Traffic differentiation - a basic step towards providing end-to-end QoS on the train-to-wayside wireless communication system

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***Abstract*—We developed a network platform that is responsible for an uninterrupted and seamless connectivity from the train to the wayside through heterogeneous wireless access technologies. However, limiting the offered services to only an onboard Internet is not a feasible business case. A viable one should extend to a broad spectrum of railway communication services like: train control, diagnostics, real time passenger information, entertainment, security CCTV surveillance etc. In a highly dynamic environment (from the communication link point of view) such a fast moving train, it is neccesary to introduce prioritization among different traffic classes. This will implicitly determine under what conditions a certain flow should get suspended or dropped in order to preserve the flows of a higher priority as long as possible and to ensure that they meet their QoS demands. The first step towards this goal is data traffic differentiation.**

Keywords-component: Data traffic differentiation, Click Modular Router, IPv6, railway

I. Introduction

A communication system between fast moving trains and the ground involves some significant challenges [1], which are mainly caused by a very dynamic behavior of communication channels due to high speed of a train. Doppler shifts, variation in line-of-sight (LoS) between train and base stations, frequency selective fading, handover etc. are the most notable ones. They cause variations in conditions of communication channels that are both spacial and temporal.

Previous research [2,4] suggested simultaneous use of three different types of wireless communication technologies (satellite links, wireless local area networks, mobile operator networks) in order to provide an uninterrupted and seamless connectivity between train and wayside. A Satellite link could be used as the main communication channel, with a backup in public 2G/3G networks when there is no LoS. WiFi communication would be used when the train is situated in a railway station.

In order to guarantee a user friendly experience, it is inevitable to provide good Quality of Service (QoS) mechanisms in the network architecture. Specific QoS research is performed in IEEE wireless technologies, such as 802.11e, 802.16e [9] and network protocols by the IETF, e.g. Diffserv, IntServ, RSVP. In literature, there is already research covering QoS in wireless heterogeneous networks and [3]. However, fast changing wireless characteristics during train mobility and the use of different wireless technologies still poses some huge challenges in this domain. Moreover, the requirements of the on-board applications can change rapidly due to the fact that the number of users/clients and applications can change quickly. Thus, it is still a big challenge to provide an adequate integrated QoS solution that can deal both with a heterogeneous and dynamic network environment and dynamic application demands.

Effects of introducing broadband connection on trains, from economical and passenger's experience point of view are presented in [16]. Discussion on opportunities for broadband deployment in this sort of environment are presented in [3] and main technical and economical challenges are elaborated in [1].

In Section II we will describe the general architecture of the system we designed with the focus on the main modules used for data traffic differentiation. Other modules are not directly involved in the above mentioned process, therefore they are out of the scope of this paper and will not be described here. Section III will present the experiments we conducted while the results are presented in Section IV. Section V includes future work and a conclusion.

II. General Architecture

We designed a new and modular architecture [6][14] for the Train-To-Wayside-Control-System (TWCS). All traffic flows from the Mobile Control Equipment (MCE) – a standard onboard gateway for all the outgoing traffic, to the Wayside Control Equipments (WCE) at the wayside, through the modules of the data plane, which is depicted in Fig. 2. A differentiation is made between connections for reliable transport (straight lines), e.g. TCP (Transmission Control Protocol) connections, and connections for unreliable transport (dotted lines), e.g. UDP (User Datagram Protocol) streams, as they have different requirements. Elements in the control and signaling plane are depicted on Fig. 1. These elements provide configuration information and process control information

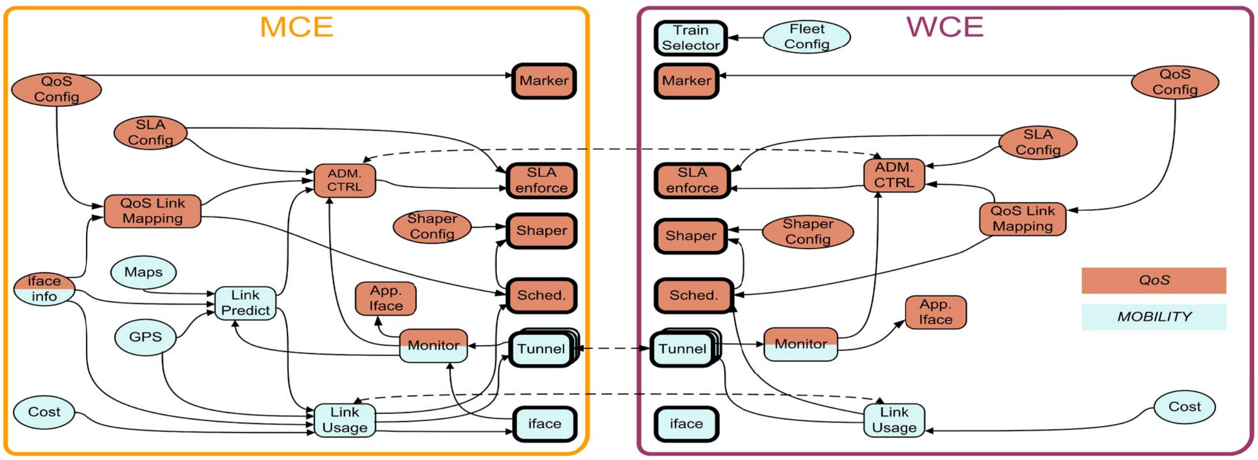

Figure1. General architecture - control plane

which is needed during the operation of the data modules.

Within the TWCS communication system we aim at offering an optimized connected experience by prioritizing Figure 2. General architecture - data plane important traffic flows, enforcing Service Level Agreement (SLA) levels, respecting traffic flow characteristics (e.g. low latency), traffic shaping according to available bandwidth etc.

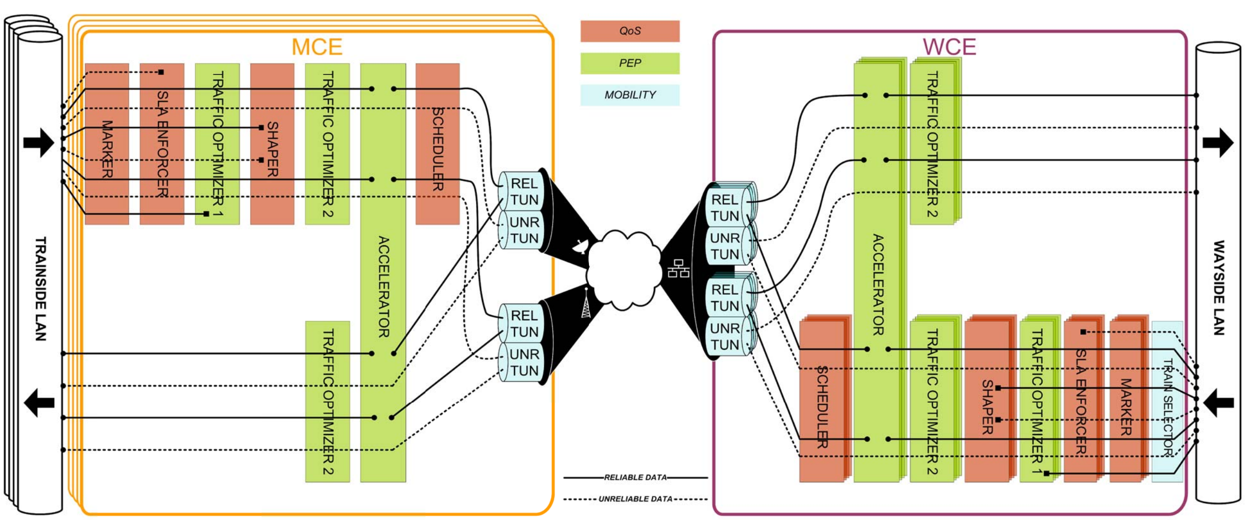

Figure 2. General architecture - data plane

This is jointly referred to as the QoS aspect of the system. The functionality is logically split into the Marker, SLA Enforcer, Shaper and Scheduler elements and they are presented as the part of a data plane. Firstly, the Marker marks packet flows architecture is used for classification within the TWCS. This is a set of enhancements to the Internet protocol to enable QoS between hosts in different networks. Traffic is classified into a limited set of service classes which are treated differently.

According to characteristics of the train-to- wayside (T2W) services, they are categorized in different ‘service classes’ (i.e. data traffic that requires specific delay, jitter and loss characteristics from the network), as stated in Table 1. Additionally, Table 2 presents a relative priority of the T2W services.

Every data flow (a sequence of IPv6 packets from one host to another) is marked with the unique flow label (20 bits) value in a packet header. The packets will also be assigned the Differentiated Service Code Point (DSCP) marker (6 bits) of the IPv6 Traffic Class bits (8 bits) in the IPv6 header [5]. This value indicates into what service class the packets are classified to and what priority they have (Table I). The other two bits of the Traffic Class field are used for Explicit

Congestion Notification (ECN). Next, the SLA Enforcer ensures that all flows that belong to the same SLA comply to the SLA stipulations (e.g. maximum data rate, data volume). Every device is subjected to a certain SLA. This agreement can restrict the type of services that a device is allowed to use. Within this architecture, all devices that are subject to the same SLA are put into a separate Virtual Local rea Network (VLAN). This way, SLA identification is indicated in the VLAN header.

By adding a unique flow label, VLAN tag and DSCP marker to the IPv6 packet header, the process of data traffic differentiation is completed. A packet will be sent towards the Shaper and Scheduler elements. Then, the Shaper will shape all flows to the available capacity on the wireless train-to-wayside link by dropping packets of flows, with respect to the relative priority of the different flows. Finally, the Scheduler needs to schedule all flows to an appropriate link, considering the service class of each flow (e.g. low latency requirement for VoIP). The flow is finally passed to the Performance Enhance Proxy (PEP) element and sent towards the wayside using the Stream Control Transmission Protocol (SCTP) [15].

TABLE I
DSCP BITS FOR T2W SERVICES

Services	Class	Priority	DSCP	Traffic Class
Passenger Internet	A	1	000011	00001100 (0x0C)
Crew Intranet	A	2	000111	00011100 (0x1C)
Diagnostics	A	3	001011	00101100 (0x2C)
Application update Content update	A	4	001111	00111100 (0x3C)
TCMS event	B	4	010011	01001100 (0x4C)
CCTV security	C	5	010111	01011100 (0x5C)
Intercom (VoIP)	D	6	011011	01101100 (0x6C)
CCTV safety	E	6	011111	01111100 (0x7C)
TCMS cyclic	F	6	100011	10001100 (0x8C)
Public address PIS control data	G	7	100111	10011100 (0x9C)
Configuration traffic	G	8	101011	10101100 (0xAC)

Just like the Marker and SLAEnforcer, both Scheduler and Shaper elements belong to the QoS part of the system, but they are out of the scope of this paper since they do not participate in the process of traffic classification. They use that sort of information to shape the traffic and schedule it to an appropriate link.

III. IMPLEMENTATION

Complete implementation has been done using the Click Modular Router 1.8.0 [8]. Basic router functions are already implemented inside the Click's kernel. However, most of the specific functionalities of our configuration are incorporated inside the elements we developed.

The IBBT iLAB Virtual Wall testbed [10,11] was used for the purpose of testing and evaluation. Six PCs, each with 3 or 4 gigabit ethernet interfaces, were organized into a small network as depicted in Fig. 3. "Trainhost1" and "Trainhost2" simulate onboard hosts. "Train" is an onboard router, while "Wayside" is its counterpart on the ground. "Waysidehost" presents a host elsewhere. The "Impair" node is used to run the scripts that should change the properties of available communication links, simulating fast movement of a train and changes links suffer according to it.

Linux Kernel 2.6.39 with latest SCTP developments was mounted on each of the PCs. For the purpose of generating data flows, we used Jperf 2.0.2 [12] and a VLC streamer [13].

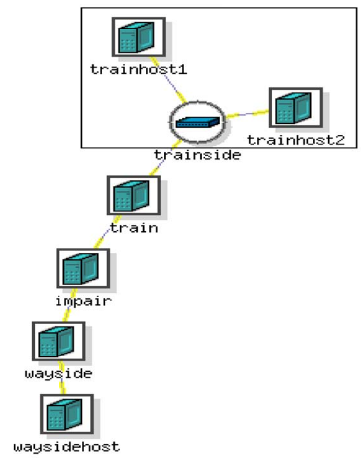

Figure 3. Experimental network topology

Details about the implementaion were previously presented [6]. The most notable adjustments we made are:

- Instead of using the IEEE 802.1q protocol, better known as VLAN tagging, we developed an element that sets up VLAN designators inside a Flow Label field of an Ipv6 header. VLAN tags are added according to the source address of packet and a VLAN to SLA mapping is predefined and static.

TABLE II
DESTINATION PORT TO TRAFFIC CLASS MAPPING

Port range*	DSCP**	Traffic Class IP6 field***	Traffic Class	Priority
0-1100	3	00001100 (0x0C)	A	1 (lowest)
1101-1200	7	00011100 (0x1C)	A	2
1201-1500	11	00101100 (0x2C)	A	3
1501-2000	15	00111100 (0x3C)	A	4
2001-3000	19	01001100 (0x4C)	B	4
3001-3500	23	01011100 (0x5C)	C	5
3501-4000	27	01101100 (0x6C)	D	6
4001-4200	31	01111100 (0x7C)	E	6
4201-4500	35	10001100 (0x8C)	F	6
4501-5000	39	10011100 (0x9C)	G	7
5001-99999	43	10101100 (0xAC)	G	8 (highest)

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- The Marker element decides upon a flow label by inspecting n-tuple of parameters in the packet header, typically including IP source address, IP destination address, source port number, destination port number and protocol identification. Every new flow label is set by means of a pseudo-random generator.

- The DSCP designator for each packet is usually determined on the application level. In the absence of the DSCP designator we used the destination port of a flow to assign a traffic class (see Table II).

IV. Results

A. Experiment 1 - introducing traffic classes

The purpose of this experiment was to demonstrate the impact of data traffic differentiation as opposed to a case when no differentiation is applied.

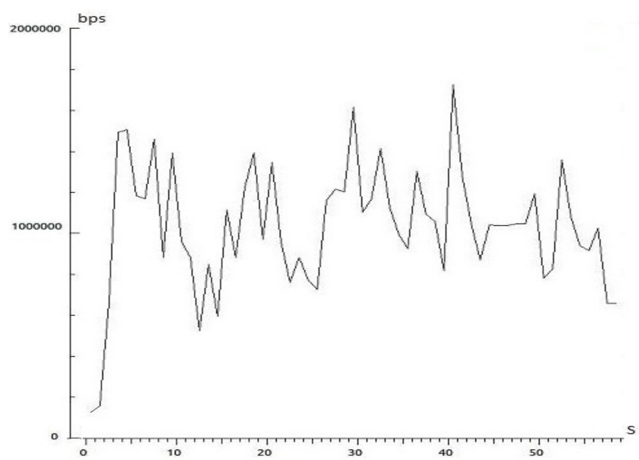

Figure 4. VLC flow trace graph - no link emulation and background flow

Click scripts (router configurations) were run on both Trainside and Wayside nodes (see Fig.3). The Impairment node was used to emulate the link between a train and a wayside. During this experiment, only one communication link was active with the dedicated bandwidth of 1.7 Mbps, delay 200ms and a 0.05% packet loss. A background UDP traffic of 1Mbps was used. It's direction was from the Trainhost1 towards the Waysidehost. The second flow was a VLC video stream sent from the Waysidehost towards the Trainhost2 (Fig.4). The recorded average rate of the flow was 1.045 Mbps.

A.1 No traffic prioritization

In the first case, both flows belonged to the same traffic class. This way, Shaper and Scheduler treated them the same way - neither of the two had the priority over the other one. The experiment was 40 seconds long. A trace of the VLC video stream was made on the network interface of the Trainhost2. The results are depicted on Fig.5.

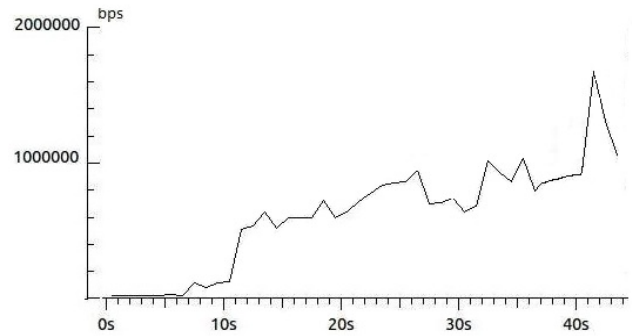

Figure 5. VLC flow trace graph - the same traffic class for both flows

As seen from the graph, the average rate of the VLC stream was significantly bellow 1Mbps. Transmission trace file showed an avrage of 680 Kbps and a 26.32 % packet loss. Jperf statistics of the background flow that the average rate of the background flow was around 780 Kbps with 11% packet loss. As expected, both flows got as much bandwidth as possible. The slow increase of a flow's rate, that can be observed at the beginning of almost every experiment, was caused by the queuing effects inside Click and a slow start windowing mechanism, introduced by the SCTP tunnels.

A.2 With traffic class prioritization

In this case, the VLC flow was assigned a higher priority by sending it to a higher destination port (3600 - Intercom, see Table II). The Random Early Detection (RED) elements inside the Shaper started shaping the flows differently, depending on the state of the incoming queue and settings assigned to a dedicated RED [7]. The results are depicted on Fig.6. It can be observed from a graph that the average rate of the VLC flow was significantly increased, to 944 Kbps with 2.35% packet loss. Jperf statistics displayed a ignificant decrease of a background flow rate - 584 Kbps with 36% packet loss.

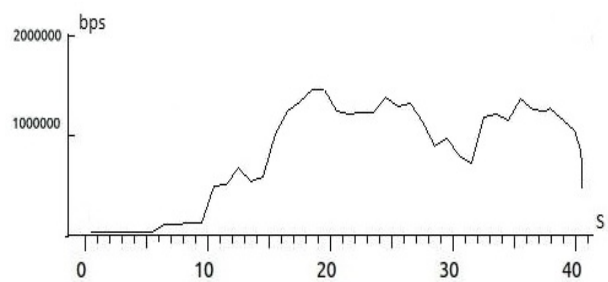

Figure 6. VLC flow trace graph - different traffic classes

B. Experiment 2 - changing link conditions

The setup used for this link was the same as in the Section A2, but this time the bandwidth and delay of a communication link were changed on the fly. This way we tested how the system responses to a sudden change of the bandwidth of a communication link.

B.1 High bandwidth oscillations

In the first case a bandwidth of a link was changed from 1Mbps to 1.7 Mbps and finally 2.5 Mbps on the 20s intervals. A trace of the VLC video stream is shown on Fig.7.

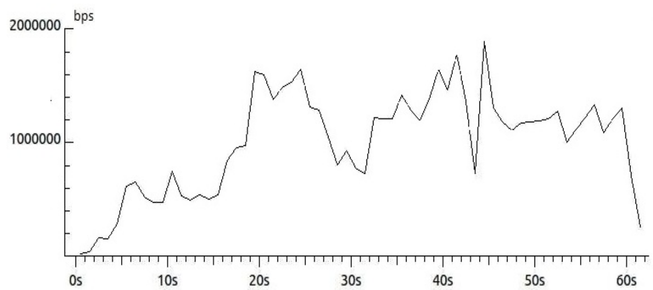

Figure 7. VLC trace graph - less frequent, high link bandwidth oscillations

It can be observed that, after approximately 20 seconds, a flow rate will increase to a value it reached in the case described in section A.2 of the Experiment 1, which was expected since the parameters of the Shaper and the communication link were the same. The next increase, at 40th second, is not as noticeable since the VLC flow rate does not surpass 1.4 Mbps at any moment after the 40th second (see Fig.4).

B.2 Much lower bandwidth oscillations

In this, more frequent bandwidth changes were introduced. However, they were not as high as in the first case. These oscillations were introduced in a fashion presented in Table III. The results of the experiment are depicted on Fig.8.

TABLE III
LOW AND FREQUENT BANDWIDTH OSCILLATIONS

Time[s]	0-6	6-13	13-22	22-28	28-35	35-40	40-45	45-60
Bandwidth	1000	1400	1200	900	800	500	400	2000

As Fig. 8 shows, it is hard to notice small changes in a bandwidth. For example, at 6th, 13th and 40th second no significant difference in the flow rate can be seen, since the oscilations in the available link bandwidth are small. For an ilustration: at the 13th second, the bandwidth changed from 1400 down to 1200 Mbps and the average flow rate dropped from 810.26 Kbps to 658.47 Kbps, respectively. However, at 22nd, 35th and 45th second, these jumps are much easier to notice.The most interesting section of the graph is the interval between 45th and 50th second. Since the bandwidth was too low for the flow to be transmitted at at its rate, the incoming queue at the Shaper was filled up to the top. After the bandwidth had suddenly jumped up to 2 Mbps, the queue immediately started to empty itself at almost constant rate (45-49 sec).

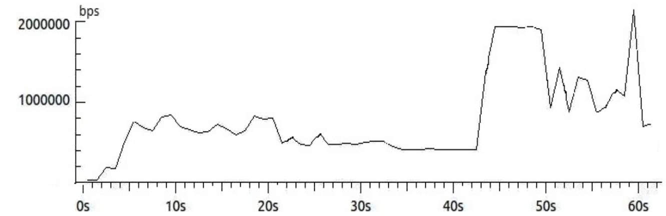

Figure 8. VLC stream graph - More frequent, low link bandwidth oscillation

B.3 Link delay oscilations

In the third case a delay of the link was being changed. We switched between 200 ms, 10 ms and 500 ms, respectively, on a 20 seconds basis. The result is presented on Fig.9. Though it is not noticeable on the graph, the changes of the link delay can be seen on the video itself in a form of glitches and a block effect. These effects last significantly longer when switching from 10ms to 500ms than during the first transition, 200ms to 10ms.

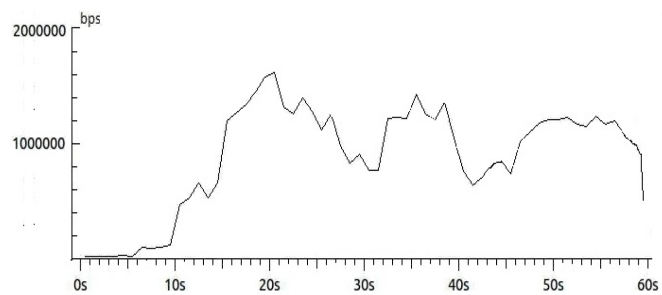

Figure 9. VLC stream graph - link delay variations

C. Experiment 3 - system response time

The final experiment was performed in order to show how fast our system can respond to a link bandwidth change.

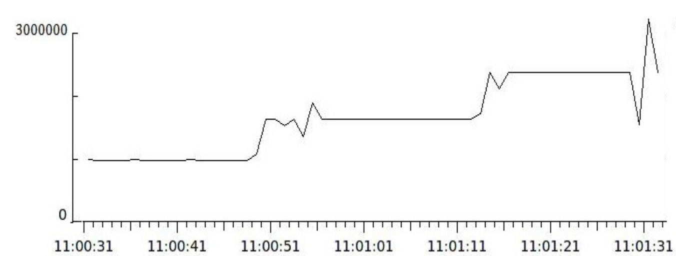

Figure 10. System response time

To make the results as clear as possible we used one UDP flow of a 5Mbps rate and emulated a communication link by changing its bandwidth from 1 Mbps to 1.7 Mbps and finally to 2.5 Mbps. Perl script, used to set up a parameters of the link, also set up time stamps to note down the exact moment when the bandwidth switched from one value to another. The results are depicted in Fig.11. Comparing the values shown on the graph and time-stamp values generated by a Perl script we can conclude the following: Start-up time stamp - T11:00:30 matches the starting time of the experiment. According to following time-stamps, link bandwidth switches occurred at T11:00:50 (1 Mbps to 1.7 Mbps) and at T11:01:14 (1.7 Mbps to 2.5 Mbps). Compared to the values marked on Fig.10, we can see that the system response time is within one second.

V. Conclusion

The basic step, in order to ensure sufficient QoS in the system we proposed, is a proper traffic class differentiation. This concept will ensure, for example, low latency to critical network traffic such as voice or streaming media, while providing simple best-effort service to non-critical services such as web traffic or file transfers.

The next step will be to design a mechanism that will dynamically change the shaping policy according to a current state of the incoming queue, status of a communication link, number of flows and their priorities. These two steps will eventually lead to the main goal and that is to ensure sufficient end-to-end QoS in a volatile environment such as the fast moving train.

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