

High - reliability low - latency cellular network communication solution for static or moving ground equipment control

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Abstract—Implementation of remote equipment data communication channel sometimes is problematic due to the network channel cost or unduly low service quality. An expanding mobile cellular network data transfer service facilitates cheaper wireless solutions for the needs of various data transfer, including mobile ground objects. However, the cellular networks cannot be used in critical and real time data transmission networks due to the unstable and non-predictable service quality. We introduce a Parallel Redundancy Protocol (PRP) as a solution that can be used to facilitate the stationary and moving equipment robust data transfer needs by using the cellular networks. In this research, a software PRP implementation was used to build redundant wireless link without any switchover time at all. Then the service quality in 3,5G networks was experimentally investigated with and without PRP implementation. The testing was done both for stationary and moving ground based equipment. Further, 3G B1 (2100 MHz), 3G B8 (900 MHz) and 4G modes are experimentally investigated to recommending the network mode (or modes combination) selection for the PRP implementation.

Keywords—Wireless communication; 3G; 4G; redundancy; network latency; network availability; jitter; service quality; parallel redundancy protocol

I. INTRODUCTION

The industrial wireless solutions usually are developed within one room. On the flip side of the coin, implementation of the remote equipment data communication channel sometimes is problematic due to the network channel cost or unduly low quality of service. An expanding mobile cellular network data transfer service facilitates cheaper wireless solutions for various data transfer needs, including moving ground objects. The region of operation of moving ground objects is limited to the cellular network operator coverage and can reach hundreds of kilometers in width. This promises a cheap solution with a great operation area.

There are several performance evaluations of 3G and 4G networks in different countries. For example [1] shows performance results for busy cellular networks in Pakistan and

reports more than 1% of lost packets. As the delay of the network depends on the number of users, a lightly loaded cellular network should render a better performance [2]. A lightly loaded 3G cellular network data transfer service in Latvia has good service quality for small packet traffic between the ground wired computer connected to WAN by wired Ethernet and stationary equipment connected to WAN with the cellular modem. It meets real-time data transfer requirements [3] of 100 ms one-way delay for the small packets traffic, but the number of lost packets cast doubt: almost 99.96% of the packets are successfully delivered [4]. The packet loss can be caused by the equipment of the cellular network operator or by failures or overload of the ground wired segment. If the application cannot tolerate with any switchover time at all, there is only one way to combat this problem: two alternate independent active paths should be provided for the same traffic to reach the same destination. A Parallel Redundancy Protocol (PRP) [5] can be used in this implementation.

The PRP uses two independent active paths. The packets are duplicated by a sending node and are transmitted via both paths simultaneously. The first arriving packet is processed, while the second copy is discarded. Therefore, the resulting parallel redundant network latency is equal to minimal value of latency of both networks. In case of a failure of one path, the second path packet backups are processed. In this situation, the parallel redundant network performance is equal to the active path performance.

The advantage of the PRP lies in the possibility to use the existing networks (paths). Furthermore, it is not necessary to use fully identical paths. The PRP protocol is implemented at the sending and receiving nodes, while the data flow structure in the paths is not changed. Also the paths, which are used by the PRP protocol, can be used by other users or services in parallel. This allows the usage of two cellular mobile operators' networks for the parallel redundancy network development. Also different modes services of the same cellular operator can be suitable for this needs. The PRP data traffic usually is not blocked by the cellular network operator.

II. EXPERIMENTAL SECTION

A. The Testbed

The mobile cellular device data packet transmission is done roughly in two stages: cellular network operator equipment and ground wired network segment. The cellular network operator equipment implies a Radio Network Subsystem (RNS), as well output network servers. The RNS and output servers cannot be bypassed. More detailed description about Latvian cellular operators structure can be found in [4]. The ground wired network segment routing is done automatically. The impact of this segment cannot be fully predicted because it depends on many factors as well on the currently used routing. The ground wired network cannot be excluded from testing because its infrastructure enables access to the destination servers. The Google free DNS server (ip: 8.8.8.8) is used as the endpoint in this research. The testing results in [4] shows that the Google free DNS server is more reliable than the RTU server (ip: 213.175.90.193). It should be noted that the use of a different ground wired network endpoint can cause more delayed or lost packets.

Starting with third generation partnership project (3GPP) specifications Release 5 and 6, the hybrid automatic repeat request (HARQ) is implemented in the NodeB to reduce network round trip time (RTT). To even more reduce network, the NodeB is now responsible for immediate acknowledgments of uplink and downlink packets, while corrupted packets are retransmitted automatically by means of HARQ [6]. As the ACK/NACK is sent with NodeB, it makes its arriving time useless as the network RTT measurement parameter. That's why a standard utility "ping" [7] has been chosen as a most suitable and simple measurement tool for the network RTT and its jitter, as well network availability measurements.

The testing is performed for the single and double attached nodes (SAN and DAN) simultaneously. The SAN request message is sent by a dedicated computer which is equipped with mobile broadband USB dongle Huawei E3372h which is LTE capable [8]. The Huawei E3372h specification is shown on Table I. The dongle is equipped with a SIM card of a randomly purchased cellular network operator No.1. The computer specification is shown in Table II.

TABLE I. CHARACTERISTICS OF THE HUAWEI E3372H USB DONGLE

<i>Characteristic</i>	<i>Value</i>
Version of the hardware	E3372h
Mode of operation	Hi-Link (CdcEthernet)
Firmware	22.200.09.01.161_M_AT_01
WEBUI	17.100.13.01.03_HILINK_Mod1.2

TABLE II. CHARACTERISTICS OF THE SAN COMPUTER

<i>Characteristic</i>	<i>Value</i>
Operating system	MS Windows XP Professional SP3
Huawei driver	22.001.26.01.03

The DAN is provided by using two dongles which are attached to another dedicated computer. Both dongles are equipped with SIM cards of a randomly purchased operator No.1 and operator No.2. The PRP is implemented as a software sub-layer of the operating system. The solution is entirely transparent to the application and network. A PRP-1 User Mode Stack is used [9]. It requires two independent network cards that should be attached to the computer. The dongles operate in Hi-Link mode and provide the virtual network cards (NDIS) which can be used by the PRP1 User Mode Stack software. The PRP is implemented in PRP-1 User Mode Stack software and provides its virtual network device.

The dongles specification is shown on Table I. The computer specification is shown in Table III.

TABLE III. CHARACTERISTICS OF THE DAN COMPUTER

<i>Characteristic</i>	<i>Value</i>
Operating system	Gentoo Linux (01.2017)
Huawei driver	22.001.03.01.03
Software PRP solution	PRP-1 User Mode Stack 1.0

B. Static Ground-Based Equipment Network Performance

The SAN and DAN computers are located in a relatively busy cellular network segment in the building of the institute at 1 Lomonosova, Riga. The test is performed within a 4 day period. We decide to use 3G mode because the testing results in [4] shows that the 4G network service quality is not stable. All three dongles are manually locked in 3G mode while B1 / B8 mode selection is done automatically by the dongle operating system. The actual signal parameters are shown in Table IV.

TABLE IV. 3G MODE FOR THE STATIC SAN AND DAN COMPUTERS

<i>Operator</i>	<i>Technology</i>	<i>RSSI, dBm</i>	<i>RSCP, dBm</i>	<i>Ec/Io, dB</i>
Nr.1	DC-HSPA+	-82	-88	-6
Nr.2	DC-HSPA+	-79	-83	-4

It should be noted that all cellular network operators switch cellular modems in WCDMA mode in the lack of data traffic. The first data packet is always sent in WCDMA mode. Once the data traffic has been detected the mobile broadband USB dongle is switched to HSPA+ or DC-HSPA+ mode (depends on the cellular network operator). It is impossible to lock the mobile broadband USB dongle in HSPA+ or DC-HSPA+ modes by the local settings because the mode of operation is defined by the cellular operator. Typically, if there is no traffic in 2 sec period, the mobile broadband USB dongle is switched back to the WCDMA mode. As the ping request is sent one per second in 32 kB packets, the dongle should always stay in DC-HSPA+. However, a short - term loss of communication can cause switching back to WCDMA mode. WCDMA mode RTT typically is 5 times greater than in the HSPA+ or DC-HSPA+ modes.

The RTT values for the SAN during 4 - day testing period is shown in Fig. 1. The RTT (an either-direction, in ms) in time is a blue curve; the lost packets are shown by the red vertical lines stemmed from the X axis.

The RTT values for the DAN are shown in Fig. 2. The RTT (an either-direction, in ms) in time is a blue curve; no packets are lost.

Summary of the experiment is shown in Table V. The packets with RTT exceeding 1000 ms are considered as lost. The packet jitter is expressed as an average of the deviation from the network mean latency and is calculated according to RFC3550 (RTP) [10].

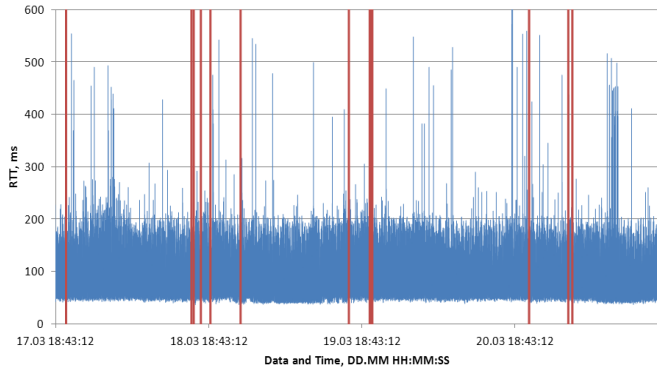


Fig. 1. Static SAN RTT values in 3G

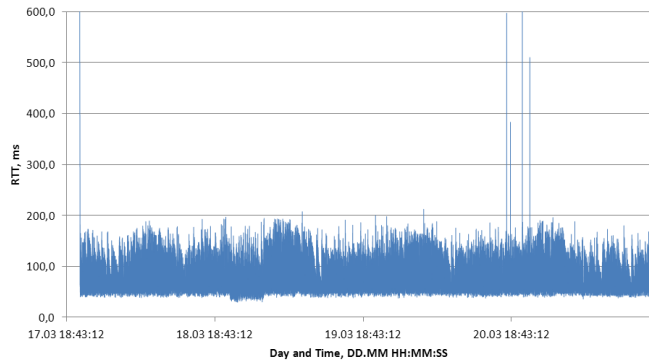


Fig. 2. Static DAN RTT values in 3G (PRP is used)

TABLE V. STATIC GROUND EQUIPMENT TESTING RESULTS IN 3G

	<i>Packets sent</i>	<i>Packets lost</i>	<i>Average RTT [ms]</i>	<i>Jitter [ms]</i>	<i>Availability [%]</i>
SAN	318017	30	86,0254	22,8226	99,990567
DAN	313394	0	74,0388	15,5169	100,000000

The DAN RTT value is smaller, because only the first arrived packet is processed, while the second is discarded. The jitter value is also decreased for the same reason.

C. Moving Ground-Based Equipment Network Performance

The SAN and DAN computers are located in a car. The car average speed is 95 km/h. The experiment is performed far away from busy cellular networks of Riga, so the networks of both cellular operators No.1 and No.2 are lightly loaded. All three dongles are locked in 3G mode while the B1 / B8 mode selection is done automatically by the dongle operating system. The actual signal parameters depend on the position and cellular operator coverage.

Network operators switch cellular modems in WCDMA mode if there is no data traffic. Once the data traffic has been detected, the mobile broadband USB dongle is switched to HSPA+ or DC-HSPA+ mode (depends on the cellular operator). Typically, if there is no traffic in 2 sec period the mobile broadband USB dongle will be switched back to the WCDMA mode. As the ping request is sent one per second in a 32 kB packet, the dongle should always stay in DC-HSPA+. However, a short-term loss of communication can cause switching to WCDMA mode. WCDMA mode RTT typically is 5 times greater than in the HSPA+ or DC-HSPA+.

The RTT values for the SAN are represented in Fig. 3. The RTT (in either-direction, in ms) in time is a blue curve; lost packets are shown by the red squares on the X axis.

The RTT values for the DAN are represented in Fig. 4. The RTT (in either-direction, in ms) in time is a blue curve; there are no lost packets.

Summary of the testing is shown in Table VI. The packets with RTT exceeding 1000 ms are considered as lost. The packet jitter is expressed as an average of the deviation from the network mean latency and is calculated according to RFC3550 (RTP) [10].

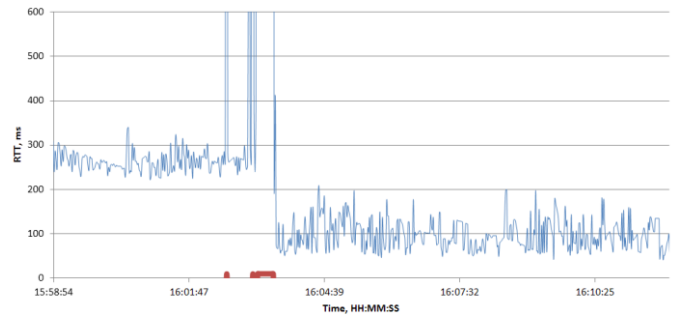


Fig. 3. Moving SAN RTT values in 3G

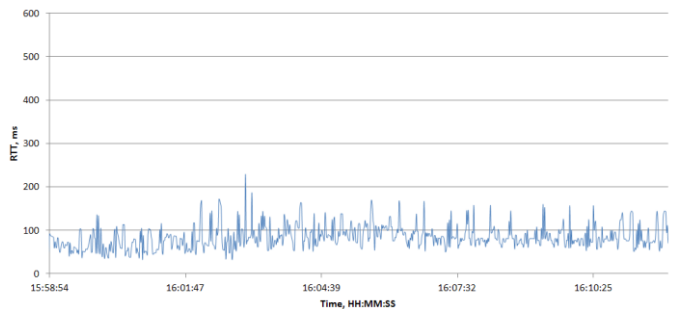


Fig. 4. Moving DAN RTT values in 3G (PRP is used)

TABLE VI. MOVING GROUND EQUIPMENT TESTING RESULTS IN 3G

	Packets sent	Packets lost	Average RTT [ms]	Jitter [ms]	Availability [%]
SAN	752	13	147,968	29,6875	98,271277
DAN	802	0	85,0711	27,5000	100,000000

The SAN is using SIM card of the cellular operator No.1. Cellular modem does not receive the command from the cellular operator to switch to the DC-HSPA+ and remains in WCDMA mode of operation for the first half of the period. This situation happens scarcely ever. Then the coverage by the operator No.1 is not sufficient in the middle of travelling and the data transmission aborts. All further packets are lost. When the second cell with sufficient signal strength is available, the cellular modem reestablishes the data link, receives a command to switch to DC-HSPA+ mode and continues its operation. More detailed information about 3G network lost packets in motion can be found in [11].

The DAN is using both cellular operators No.1 and No.2 3G services. The second operator has sufficient signal strength in the middle of traveling and replaces disconnected service of the operator No.1. For the given period the RTT values become slightly increased, because “the first arrived packet is processed, the second is discarded” does not work here due to the loss of connection of the cellular operator No.1.

PRP effectively resolves loss of connection of the cellular operator No.1 and no packets are lost. Hence, the data link recovery time is equal to zero.

D. Redundant Network Selection

The best solution is to use the services of different cellular operators as is shown in B and C subsections of the Experimental Section. Typically, their cells have different coverage. However, sometimes two different cellular network operators cannot be used due to many reasons: awarded contract with a single operator, single operator’s service in the given area, etc. The following experiments are done to find alternatives on two 3G networks to build a redundant network.

Alternative possibilities are: same cellular operator 3G different bands (B1 2100 MHz and B8 900 MHz) or single cellular operator 3G and 4G cells combination.

Two SAN computers are located in a car to test a 3G performance in B1 and B8 modes. Each computer is equipped with one cellular modem dongle. Each dongle is equipped with operator No.1 SIM card. The first computer’s cellular modem is manually locked on 3G B1 (2100 MHz), the second is manually locked on 3G B8 (900 MHz). Both computers are working simultaneously by sending a 32 kB ping request once a second. The following illustrations show an RTT for both modes.

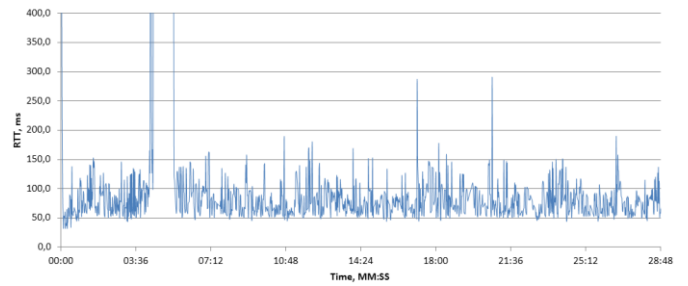


Fig. 5. Moving SAN RTT values in 3G B1 (2100 MHz) mode

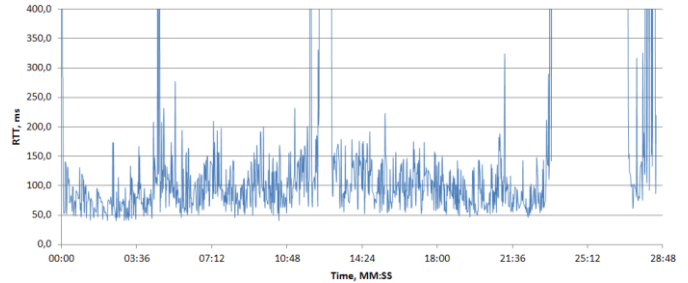


Fig. 6. Moving SAN RTT values in 3G B8 (900 MHz) mode

The 3G B1 mode has better RTT values than 3G B8. Also, 3G B1 RTT values are more stable with a smaller packet jitter. When the 3G B1 communication is lost due to unacceptable low signal strength, 3G B8 is still able to work. When 3G B8 communication is lost, 3G B1 is still able to work. This means that the DAN can be realized by using network from the same operator operating in 3G B1 and 3G B8 modes.

The second possible solution is the use of 3G and 4G combination to build a DAN. Now a cellular modem dongle with SIM card operator No.1 is located in a car. The cellular modem is manually locked in 4G mode. The car travelling testing route is similar with the results displayed in Fig. 3.

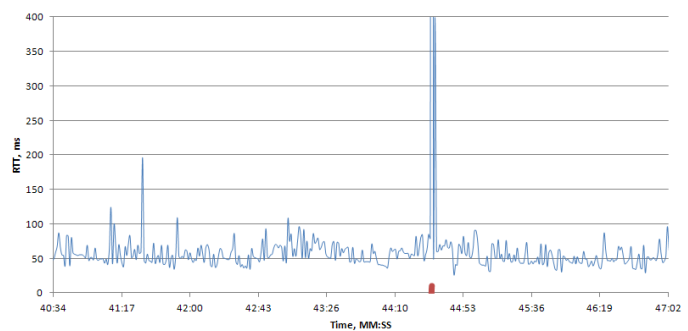


Fig. 7. Moving SAN RTT values in 4G mode

The RTT values for the SAN operating in 3G B1 mode are shown in Fig. 3. The RTT (in either-direction, in ms) in time is a blue curve; lost packets are shown by the red squares in the X axis.

The RTT values for the SAN operating in 4G mode are shown in Fig. 7. The RTT (an either-direction, in ms) in time

is blue curve; lost packets are shown by the red squares in the X axis.

Both 3G B1 and 4G of the same cellular operator connections are lost at the same point of travelling due to low signal strength. 4G RTT values are smaller than 3G B1. Also in 4G there is no problem with WCDMA – HSPA+ switching. But in a contrast, 4G service is less stable than 3G [4], [12].

III. CONCLUSION

A 3G/4G cellular redundant wireless network with a zero recovery time can be made by using a PRP.

The 3G network DAN RTT is decreased by 15% approximately compared with SAN. The jitter value is decreased by 30% approximately. A network availability is increased significantly (none of 313 hundred packets were lost by PRP in contrast with 0.0094% in a case of a single 3G network usage). A combination of two 3G cellular operators' services should be used to build a very stable redundant solution. As cellular operators' output network servers infrastructures are replicated one another, the reliability of the system is increased. The use of two different cellular operators helps to separate part of the ground wired segment due to the separate location of the operators' ground wired servers. However, the final wired segment reliability is not increased. This solution is suitable both for static and moving ground based equipment.

The benefit of different cellular operators' 3G and 4G services combination is much more reduced packets delays. This solution is also suitable both for static and moving ground based objects. The disadvantage is that 4G service is less stable than 3G and usually is less deployed in sparsely-populated areas. In a case of 4G inoperative service, all payload data will be transmitted thru the single 3G. This will reduce reliability of the network in general. Such solution gives 4G network performance with reliability higher than single 3G network. This solution is suitable both for static and moving ground based equipment. However, 4G cells coverage in the area of interests should be taken into account.

The use of 3G and 4G services of a single operator simultaneously is reasonable only if it is necessary to reduce the packet delays, but an unstable 4G service quality does not satisfy the requirements and no services of other cellular operators are available. In this case, the cellular network operators' output network servers' infrastructure is not duplicated and replication does not exist. It will affect on the system reliability. The advantage lies in the 4G network performance with 3G network reliability. This method is mostly applicable to the static ground based equipment only.

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The use of 3G B1 and 3G B8 services of a single operator simultaneously is reasonable only if the ground based equipment is moving and only one cellular operator is available. This solution gives 3G B1 mode performance. Operators' output network servers are also not replicated, but the network coverage is increased.

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