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An Experimental Study of Ground-Based Equipment Real Time Data Transfer Possibility by Using Cellular Networks

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***Abstract* – An expanding mobile cellular network data transfer service offers cheaper wireless solutions for various data transfer needs. This paper presents an experimental testing of data transfer performance in 3G and 4G modes. The purpose of testing was to check the possibility of real-time and critical data transfer over the mobile cellular networks. The testing was performed in Riga in July and August 2016 using the most popular mobile service operators in Latvia: Tele2-LV, BITE-LV and LMT. The testing confirmed that the overload of Riga's 4G networks causes serious service deterioration or even interruption. Riga's 3G networks are more stable. However, 3G network service quality depends on a cell load. Lightly loaded 3G network meets real-time data transfer requirements of 100 ms one-way delay of the small packet traffic.**

***Keywords* – 3G; 4G; Jitter; Network availability; Network latency.**

I. Introduction

The growing deployment of 3G and 4G technologies and infrastructure of cellular networks enables a variety of new wireless mobile applications. For today, the most popular Latvian mobile service operators (Tele2, BITE and LMT) promise almost full coverage of the territory of Latvia [1]–[3]. While most of the traffic is non-essential data (website access, non-real-time applications such as Facebook and Twitter) which does not require real-time data transfer service, there is a suggestion that cellular network data transfer service can be used for critical and real-time data transmission. We suppose that the cellular network data transfer service can be used to monitor data transfer as well as to transmit various real-time control signals. Therefore, it is crucial to understand the performance indicators of cellular network data transfer service such as network latency and jitter, as well as network availability. The tests were performed in 3G and 4G modes in Riga for Tele2, BITE and LMT cellular network operators.

3G networks are now fully deployed in Latvia. High Speed Packet Access (HSPA) mode comprises two protocols: High Speed Downlink Packet Access (HSDPA) for downlink and High Speed Uplink Packet Access (HSUPA). These are described in Third Generation Partnership Project (3GPP) releases 5 and 6 respectively [4]. The use of Adaptive Modulation and Coding (AMC) schemes in conjunction with Hybrid Automatic Repeat Request (HARQ) technology offers downlink speed up to 14.4 Mbps and uplink speed up to 5.76 Mbps with reduced delays (compared to WCDMA). In an active HSDPA the User Equipment (UE) must send Acknowledgement or Non-Acknowledgment (ACK or NACK) as well as Channel Quality Indicator (CQI) to the NodeB. There is a certain AMC scheme that provides the highest data throughput at a given signal to interference ratio (SINR) [5]. However, if the SINR deteriorates, the BLock Error Rate (BLER) increases significantly. The UE uses CQI to request a certain AMC scheme from the NodeB to operate at the 10 % BLER. Then the lost data packets are retransmitted by the HARQ. One resend add 10 ms typically if the cell is not used by multiple users. The benefit of this approach is that the throughput can be improved by switching to better AMC while the Bit Error Rate (BER) is kept low (typically at the level of 0.1 % [6]). The NodeB is also responsible for immediate ACK of all received packets and their retransmission in case of transmission error. The network Round Trip Time (RTT) is reduced dramatically as the sender receives ACK immediately from the NodeB and can continue to send the next packet because the HARQ will retransmit all lost data.

The next 3G network improvement was done by implementing HSPA+ standard according to 3GPP specification Release 7 [7]. A HSPA+ is sometimes referred to as 3.5G network. It offers up to 28.8 Mbps and up to 11.5 Mbps uplink by using higher order modulation (65QAM) with a multiple input multiple output (MIMO) antenna solution downlink. The simultaneous use of 64QAM modulation and MIMO downlink technology is not possible in Release 7 Its latency value is even more reduced: below 50 ms compared to 100 ms of HSPA. The simultaneous use of MIMO and 64QAM modulation in downlink is implemented in Release 8 and the mode of operation usually is referred as DC-HSPA+.

There is a number of available papers with the live 3G network measurement results [8], [9]. However, the results of these papers are averaged and taken from the best measured values. Such approach helps to reduce the effect of busy cellular and ground network impact, but misinforms about 3G-network service quality under real conditions.

4G network technologies promise excellent performance [10]. However, available scientific papers report that 4G network delays are higher than in HSPA+ network [11]. In spite of that, the testing included both 3G HSPA+ and 4G networks.

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II. Measurement Setup

The UE data packet is transmitted roughly in two stages: using cellular network operator equipment and using ground wired network segment. The cellular network operator equipment implies air interface, NodeB and Radio Network Subsystem (RNS). In the following description, all the above-mentioned will be referred to as “Cellular Network Operator network”.

The ground wired network segment routing is done automatically and the impact of this segment cannot be fully predicted because it depends on many factors as well as on the routing path, which is in use. This segment will be referred to as “Ground Wired network”.

The Ground Wired network cannot be excluded from the testing because its infrastructure enables access to the destination servers or other equipment. On the other hand, the Ground Wired network can cause packet loss. It is not possible to identify where the packet has been lost. To exclude these kind of problems, two endpoints are used. One of them is located in Riga, the other is selected as the Google free DNS server (IP: 8.8.8.8). In this case, if one route does not respond and the other one is still operational, it is possible to conclude that the cellular network operator service is in good condition while the data transmission error is caused by the ground wired segment network.

The use of ACK/NACK packets is usually preferred for the network latency/RTT, jitter and number of packet loss measurements [8], [9]. However, as it was mentioned in Introduction, starting with the requirements of 3GPP specification Release 5, the NodeB is responsible for the immediate acknowledgement of all received packets. This means that the packet retransmissions made by HARQ, if they occur, are not added to the time difference between sending a packet from the dongle and the ACK reception. This is the reason why delays, delay jitter and network availability were measured using a standard Windows “ping” utility [12]. The “ping” reported delay implies the sum of “send” and “reply” message travel time “to and back”. It is known as a round trip time (RTT).

The request message was sent by the computer, which was equipped with the LTE capable mobile broadband USB dongle Huawei E3372h [13]. The Huawei E3372h is a 24th category 3G device which supports 64-QAM modulation and can be operational in dual cell DC-HSPA+ mode and a 4th category 4G device which supports full duplex operation with 20 MHz bandwidth. The dongle specification is shown in Table I.

TABLE I

Characteristics of the Huawei E3372H USB Dongle

Hardware	E3372h
Mode of operation	Hi-Link
Firmware	22.200.09.01.161_M_AT_01
WEBUI	17.100.13.01.03_HILINK_Mod1.2

Three dongles were used to facilitate parallel testing of all three mobile service operators simultaneously. Each mobile broadband USB dongle was attached to the dedicated computer. Computer specification is shown in Table II.

TABLE II

Characteristics of the Computer

Operating System	Microsoft Windows XP Professional SP3
Huawei driver	22.001.26.01.03

Three computers were working simultaneously to measure network parameters of Tele2, BITE and LMT cellular network operators.

The first selected endpoint was the RTU server (IP: 213.175.90.193). The second selected endpoint was the Google free DNS server (IP: 8.8.8.8).

A standard Windows “tracert” utility [14] was used to display both routes (paths) to the first and to the second endpoint. Operational mode of the mobile broadband USB dongles was set to Hi-Link (CdcEthernet). Then the second “tracert” reported hop was made by the mobile broadband USB dongle internal NAT server.

Fig. 1, Fig. 2 and Fig. 3 show the paths for BITE, Tele2 and LMT cellular network operators respectively.

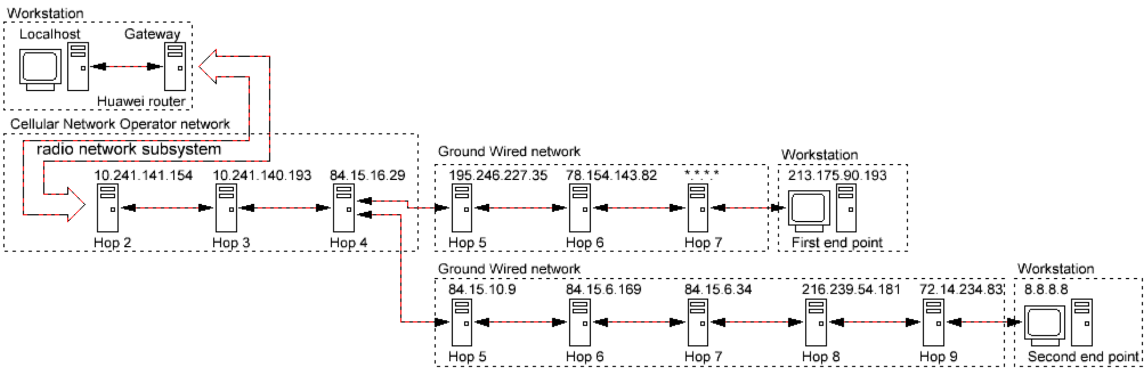

Fig. 1. BITE paths.

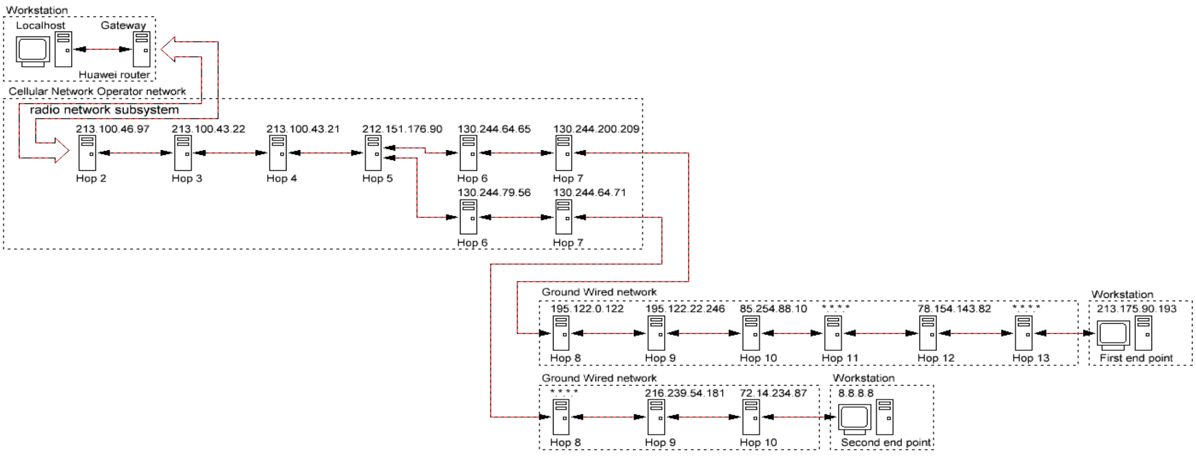

Fig. 2. Tele2 paths.

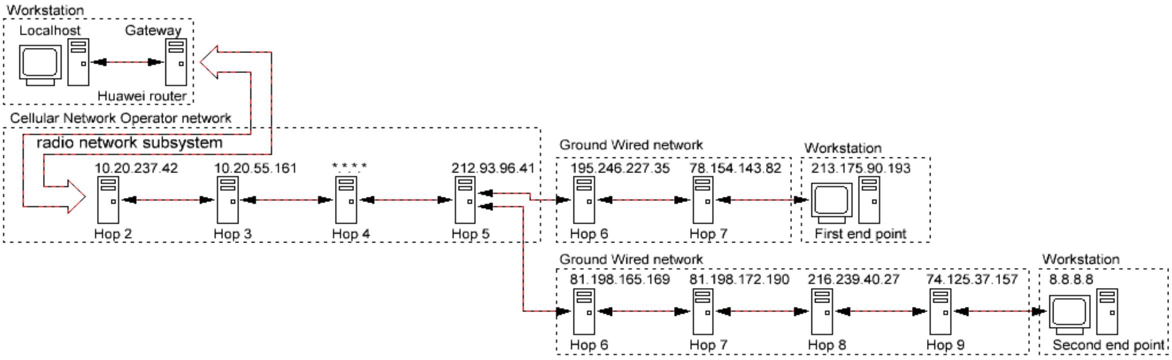

Fig. 3. LMT paths.

The RNS of all cellular network operator networks were defined as Hop 2. The end of the output networks server path, as well as the first and the second endpoint Hop numbers were individual for each operator.

Table III summarizes distinctive points for the following experiments.

TABLE III

DISTINCTIVE POINTS

Radio network subsystem	Operators output network servers	First endpoint	Second endpoint
BITE			
Hop 2: 10.241.141.154	Hop 4: 84.15.16.29	Hop 8: 213.175.90.93	Hop 10: 8.8.8.8
Tele2			
Hop 2: 213.100.46.97	Hop 5: 212.151.176.90	Hop 14: 213.175.90.93	Hop 11: 8.8.8.8
LMT			
Hop 2: 10.20.237.42	Hop 5: 212.93.96.41	Hop 8: 213.175.90.93	Hop 10: 8.8.8.8

The data transfer performance testing was done by running a standard Windows “ping” utility [12]. The “ping” settings are shown in Table IV.

TABLE IV

PING SETTINGS

Send buffer size	32 bytes
Timeout	1 s
Period	10 s
Address	Destination IP
Logging	Text file output

The computers were located in Riga Technical University (RTU) building at Lomonosova 1, k-1. The mobile broadband USB dongles were equipped with randomly purchased SIM cards. The SIM card services are shown in Table V.

TABLE V

CELLULAR NETWORK OPERATORS SERVICES

BITE	“Bite 1”: provide voice, sms and data communications (including 4G service) [15]
Tele2	“Datu plans 5”: provide sms and data communications (including 4G service) [16]
LMT	“Prieksapmaksas mobilais internets”: provide sms and data communications (including 4G service) [17]

The key parameters of the data transfer performance are round trip time (RTT), jitter and network availability.

Round trip time (RTT) can be expressed by (1):

$$RTT = \frac{s}{C_{up} \cdot 10^{-6}} + d_{up} + \frac{s}{C_{down}} + d_{down}, \quad (1)$$

where

RTT	round trip time, s;
s	packet size, bits;
C_{up}	upload speed, Mbps;
C_{down}	download speed, Mbps;
d_{up}	upload delay, s;
d_{down}	download delay, s.

The packet jitter (J) is expressed as an average deviation from the network mean latency and is calculated using (2) described in RFC3550 (RTP) [18].

$$J = \text{average}\left(J(i-1) + \frac{\left(\left|RTT_i - RTT_{i-1}\right| - J(i-1)\right)}{16} \right), \quad (2)$$

where

J	packet jitter or PDV, ms;
i	packet number;
RTT_i	actual packet round-trip time, ms;
RTT_{i-1}	previous packet round-trip time, ms;
16	jitter value averaging.

The network availability (A) can be expressed by (3):

$$A = \frac{S - S_{lost}}{S} \cdot 100, \quad (3)$$

where

A	availability, %;
S	number of sent packets;
S_{lost}	number of lost packets.

III. 4G Network Performance Results

All the following data was obtained in July 2016. Three computers were equipped with the mobile broadband USB dongles and were working simultaneously. The test was performed during a one-week period. To exclude the impact of the ground wired network, the data was obtained only for the operator output network servers. The operator output network servers are shown in Table III.

The signal averaged parameters are shown in Table VI.

TABLE VI
4G Mode

	Technology	RSSI, dBm	RSRP, dBm	RSRQ, dB	SINR, dB
BITE	LTE	–57	–79	–7	17
Tele2-LV	LTE	–63	–92	–10	3
LMT	LTE	–59	–83	–7	4

Figure 4, Fig. 5 and Fig. 6 show the RTT as a function of time. Lost packets are shown as red rhombs on the X-axis.

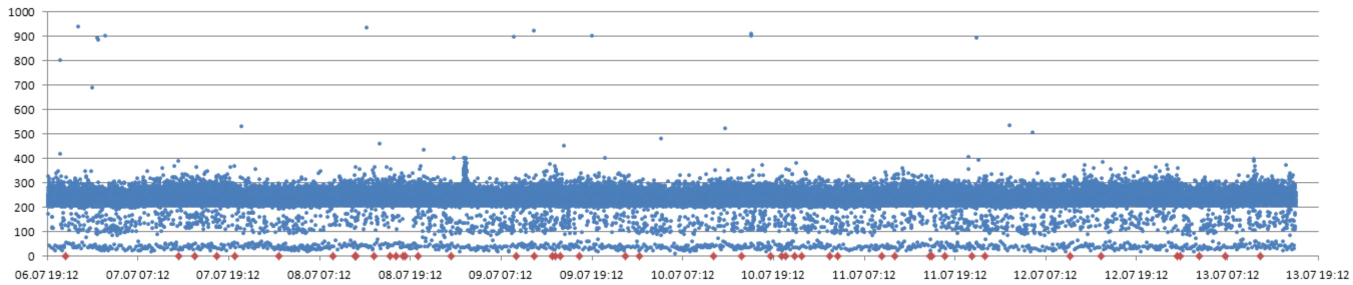

Fig. 4. RTT of BITE 4G cellular network operator subsystem, ms.

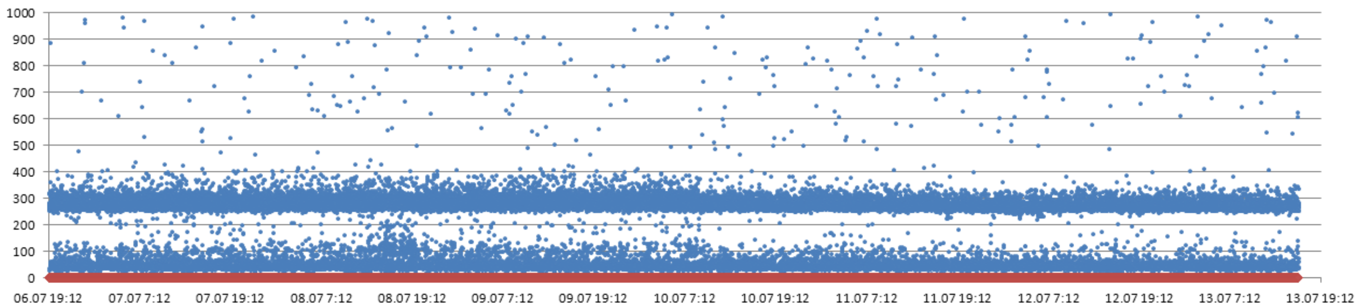

Fig. 5. RTT of Tele2 4G cellular network operator subsystem, ms.

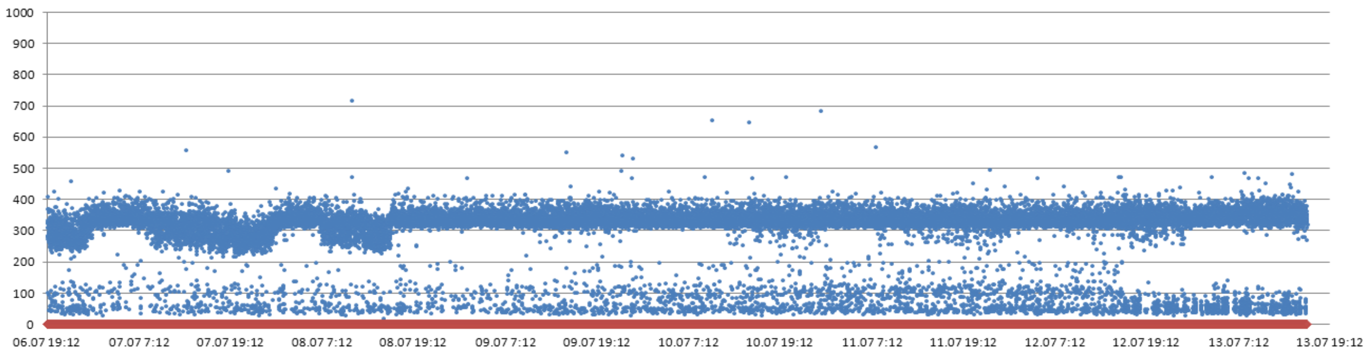

Fig. 6. RTT of LMT 4G cellular network operator subsystem, ms.

The summary for the 4G mode is presented in Table VII.

TABLE VII
4G MODE RESULTS

	Packets send	Packets lost	Average RTT, ms	Jitter, ms	Availability, %
BITE	66 695	51	233.777	31.3756	99.9235
Tele2	62 085	21 113	414.029	412.834	65.9934
LMT	61 240	25 476	520.369	334.119	58.3997

Large number of lost packets as well as high level of packet jitter show that the 4G infrastructure is overloaded in Riga and does not withstand the applied load. A typical 4G mobile broadband USB dongle switches to 3G mode under these conditions. The mobile broadband USB dongles were manually locked in 4G mode during the experiment. It was concluded that the quality of the 4G network service is not stable. It cannot be used for critical data transfer. Therefore, further analysis of 4G network was not performed.

IV. 3G NETWORK PERFORMANCE RESULTS

The results were obtained in August 2016. Three computers were equipped with the mobile broadband USB dongles and were working simultaneously. The test was performed during the working days of a one-week period. The data was obtained for the operator output network servers as well as for the endpoints (RTU server and Google free DNS server). See Table III for more details. Two endpoints were used to exclude the impact of the ground wired network.

The signal parameter mean values for all three mobile network operators are shown in Table VIII.

TABLE VIII
3G MODE

	Technology	RSSI, dBm	RSCP, dBm	E_C/I_O, dB
BITE	DC-HSPA+	–65	–71	–6
Tele2	HSPA+	–53	–60	–7
LMT	DC-HSPA+	–60	–65	–5

Mobile broadband USB dongles of all cellular network operators switch to WCDMA mode if there is no data traffic. The first data packet is always sent in WCDMA mode. As soon as the data traffic is detected, the dongle switches to HSPA+ or DC-HSPA+ mode (depending on cellular network operator). It is impossible to lock the dongle in HSPA+ or DC-HSPA+ modes using the local settings. If there is no traffic for 2 seconds, the dongle switches back to WCDMA mode. As the ping request is being sent every 10 seconds, the mobile broadband USB dongle switches to HSPA+ or DC-HSPA+ and back to the WCDMA mode. To overcome this problem, low-capacity background traffic was used: a pinging of randomly available server was done in a one-second period with 32-byte packet.

The RTT data of the less-loaded 3G cellular network operator subsystem is shown in Fig. 7 as a function of time. Lost packets are shown as red rhombs on the *X*-axis. Their distribution is shown in Fig. 8. The CDF is shown as red squares. The distribution is obtained for three standard deviations (99.7 %).

It is important to consider the impact of the ground wired network segment. The RTT for the first and the second endpoint are shown in Fig. 9 and Fig. 10 respectively as a function of time. Lost packets are shown as red rhombs on the *X*-axis.

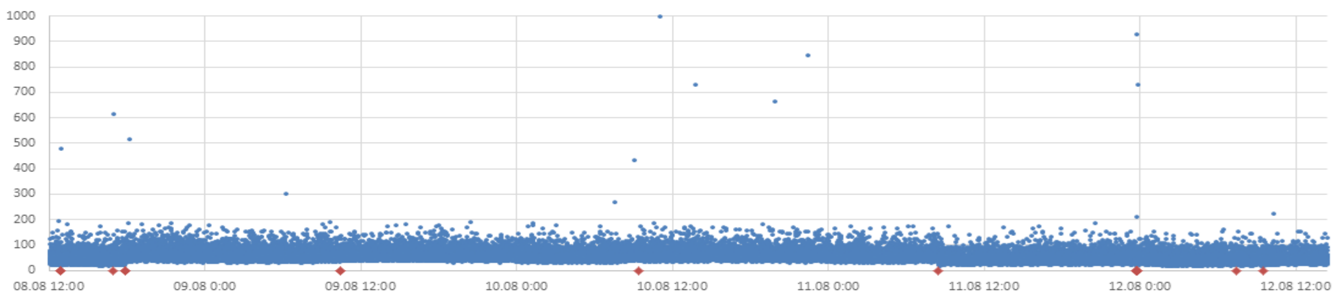

Fig. 7. RTT of lightly loaded LMT 3G cellular network operator subsystem, ms.

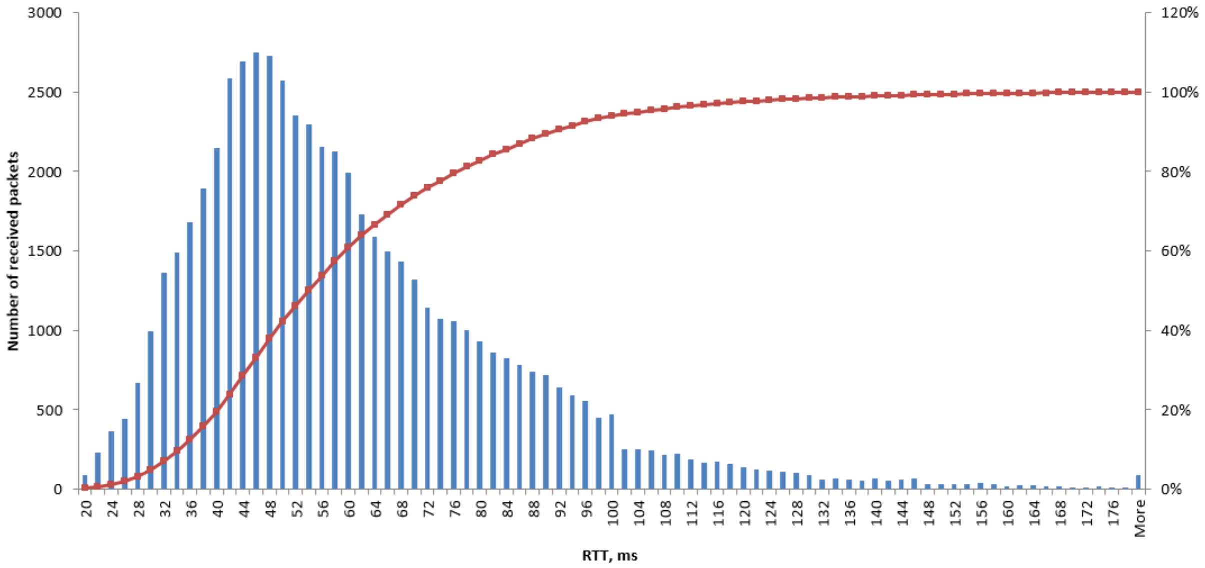

Fig. 8. RTT distribution in lightly loaded LMT 3G cellular network operator subsystem.

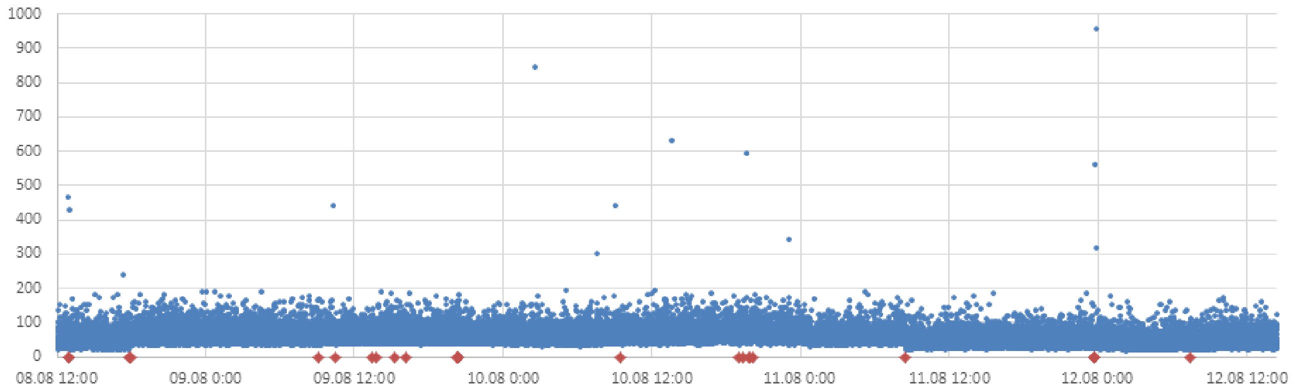

Fig. 9. RTT of lightly loaded LMT 3G first endpoint (RTU server), ms.

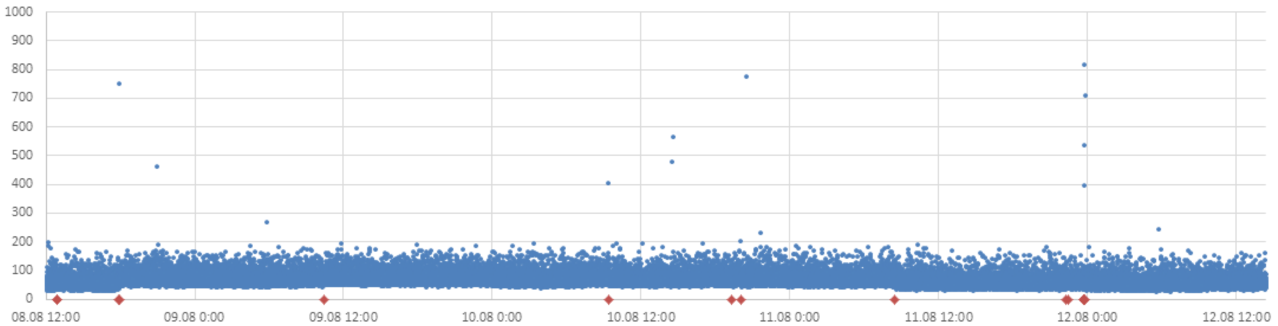

Fig. 10. RTT of lightly loaded LMT 3G second endpoint (Google free DNS), ms.

The results for the lightly loaded 3G mode (Ec/Io = -5dB) are summarized in Table IX.

TABLE IX
LIGHTLY LOADED 3G NETWORK RESULTS

	Packets sent	Packets lost	Average RTT, ms	Jitter, ms	Availability, %
LMT output network server	58 490	30	60.0174	25.3284	99.9487
LMT 3G to the first endpoint	58 488	36	61.1444	61.1444	99.9385
LMT 3G to the second endpoint	58 487	25	70.3126	25.8207	99.9573

The RTT of the heavily loaded 3G cellular network operator subsystem is shown in Fig. 11 as a function of time. The mobile broadband USB dongle is locked in 3G mode and cannot automatically switch to the 2G mode. The cellular network operator chooses 3G operation mode between HSPA+ when the network is not overloaded, and WCDMA when the network is overloaded. Lost packets are shown as red rhombs on the *X*-axis.

The RTT distribution of the heavily loaded 3G cellular network operator subsystem is shown in Fig. 12. The CDF is shown as red squares, PDF is shown as blue columns. The distribution is obtained for three standard deviations (99.7 %).

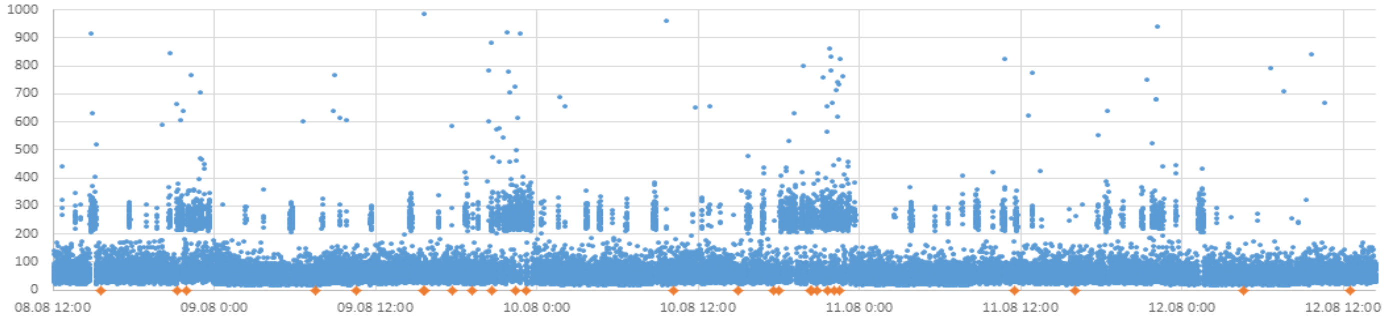

Fig. 11. RTT of heavily loaded Tele2 3G cellular network operator subsystem, ms.

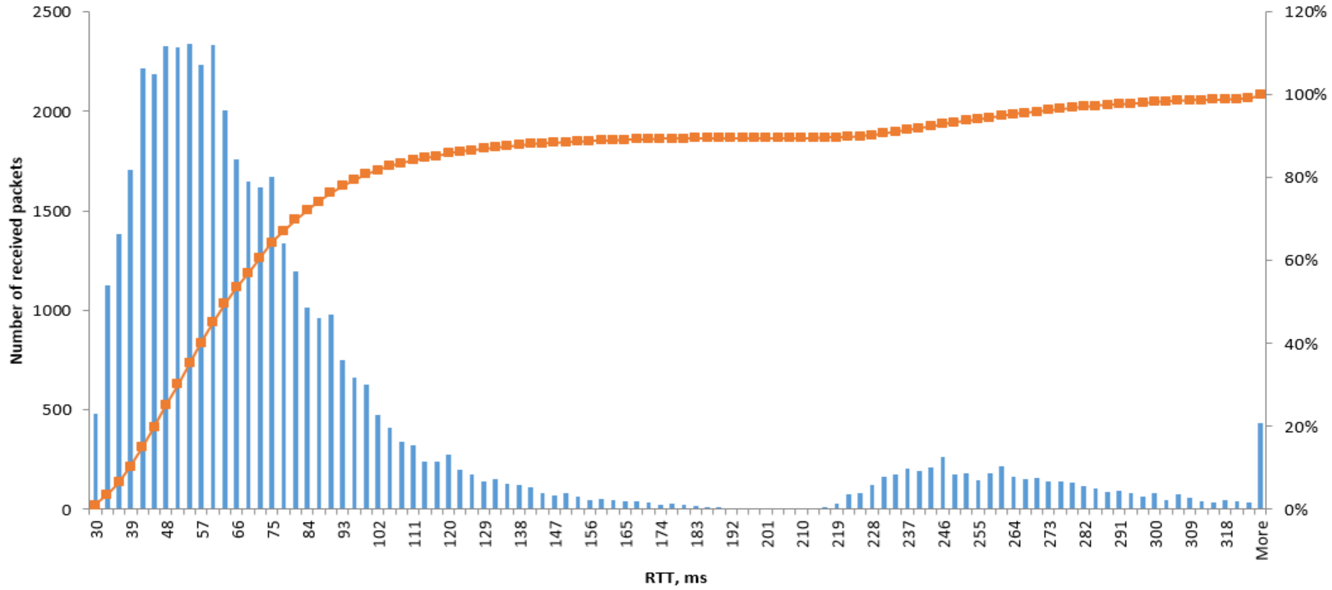

Fig. 12. RTT distribution in heavily loaded Tele2 3G cellular network operator subsystem.

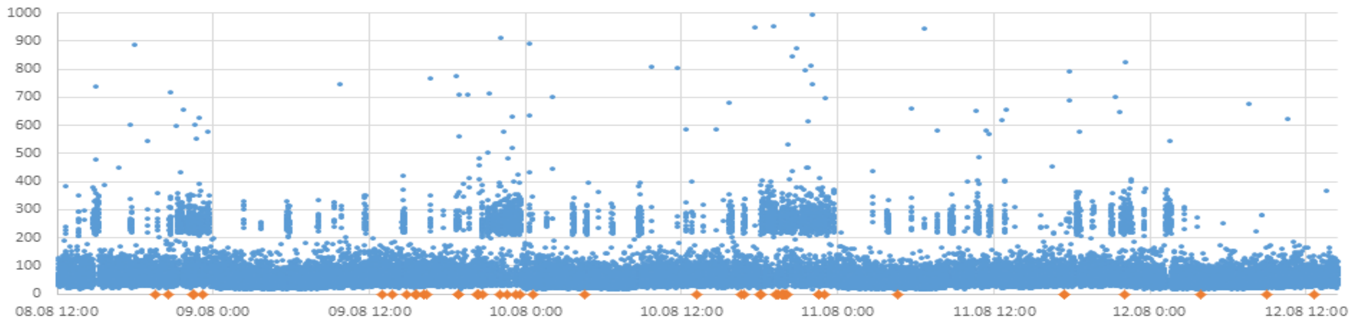

Fig. 13. RTT of heavily loaded Tele2 3G first endpoint (RTU server), ms.

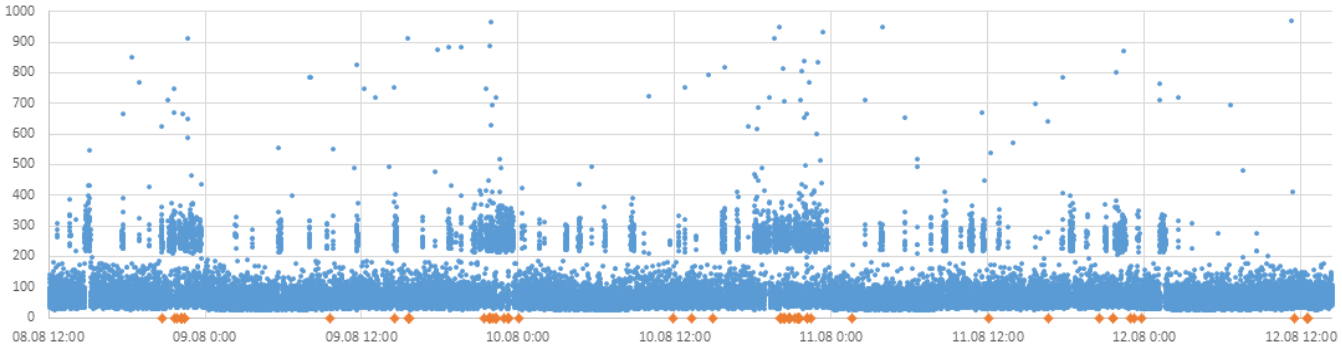

Fig. 14. RTT of heavily loaded Tele2 3G second endpoint (Google free DNS), ms.

TABLE X

HEAVILY LOADED 3G NETWORK RESULTS

	Packets send	Packets lost	Average RTT, ms	Jitter, ms	Availability, %
Tele2 output network server	45 725	33	81.0260	30.5914	99.9278
Tele2 3G to the first endpoint	45 712	59	82.4103	30.4748	99.8709
Tele2 3G to the second endpoint	45 695	58	87.9433	31.3205	99.8731

The results for the heavily loaded 3G mode (*Ec*/*Io* = −6 dB and less) are summarized in Table X.

Typically, the switching between HSPA+ to WCDMA and back can cause one packet loss. Figure 15 and Fig. 16 show the RTT of the heavily loaded 3G cellular network as a function of time with a time delay between modes of operation switching. In this case, the number of switching events is limited. Lost packets are shown as red rhombs on the *X*-axis. Due to the 10-second ping interval, only one packet can be lost during the switching of operation mode while the other will pass. To demonstrate all the lost packets, all three results for the network operator subsystem, first and second endpoints are presented in Fig. 15. Zoomed-in section of Fig. 15 diagram is shown in Fig. 16.

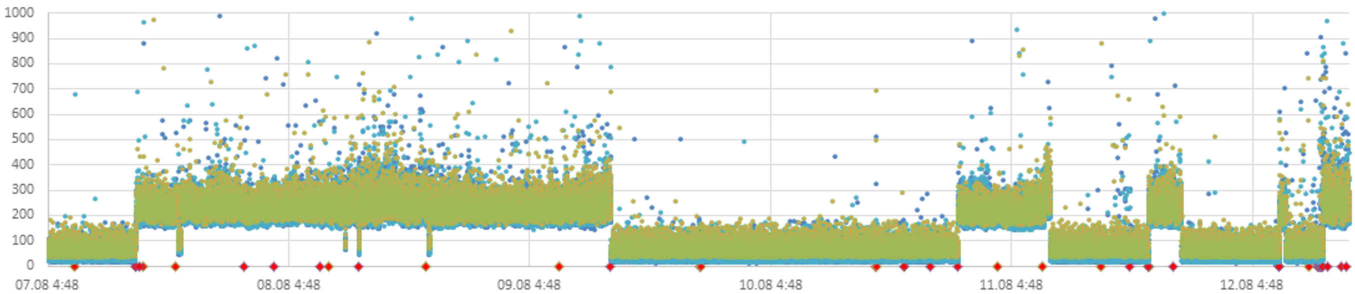

Fig. 15. RTT of all three points of heavily loaded BITE 3G, ms.

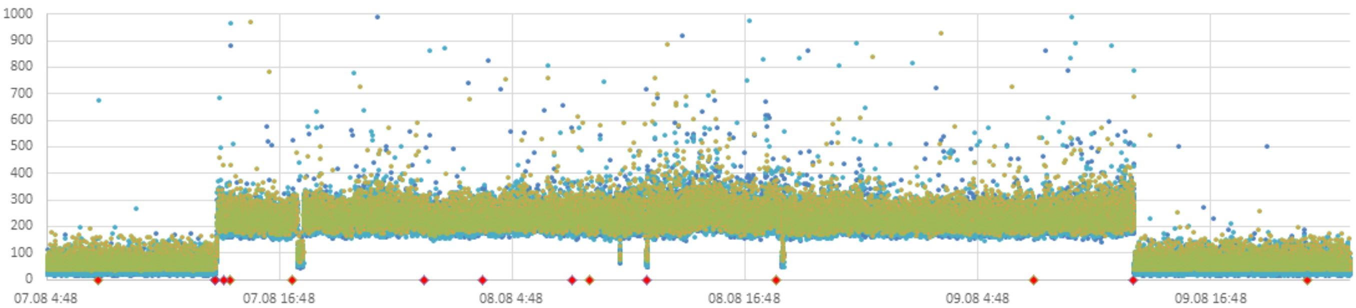

Fig. 16. Zoomed-in part of heavily loaded BITE 3G RTT for all three points, ms.

V. Conclusion

4G networks in Riga are overloaded and their service quality is unstable. In our experiments, the network availability of only one 4G cell is 99.95 %, while the network availabilities of two other cells are 66 % and 58 % only. The RTT mean value is more than 4 times bigger than in HSPA+ mode. Such network technologies promise excellent performance, but in real life, cities 4G cells are overloaded and cannot be used for real-time or critical data transmission.

A lightly loaded 3G network with (E_C/I_O more than –6 dB) has excellent performance for the small packet traffic between the ground wired server and stationary computer equipped with mobile broadband USB dongle. Its RTT (including ground wired network delays) is almost 70 ms and network availability (measured during a one-week period) is more than 99.95 % (see Table IX). It meets real-time data transfer requirements of 100 ms one-way delay for the small packet traffic [19]. It is desirable to keep in mind that the end service quality of data transmission also depends on the quality of service of the ground network segment.

It is worth noting that in our experiments the 3G network minimum RTT value for the 32-byte packet is 20 ms. However, RTT mean value is 70 ms and packet jitter mean value is almost 25 ms. As can be seen from Fig. 7 to Fig. 10, the RTT value is around 70 ms, however, some spikes are noticeable. As the signal strength is almost constant, the AMC scheme should not be changed. Then the RTT jitter is mainly caused by multiple user operation via single shared channel and HARQ system operation. However, we comprehend the RTT value “spikes” as the HARQ multiple retransmissions when the data block is decoded by the receiver using multiple partially corrupted received data blocks.

When the 3G cell approaches its saturation, the mode can be switched to WCDMA. Then the switching between WCDMA and HSPA+ modes reduces network performance because the switching usually comes with a loss of at least one packet (see Fig. 16). In addition, WCDMA mode has worse performance: its RTT value is approximately 4 times greater. In the case of operation in highly loaded network (E_C/I_O drops to less than –7 dB while RSSI is stable), it is hard to foresee the parameters of the network to estimate real-time transfer mechanism of critical data.

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