum rate declared for a class of flows). The proper (acceptable) values of the other QoS parameters, like transmission delay or jitter were assured by FAN, because only limited number of flows which could be transmitted without losses was accepted. The mean flow rates (MFR) in each analyzed case were comparable which confirms that basic FAN, MFAN and MFAN with the Intelligent Routing can be successfully implemented in the IPv6 QoS Parallel Internet. We may also see that MFAN allows for sending more traffic in a network (in case analyzed in the paper the total amount of transmitted traffic was doubled in MFAN in comparison to basic FAN). MFAN with the Intelligent Routing additionally allows for increasing of total amount of traffic sent in a network.

The results presented in Tab. III confirm that Flow-Aware Networks are scalable. Similar (proportional) results are obtained for 100 Mbit/s and 1 Gbit/s links which proves that the proposed solution can be implemented in more complex networks with the same effectiveness.

VI. Conclusion

The IIP System is a promising solution for the Future Internet. It is composed of three Parallel Internets, called IPv6 QoS, CAN and DSS. The Parallel Internets are virtually implemented based on the physical infrastructure.

In this paper, Flow-Aware Networks have been proposed as a possible architecture for the IPv6 QoS Parallel Internet. Using FAN adapted to the specific needs of the IPv6 QoS Parallel Internet makes it possible to guarantee proper QoS for transmitted flows. Moreover, it was shown that MFAN and the Intelligent Routing may additionally improve transmission in the IPv6 Parallel Internet. The proposed solution is scalable and conforms to the net neutrality rules.

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TABLE I
VALUES OF SIMULATION PARAMETERS

Parameter	Value for 100 Mbit/s link	Value for 1 Gbit/s link
no. of simulation runs	30	30
duration of a simulation run	300 s	300 s
no. of class 3 elastic flows (TCP)	1000	10000
no. of class 2 elastic flows (TCP)	1000	10000
no. of class 1 elastic flows (TCP)	1000	10000
shape parameter for Pareto distribution	1.5	1.5
mean size of flows for Pareto distribution	150 Mbit	150 Mbit
packet size of elastic flows	1000 B	1000 B
interarrival of elastic flows generated with exponential distribution	mean interarrival time: 0.2 s	mean interarrival time: 0.2 s
capacity of FAN link	100 Mbit/s	1 Gbit/s
capacity of access links	1 Gbit/s	10 Gbit/s
size of buffer	1000 packets	10000 packets
flow time out	2 s	2 s
warm-up time	50 s	50 s
min_th	4000 packets	4000 packets
max_th	9000 packets	9000 packets
w_q	0.02	0.02

TABLE II
THE VALUES OF TOTAL TRAFFIC SENT AND MEAN FLOW RATE IN FAN WITH 100 MBIT/S LINKS

Architecture	Traffic sent [Gbit]	MFR of class 1 [Mbit/s]	MFR of class 2 [Mbit/s]	MFR of class 3 [Mbit/s]
basic FAN	22.38±0.13	9.76±0.13	4.82±0.08	0.92±0.05
MFAN	44.65±0.16	9.78±0.08	4.87±0.06	0.93±0.03
MFAN with Intelligent Routing	66.48±0.16	9.75±0.10	4.78±0.10	0.90±0.02

TABLE III
THE VALUES OF TOTAL TRAFFIC SENT AND MEAN FLOW RATE IN FAN WITH 1 GBIT/S LINKS

Architecture	Traffic sent [Gbit]	MFR of class 1 [Mbit/s]	MFR of class 2 [Mbit/s]	MFR of class 3 [Mbit/s]
basic FAN	221.71±0.15	9.69±0.13	4.63±0.11	0.89±0.02
MFAN	445.29±0.43	9.73±0.18	4.67±0.10	0.90±0.03
MFAN with Intelligent Routing	659.79±0.61	9.75±0.11	4.65±0.13	0.89±0.04