Journal of Modern Technology & Engineering
Vol.3, No.1, 2018, pp.63-74

CELLULAR NETWORKS SELECTION FOR THE REMOTE CONTROL VEHICLES' CONTROL CHANNEL SETUP WITH PARALLEL REDUNDANCY

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Abstract. A lightweight Remote Control Vehicles (RCV) operation range is limited by the wireless communication link capabilities. Expanding mobile cellular network data transfer services facilitate cheaper wireless solutions for various data transfer needs. However, cellular data transfer services performance and availability are not sufficiently stable to be able to operate in near to real-time remote-control applications. The parallel redundancy can be implemented here to significantly increase cellular data transfer service reliability. The aim of this research is to specify better combination of cellular data transfer services to build redundant link solution for the moving ground equipment. It has been found that the best cellular data transfer services combinations are different for the dense cities and uderpopulated rural areas and must be discussed separately.

Keywords: *wireless communication, LTE, 3G, moving equipment, RCV, parallel redundancy*.

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Manuscript received: *17 January 2018*

1. Introduction

A Remote Control Vehicles (RCV) remotely piloted operations are beyond the Radio Line-Of-Sight (LOS) distance. The LOS distance for the RCV is within several hundred meters only. The actual communication range sometimes is much less due to the regional morphology limitations, as hills or buildings. Utilized radio spectrum and safety regulatory standards also should to be taken into account when communication link is developed (Paredes & Ruiz, 2014). The growing deployment of 3G and 4G technologies and well-developed cellular network infrastructure is enabling a variety of new, ready to use wireless mobile applications. For today, Latvian most popular mobile cellular service operators (Tele2, BITE and LMT) promise almost whole coverage of the Latvia territory (Bite.lv, 2016; Lmt.lv, 2016; Tele2.lv, 2016). A 3G and LTE services enable a new wireless datalink solution for the RCV which is mainly limited by the mobile cellular network coverage.

For today, both 3G HSPA+ / DC-HSPA+ and LTE networks are deployed in Latvia. A 3G HSPA+ standard according to 3GPP specification Release 7 (Holma *et al.*, 2007) utilizes multiple input multiple output (MIMO) antenna solution downlink and higher order downlink modulation 64QAM, but these benefits cannot be used simultaneously (Kottkamp, 2012). The uplink MIMO in the 3GPP Release 7 is not supported. The maximum data rate depends on the User Equipment (UE) categories: up to 28 Mbps downlink is possible with Categories 16 and 18. This technology promises downlink latency below 50 ms for the radio link.

Starting from 3GPP specification Release 8 both downlink MIMO and 64QAM modulation can be used simultaneously, forming Dual Carrier mode (DC-HSPA+). The UE must be Category 19 or 20 device to be able to work with maximum downlink speed of 35.28 Mbps or 42.20 Mbps respectively in DC-HSPA+ mode. 3GPP release 8 UE allows to build tuned outdoor or indoor solutions and isolated cell scenarios.

A 3GPP Release 9 specification allows dual cell operation in dual band (DB-DC-HSDPA mode). The simultaneous use of 64QAM, MIMO and Dual Cell increase uplink speed up to 84.40 Mbps for the UE Category 27/28.

The key goals of Long Term Evolution (LTE) network development is to get higher downlink speeds; achieve better spectrum utilization; and to decrease network latency. The LTE technology is implemented both in 3G and 4G networks.

The UMTS Long Term Evolution (LTE or 3G LTE) technology was introduced in 3G in 3GPP Release 8 (Astély *et al.*, 2009). Starting from this point, HSPA+ and 3G LTE technologies grew in parallel. 3G LTE is also referred to as E-UTRA (Evolved UMTS Terrestrial Radio Access) or E-UTRAN (Evolved UMTS Terrestrial Radio Access Network). The key difference between 3G LTE and conventional 3G HSPA+ is the use of a more spectrum- efficient Orthogonal Frequency-Division Multiple Access (OFDMA) for the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in uplink. Flexible bandwidth setting from 1.4 and up to 20 MHz is also possible in LTE, while conventional 3G HSPA+ is operating at fixed 5 MHz bandwidth. The UE LTE Categories from 1 to 5 are specified in 3GPP Release 8 and meet 3G LTE requirements (Gessner *et al.*, 2008). The most typical 3G LTE UE type is LTE Category 4 with maximum (peak) downlink and uplink speeds of 151 Mbps and 51 Mbps respectively at 20 MHz channel bandwidth. This technology promises even more reduced downlink latency below 10 ms for the radio link. The use of eNodeB base station instead of NodeB makes 3G LTE incompatible with existing 3G cells and requires additional LTE cells to be deployed and frequency bands to be assigned.

A LTE-Advanced (LTE-A) was officially introduced in 3GPP Release 10. The LTE-A is an acknowledged 4G technology (Roessler *et al.*, 2013). LTE-A supports simultaneous multiple carrier usage (Carrier Aggregation or CA) in downlink and uplink; and 2 by 2, 4 by 4 or 8 by 8 MIMO. A 6, 7 and 8 LTE Categories are covered in 3GPP Release 10. The most typical 4G LTE (LTE-A) UE type is LTE Category 6 with maximum data rates of 300 Mbps and 50 Mbps in downlink and uplink respectively. The LTE Cat 6 supports CA only in downlink and up to 2 carriers can be used simultaneously.

Both 3G HSPA+ (or DC-HSPA+) and 3G LTE utilize Adaptive Modulation and Coding (AMC) schemes and Hybrid Automatic Repeat Request (HARQ) technology. The UE uses Channel Quality Indicator (CQI) based on Signal to INterferece Ratio (SINR) to request a certain AMC scheme from the NodeB or eNodeB in order to operate at the 10 % BLock Error Rate (BLER). This is done to increase data transfer speed at low SINR. Then the lost data blocks are retransmitted by the HARQ and the Bit Error Rate (BER) is kept low (typically at the level of 0.1 % (Kottkamp, 2012)). One resend operation typically adds 10 ms, if the cell is not used by multiple users (Jurvansuu *et al.*, 2007). This approach helps to improve data throughput at the expense of higher jitter and relatively high BER of 0.1% (Stuhlfauth, 2012). Also, the NodeB and eNodeB are responsible for immediate ACKnowledgement (ACK) of all received packets and their retransmission in case of transmission error.

The key benefit of the cellular data transmission service is to support UE mobility. This is done by synchronizing carriers to exclude Doppler shift caused by UE ground speed radial component with respect to the ground base station. The UE transition from one base station to the next one is done transparently with respect to the data flow (so called soft-handover). The cell search, selection and reselection is good explained in (Roessler, 2009) and is not discussed here.

The idea of cellular data transfer usage in RCV or Unmanned Air Vehicle (UAV) control channel development is not new. However, such implementations use cellular data transfer service "as is" (Santos *et al.*, 2017; Yamamoto *et al.*, 2014). This leads to several problems, such as short-time increased network latency or data transfer interruption. This limit the use of cellular data transfer services in such applications or makes such implementations more complex because data temporary storage and retransmission mechanisms should be used.

Mainly data transfer quality is affected by signal strength, high UE speed and angular position elevations as well selected cell load. The signal strength mainly depends on distance between base station and UE, as well regional morphology, as hills or buildings may cause shadows for the radio signal path. If the UE is moved fast, the signal strength can be rapidly changed. In this situation it is impossible to set optimum AMC and the BLER can be increased very quickly. Failed blocks will be retransmitted by the HARQ, what will cause increased latency and jitter values (Tso *et al*., 2012). At the same time, cell overload, 3G cell mode transmission between UMTS and HSPA+ or temporary signal loss due to the shadows cannot be compensated at all. Considering target of 10 % BLER and, as a result, increased jitter and lost packets, a 3G, 3G LTE and 4G LTE-A networks are not suitable for critical and real-time data transmission applications (Brodnevs & Kutins, 2017).

Regardless non-thrusted data transmission, cellular networks offers cheap alternative to build wireless solution for lightweight RCV remote control from any part of the world.

In our experiments we suppose that the RCV control terminal will be connected to the wired ethernet. An IEEE Std 802.3 defines that for the 100 Mbit Ethernet BER should not be more than 1e-10 and for the 1000 Mbit Ethernet BER should not be more than 1e-12 (IEEE Computer Society, 2012). This makes wired Ethernet extremely safe compared with cellular data transmission service with BER of 1e-4 (Stuhlfauth, 2012).

The cellular network data transfer service BER can be improved by using two cellular operators' services simultaneously. The idea is to send simultaneously two identical packets over two different cellular operators services to increase air interface availability, while more trusted ethernet path may not be duplicated.

The Parallel Redundancy Protocol (PRP) (IEC, 2016) is an IEC standard that is used to build redundant industrial ethernet solutions for the critical applications that cannot tolerate with packet losses and require hitless network. The PRP sends identical packets via two independent paths (networks). The key benefits of PRP are the ability to use paths with identical protocol but with different topology, as well as transparent operation for the network equipment. As PRP operation is transparent for both paths, its traffic usually is not blocked by the network equipment (Rentschler & Heine, 2013). On the receiving side first arriving packet is processed and second (its duplicate) is discarded. As a result, PRP promises fail-safe data transfer with zero-time recovery in case of a single path failure; as well decreased data transfer service latency and jitter values if both paths are in operation.

To implement PRP, the node must be connected to two different networks with same protocols. Such node name is Dual Attached Node (DAN). Both networks can be still accessible by other equipment, called Single Attached Nodes (SANs). Simplified PRP network structure is represented in Fig. 1.

The use of PRP protocol enables possibility to send identical packets via two cellular operator services. In the presented solution the DAN should be equipped with two cellular modems (dongles). Both dongles can operate in same or different data transfer modes (eg 2G, 3G, LTE) and in same or different frequency bands. This provides wireless path duplication, while final wired segment duplication depends on cellular operators ground wired segments locations and topologies. Typically ground wired segment will be partially duplicated. Typical cellular networks redundant solution topology is represented on Fig. 2. A more detailed explanation of Latvian cellular operators subsystem structure can be found in (Brodnevs & Kutins, 2017).

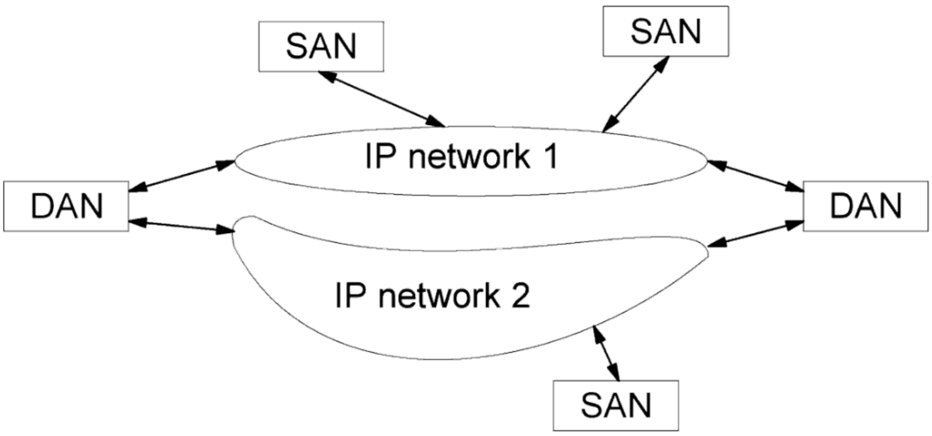

Figure 1. Simplified structure of the PRP network

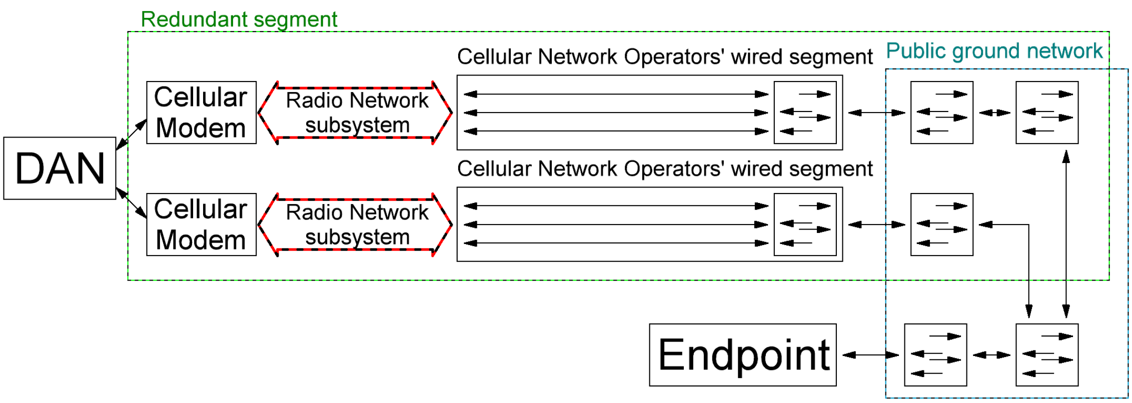

Figure 2. Structure of the redundant network implemented on two different cellular operators' networks

An application example of redundant cellular network solution for the ground equipment remote control can be found in (Brodnevs & Bezdel, 2017). However, the choice of 3G / LTE networks was not sufficiently motivated. The aim of this research is to specify better combination of cellular data transfer services to build redundant link solution for the moving ground equipment both in well-populated and rural areas.

2. Experimental Section

2.1. The testbed

To reduce possible impact of ground wired network failures, a Google free DNS server (ip: 8.8.8.8) is used as a more trusted endpoint (Brodnevs & Kutins, 2017). All experiments were done to both SAN and DAN simultaneously.

The request messages are sent by the portable computer which is equipped with three mobile broadband USB dongles Huawei E3372h. The Huawei E3372h is Cat 24 device which can operate in 3G dual cell DC-HSPA+ mode; and LTE Cat 4 device which, in addition, supports 2 CA in downlink up to 150 Mbps. By default, its operational mode is HiLink (CdcEthernet). Two dongles are used to build DAN, while the third one is used to build SAN. All dongles are running HiLink (CdcEthernet) software (version 22.200.09.01.161_M_AT_01). In this mode dongles operate as NAT servers (default gateway ip: 192.168.8.1) and emulate its virtual 150 Mbps network cards (NDIS) on the local computer. Please note that dongles gateway IP addresses must be manually configured to different addresses to be able to operate simultaneously.

The portable computer is running Gentoo Linux with 64 bits kernel version 4.9 assembled in 01.2017. To be able to operate with flip-flop device Huawei 3372h an usb_modeswitch version 2.4.0-r1 is used.

The first two dongles are equipped with randomly purchased cellular operator Nr.1 and Nr.2 SIM cards. These dongles are used to build DAN. The DAN is created by implementing PRP as a software layer. A PRP-1 User Mode Stack software solution is used (ZHAW Institute of Embedded Systems InES, n.d.). The third dongle is equipped with randomly purchased cellular operator Nr.1 SIM card and represents SAN.

As NodeB (and eNodeB) is responsible for immediate uplink and downlink packets acknowledgement, an ACK packet arriving time cannot be used to estimate overall network Round Trip Time (RTT). That's why the network RTT is measured by using ping utility from iputils package version 20161105. Ping's ICMP packets are not acknowledged by the NodeBs and its receiving delays represents overall network RTT values.

The ping request period is 1 sec, timeout is 1 sec and ICMP packet size is 32 bytes. Please note that mentioned above ping utility version does not reports lost packets by default. The ping timeout, packet size, interface name and enabled lost packets report was specified by corresponding command attributes.

Network round-trip time (RTT) is expressed in Eq.(1) and represents a time delay in an either-direction "from the source to the destination and back to the source".

$$RTT = \frac{s}{C_{up} \cdot 10^{-6}} + d_{up} + \frac{s}{C_{down}} + d_{down} \tag{1}$$

where RTT is round-trip time, sec; s is packet size, bits; C_{up} is upload speed, Mbps; C_{down} is download speed, Mbps; d_{up} is upload delay, sec and d_{down} is download delay, sec. It should to be noted that all the following RTT data represents an either-direction "from the source to the destination and back to the source".

The packet jitter (*J*) is expressed as an average deviation from the network mean latency and is calculated using Eq.(2) described in RFC3550 (IETF, 2003).

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

where J is packet jitter (or PDV), ms; i is packet sequence number; RTTi is current packet round-trip time, ms; RTTi-1 is previous packet round-trip time, ms and 16 is jitter value averaging.

The following sections represent experimental results from SAN and DAN simultaneous operation. All experiments were done by transporting portable computer by a car at the allowed speeds. All measurements are divided into two groups: in the city (dense urban area) and out of the city (rural area). The city experiments were performed by travelling 25 km long path thru dense Rigas' center part. The out of city path is 95 km long and implies flatlands and lowlands with and without forests.

2.2. 3G plus 3G DAN compared with 3G SAN in the city

In the following experiment all dongles are locked in 3G mode. In Riga all available cells are operating in B1 (2100 MHz) band. The mode of operation is HSPA+ or DC-HSPA+ (mode selection is done automatically depending on signal quality). The experimental results are represented in Fig. 3.

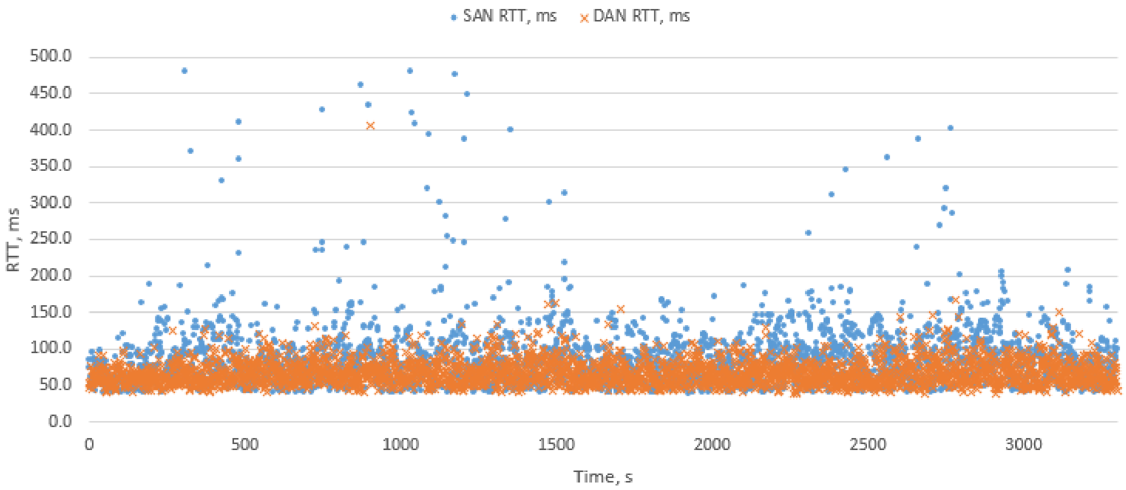

Figure 3. 3G SAN and 3G + 3G DAN in the city

13 packets (0.3831%) are lost in SAN, average RTT is 87.8 ms and average jitter is 32.3 ms. None of packets are lost in DAN, average RTT and jitter are also reduced: 67.3 ms and 13.4 ms respectively.

2.3. 3G plus 3G DAN compared with 3G SAN in rural region

In the following experiment all dongles are locked in 3G mode, while band selection is done automatically. In populated areas, cells typically operate in band B1 (2100 MHz), in non-populated regions - in band B8 (900 MHz), while in transition between populated and non-populated areas both B1 and B8 are available. The mode of operation is HSPA+ or DC-HSPA+. It should to be noted, that 3G networks automatically switches to low speed mode (usually called UMTS) if there is no traffic. As soon traffic is detected, the mode of operation switches to HSPA+ or DC-HSPA+ (depending on signal quality). This means that after short-time data interruption (from 1 to 5 sec, depending on cellular operator settings) network switches to UMTS. Very seldom traffic becomes unrecognized and mode of operation remains UMTS. This situation cannot be fully foreseen and results up to 5 times greater network RTT values. The experimental results are shown in Fig. 4.

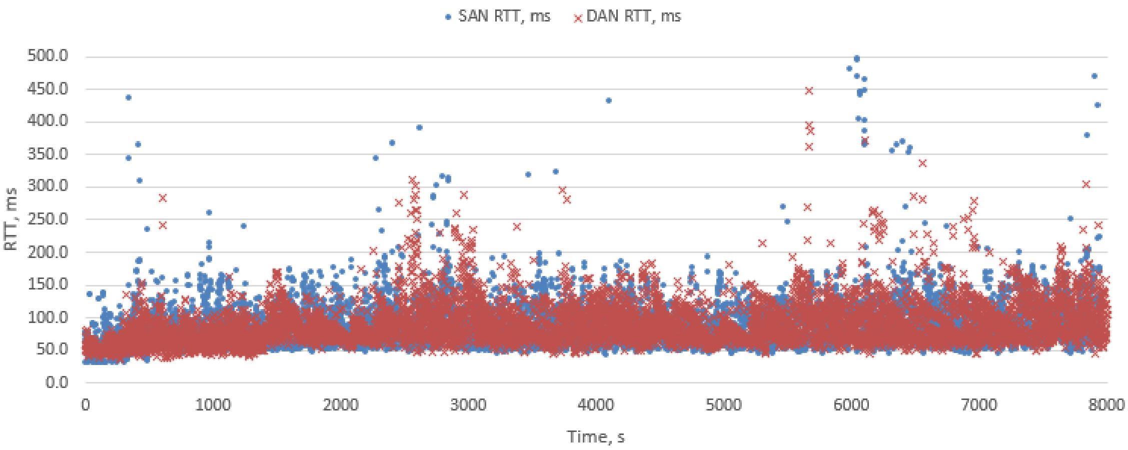

Figure 4. 3G SAN and 3G + 3G DAN in rural region

45 packets (0.5654%) are lost in SAN, averaged RTT and jitter are 91.7 ms and 28.8 ms respectively. In DAN average RTT is 92.1 ms and average jitter is 23.1 ms and none of packets are lost. It should to be noted, that RTT in DAN is greater that in SAN. This is explained by the fact, that most of the time DAN second dongle was operating in UMTS mode, while the first DAN dongle and the SAN dongle were operating in HSPA+ and uses same operator Nr.1 service. Thus, second DAN dongle with increased RTT was used only if first dongle packet was lost or significantly delayed. All lost packets were successfully delivered by the second dongle with 5 times higher RTT, resulting higher overall DAN RTT.

2.4. 3G LTE plus 3G DAN compared with 3G LTE SAN in the city

LTE networks offer higher throughput, lower RTT and jitter, as well as reduced starting time. However, as LTE cells are UEs' prime choice, these cells are more loaded compared with 3G cells. Due to LTE cells overload in dense cities, sometimes conventional 3G provide better availability and performance (Brodnevs & Kutins, 2017; Laner *et al.*, 2012). In the following experiment SAN dongle is locked in 3G LTE mode while DAN comprises 3G LTE and 3G services. All dongles band selection is done automatically.

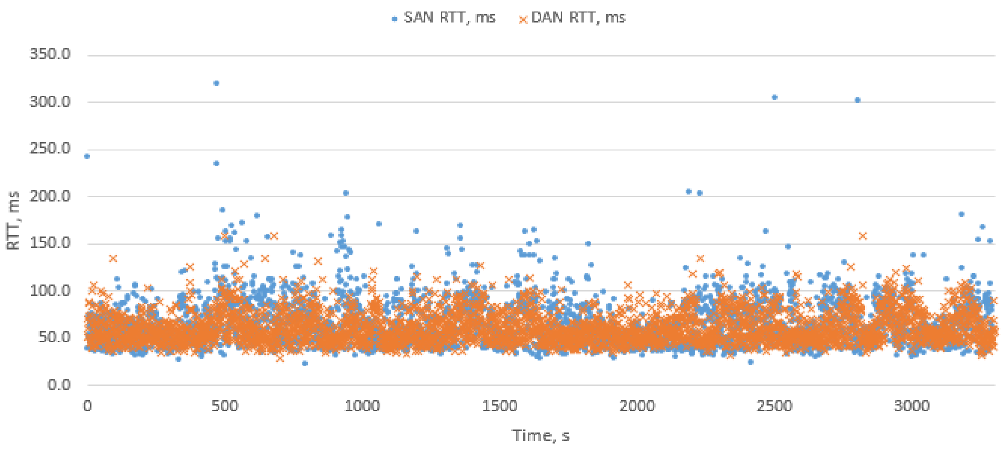

Figure 5. LTE SAN and LTE + 3G DAN in the city

1 packet (0.0303%) is lost in SAN, average RTT is 64.8 ms and average jitter is 20.9 ms. DAN have no lost packets, averaged RTT and jitter are 61.0 ms and 14.5 ms respectively. It can be concluded that LTE cells were not overloaded in Riga and, since LTE provides smaller RTT, most packets were processed from LTE service.

2.5. 3G LTE plus 3G DAN compared with 3G LTE SAN in rural region

LTE cells are low loaded in rural regions, thus should provide better performance compared with 3G HSPA+ cells. Also, it should to be noted, that 3G in rural regions operates in B8 (900 MHZ) band, that results in higher delays. As 3G requires NodeB and LTE requires eNodeB and these are usually, operating in different bands hence its coverage must be different by default. This is the main motivation to use 3G as a second node for the DAN in rural regions.

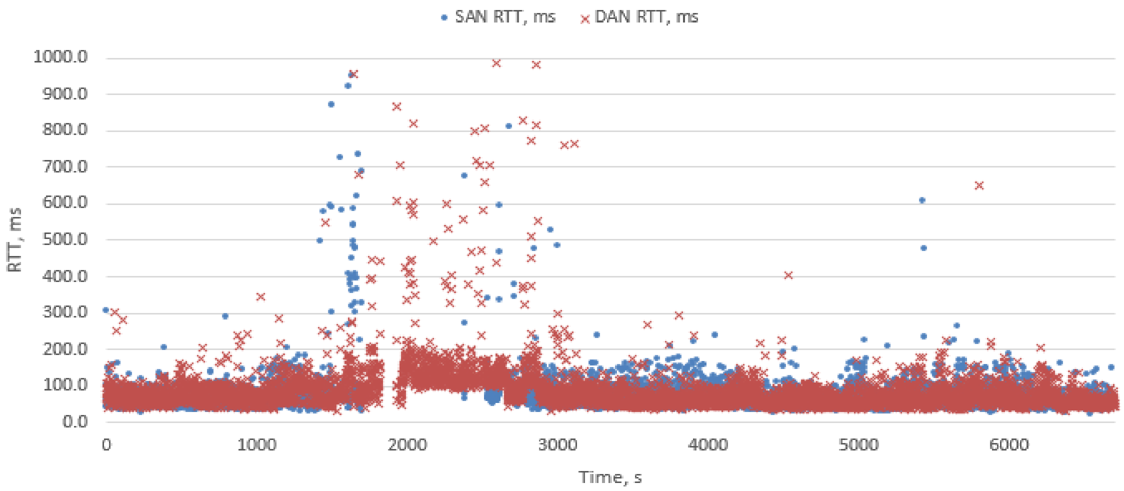

Figure 6. LTE SAN and LTE + 3G DAN in rural region

1038 packets (15,53%) are lost in SAN, RTT and jitter averaged values are 73.2 ms and 28.4 ms respectively, DAN number of lost packets is 218 (3.249%), averaged RTT is 85.0 ms and averaged jitter is 28.1 ms. In spite of different 3G and LTE cells coverage, deep rural valley coverage is problematic for all existing cellular technologies. This results in both service failures or near to miss operation in the region of 1700 .. 2800 sec of the experiment, resulting in DAN data transfer interruption.

2.6. 3G LTE plus 3G LTE DAN compared with 3G LTE in the city

If there is no problem with LTE cells overload, a combination of different cellular operator LTE services can be used to build DAN to improve network reliability. In the following experiment all three dongles are locked in LTE mode. In Riga more than one band is available for simultaneous operation. As dongle band selection is done automatically, it is not possible to foresee does whether dongles are operating in same or in different in bands.

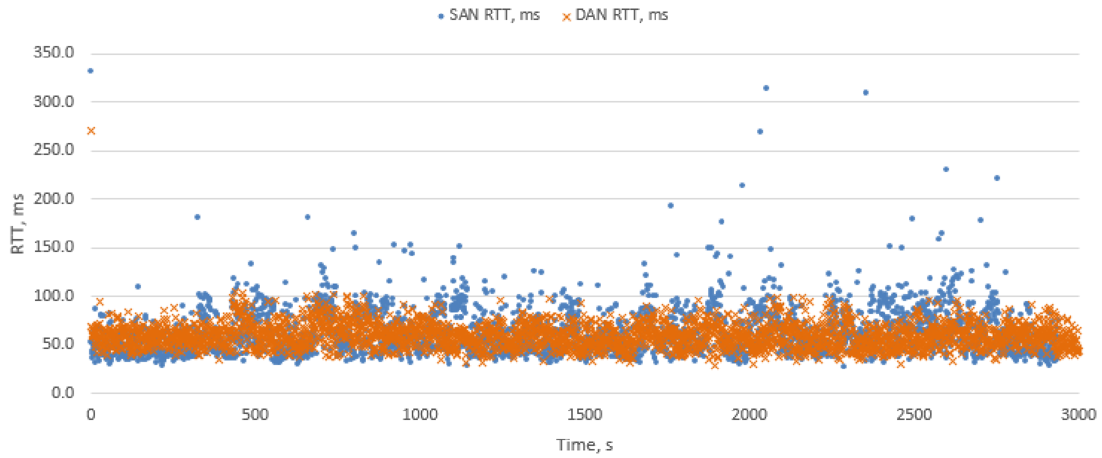

Figure 7. LTE SAN and LTE + LTE DAN in the city

3 packets (0.1022%) are lost in SAN, RTT and jitter averaged values are 62.6 ms and 18.9 ms respectively. There are no lost packets in DAN, its RTT and jitter averaged values are 59.6 ms and 11.5 ms respectively.

2.7. 3G LTE plus 3G LTE DAN compared with 3G LTE in rural region

Over recent years LTE coverage in rural regions in Latvia was significantly improved. This makes possible to use different cellular network operators' LTE services combination to build stable DAN solution with reduced RTT and jitter also in rural areas. In the following experiment all three dongles are locked in LTE mode, while band selection is done automatically.

The number of lost packets in SAN is 186 (2.648%), RTT and jitter averaged values are 77.9 ms and 29.5 ms respectively. Only 11 packets (0.1586 ms) are lost in DAN, while RTT and jitter averaged values are 64.7 ms and 14.6 ms respectively.

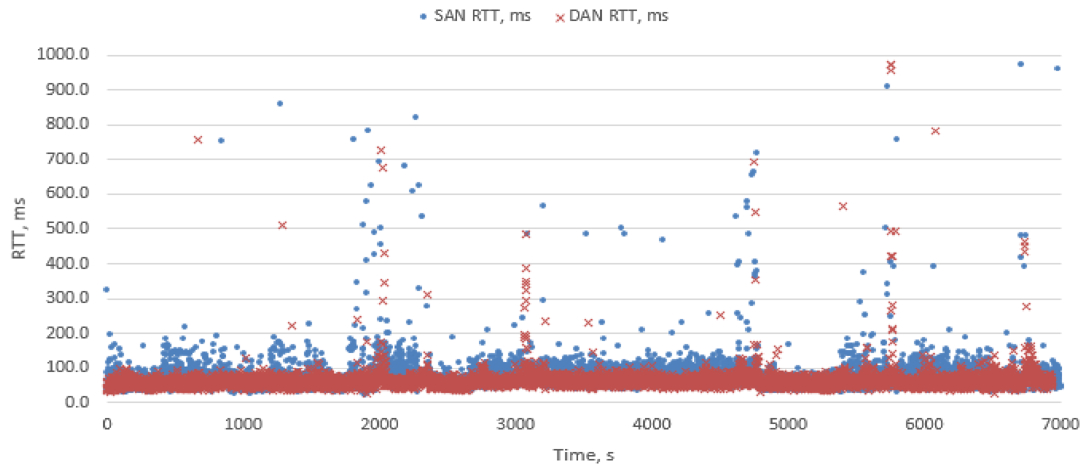

Figure 8. LTE SAN and LTE + LTE DAN in rural region

3. Conclusion

The experimental results are summarized in Table 1. Improvement calculation results are inverted to get positive improvement values when RTT and Jitter values are decreased.

Table 1. Summarized results

	SAN	DAN	Improvement	
RTT, ms	87.8	67.3	23.3%	3G SAN vs 3G+3G DAN in the city
Jitter, ms	32.3	13.4	58.5%	
Number of lost packets, %	0.3831%	none	100.0%	
RTT, ms	91.7	92.1	-0.4%	3G SAN vs 3G+3G DAN in rural region
Jitter, ms	28.8	23.1	19.8%	
Number of lost packets, %	0.5654%	none	100.0%	
RTT, ms	64.8	61.0	5.9%	LTE SAN vs LTE+3G DAN in the city
Jitter, ms	20.9	14.5	30.6%	
Number of lost packets, %	0.0303%	none	100.0%	
RTT, ms	73.2	85	-16.1%	LTE SAN vs LTE+3G DAN in rural region
Jitter, ms	28.4	28.1	1.1%	
Number of lost packets, %	15.530%	3.249%	79.1%	
RTT, ms	62.6	59.6	4.8%	LTE SAN vs LTE+LTE DAN in the city
Jitter, ms	18.9	11.5	39.2%	
Number of lost packets, %	0.1022%	none	100.0%	
RTT, ms	77.9	64.7	16.9%	LTE SAN vs LTE+LTE DAN in rural region
Jitter, ms	29.5	14.6	50.5%	
Number of lost packets, %	2.6480%	0.1586%	94.0%	

Experimental results graphical representation is shown in Fig. 9. Network RTT and Jitter averaged values are represented in ms (left Y axis); number of lost packets, as well as RTT and jitter improvements are in % (right Y axis).

It can be concluded, that it is possible to use parallel redundancy in cellular network data transfer services. The use of parallel redundancy significantly decreases number of lost packets. The use of parallel redundancy has no significant effect on RTT and jitter and depends on services combination.

The use of two 3G HSPA+ (DC-HSPA+) services from different cellular network operators in dense populated areas allows to get resulting network performance, comparable to 3G LTE performance. However, in rural regions 3G HSPA+ (DC-HSPA+) services performance is decreased as these are operating in B8 (900 MHz) band, hence such resulting parallel redundant network performance is more badly compared to dense populated areas service.

For today both 3G and LTE cells are well developed both in rural and dense areas. The best solution to build DAN in Latvian rural regions is to use different cellular operators' LTE services, because these are more spectrum-efficient, hence are less affected by low frequency band, rather than conventional 3G services and there are no problems with switching between HSPA+ and UMTS.

It should to be noted, that in a case of a rugged topography in rural regions, parallel redundancy cannot provide fully reliable data transfer service, because all cellular services can be failed in deep valleys.

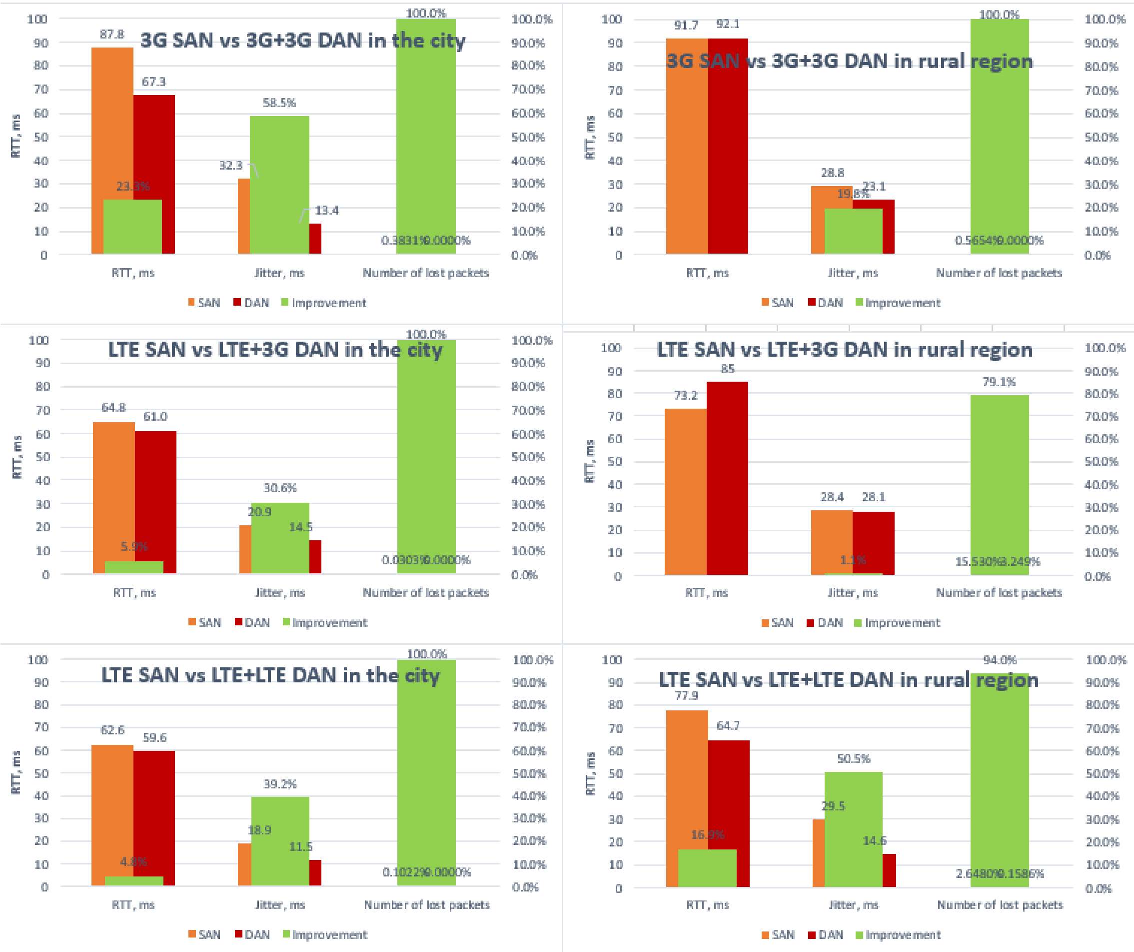

Figure 9. Summarized results

In dense urban regions a combination of 3G + 3G, 3G + LTE or LTE + LTE can be used to get highly reliable data transfer service with comparable performance results. In this case, LTE service benefits are faster startup and zero problems with switching between low speed UMTS and high speed HSPA+ modes. In contrast to LTE, 3G cells are less loaded in dense areas, hence their services typically are more stable.

References

Astély, D., Dahlman, E., Furuskär, A., Jading, Y., Lindström, M., & Parkvall, S. (2009). LTE: The evolution of mobile broadband. *IEEE Communications Magazine*. https://doi.org/10.1109/MCOM.2009.4907406

Bite.lv. (2016). BITE: coverage in Latvia. Retrieved September 28, 2016, from https://www.bite.lv/parklajums/atrs-internets-visa-latvija/ar-4g-internetu-viss-dzive-ir-iespejams-daudz-atrak

Brodnevs, D., Bezdel, A. (2017). High - Reliability low - Latency cellular network communication solution for static or moving ground equipment control. In *2017 IEEE 58th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)*, 1–6. Riga: IEEE. https://doi.org/10.1109/RTUCON. 2017.8124756

Brodnevs, D., Kutins, A. (2017). An Experimental Study of Ground-Based Equipment Real Time Data Transfer Possibility by Using Cellular Networks. *Electrical, Control and Communication Engineering*, *12*(1), 11–19. https://doi.org/10.1515/ecce-2017-0002

Gessner, C., Roessler, A., & Kottkamp, M. (2008). UMTS Long Term Evolution (LTE) Technology Introduction. *Rohde & Schwarz Application Note*, *5*(3), 1–55.

Holma, H., Toskala, A., Ranta-aho, K., & Pirskanen, J. (2007). High-speed packet access evolution in 3GPP release 7. *IEEE Communications Magazine*, *45*(12), 29–35. https://doi.org/10.1109/MCOM.2007.4395362

IEC. (2016). International Standart 62439-3:2016 Industrial communication networks – High availability automation networks.
Retrieved from https://webstore.iec.ch/publication/24447

IEEE Computer Society. (2012). IEEE Standard for Ethernet 802.3. In *IEEE Standard for Ethernet* (Vol. 2012, pp. 1–400). https://doi.org/10.1109/IEEESTD.2012.6419735

IETF. (2003). Request for Comments RFC3550 - RTP: A Transport Protocol for Real-Time Applications. Retrieved from https://tools.ietf.org/html/rfc3550

Jurvansuu, M., Prokkola, J., Hanski, M., & Perala, P. (2007). HSDPA performance in live networks. In *IEEE International Conference on Communications*, 467–471. https://doi.org/10.1109/ICC.2007.83

Kottkamp, M. (2012). HSPA + Technology Introduction. *Rohde & Schwarz White Paper*.

Laner, M., Svoboda, P., Romirer-Maierhofer, P., Nikaein, N., Ricciato, F., & Rupp, M. (2012). A Comparison Between One-way Delays in Operating HSPA and LTE Networks. *Proceedings of the 8th International Workshop on Wireless Network Measurements (WiNMee 2012)*, (May), 14–18.

Lmt.lv. (2016). LMT: 4G coverage in Latvia. Retrieved September 28, 2016, from https://www.lmt.lv/ru/vozmozhnosti-interneta-4g

Paredes, M., Ruiz, P. (2014). Challenges in Designing Communication Systems for Unmanned Aerial Systems Integration into Non-segregated Airspace. *2014 IEEE Military Communications Conference*. https://doi.org/10.1109/MILCOM.2014.237

Rentschler, M., Heine, H. (2013). The Parallel Redundancy Protocol for industrial IP networks. In *Proceedings of the IEEE International Conference on Industrial Technology* (pp. 1404–1409). https://doi.org/10.1109/ICIT.2013.6505877

Roessler, A. (2009). Cell search and cell selection in UMTS LTE. *Rohde & Schwarz Application Note*.

Roessler, A., Kottkamp, M., & Schlienz, J. (2013). LTE- Advanced (3GPP Rel.11) Technology Introduction. *Rohde & Schwarz White Paper*, 1–38.

Santos, N., Raimundo, A., Peres, D., Sebastião, P., & Souto, N. (2017). Development of a software platform to control squads of unmanned vehicles in real-time. In *2017 International Conference on Unmanned Aircraft Systems, ICUAS 2017*, 1–5. https://doi.org/10.1109/ICUAS.2017.7991528

Stuhlfauth, R. (2012). *High Speed Packet Access* (First Edit). Munchen: Rohde&Schwarz GmbH&Co. KG2012.

Tele2.lv. (2016). Tele2: 4G coverage in Latvia. Retrieved September 28, 2016, from https://www.tele2.lv/ru/4ginternets/

Tso, F. P., Teng, J., Jia, W., & Xuan, D. (2012). Mobility: A double-edged sword for HSPA networks: A large-scale test on hong kong mobile HSPA networks. *IEEE Transactions on Parallel and Distributed Systems*, *23*(10), 1895–1907.
https://doi.org/10.1109/TPDS.2011.289

Yamamoto, H., Fujii, T., Ha, P. T. T., & Yamazaki, K. (2014). New development of remote control system for air vehicle using 3G cellular network. *Advanced Communication Technology (ICACT), 2014 16th International Conference on*, 456–461.
https://doi.org/10.1109/ICACT.2014.6779002

ZHAW Institute of Embedded Systems InES. (n.d.). PRP-1 Software Stack. Retrieved January 15, 2017, from https://www.zhaw.ch/en/engineering/institutes-centres/ines/products-and-services/high-availability/prp-1-software-stack/#%2Fc46689