

Practical 5G KPI Measurement Results on a Non-Standalone Architecture

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Abstract—While mobile network operators have started announcing their 5G-capable network implementations, practical details of their capabilities are not widely supported through measurements. This paper describes a practically implemented 5G architecture – based on the 5G Option 3x reference model – and initial results on its KPI (Key Performance Indicator) measurements.

Beside being matched against the 5G network expectations, the results are compared to our actual hands-on 4G network measurements. The analysis of the 5G testbed result shows that – as expected – 5G outperforms 4G in all basic KPIs, including up- and downlink throughput as well as latency. Furthermore, the practical measurement results on this non-standalone 5G architecture show that – when traffic preferences are configured well – latency and jitter are not significantly affected by the load of the cell or the core network. This is a long-awaited proof on 5G KPI promises coming true.

Keywords—Cellular Mobile Networks, 5G, Practical Measurements, Latency, Jitter, Throughput, PER

I. INTRODUCTION

THE first instances of 5th generation mobile networks have already launched in 2019, all over the world. Most of these networks are operating only for test purposes so far, meaning that anybody who has subscription can connect and transmit data – but the generic processes for QoS (Quality of Service) guarantees are not implemented yet. Operators usually run “friendly customer tests” with no fees for this service. However, it cannot be considered as a partial public test process, as user devices and equipment are expensive and hardly available at this stage [1]. Furthermore, there is a chance that current 5G-capable user devices will not be fully operational in the future on the live network. At present, neither the network services nor the User Equipment (UE) have been tuned [2] for the three main use-cases, namely enhanced Mobile BroadBand (eMBB), Ultra-Reliable Low Latency Communications (URLLC) and Massive Internet of Things (MIoT) [3]. In many cases service providers merely publish that their “5G network is operational”, but do not detail which parts of the 5G standards have already been built, and which parts are to be built after further consideration [4]. There are numerous methods and tools that are available for examining (Long-Term Evolution) LTE

network and service performance. While currently used network and service validation systems can be useful on 5G networks as well, significant improvements on tools will be needed for detailed validation and verification on meeting 5G targets.

The upcoming promises of 5G include 1 Gbps throughput, 1 ms latency, 1 million *devices/km²* and 10 times less energy consumption (compared to 4G UE), however, the combined effect of these attributes to the network is not fully known yet. There are dozens of new – but theoretical – use-cases for 5G, however, these are not tested on a live network, so it can not be known which will fulfil the expectations. When Facebook became popular, 3G networks could not serve increased multimedia traffic demands. Something similar could happen for 5G, as we do not fully know how the new use-cases will affect the network. Some services could be overloaded for significant periods of time. One approach to be prepared for such overloads and transient effects is to examine the existing, “pre-5G” use-cases and create test environments on 5G networks.

II. RELATED WORK

Both the signalling and data planes of mobile networks need to be analyzed all along their lifecycle – especially before going live. Ultimately, users’ Quality of Experience (QoE) would define the requirements; although best practice shows that initially, the basic QoS metrics must be taken care of. A mixture of these can be correlated with QoE [5].

A. Basic QoS measurements

Being very practical, it is usual that service providers examine only the basic attributes in case of data networks [6]. (Such real-life tests do not necessarily include e.g., packet inter-arrival time or its jitter.) These can be short-period, functionality-based measurements, or long-term measurements that are often combined with stability tests. Since the transmission system is considered as Device or Network Under Test (DoNUT), there are more parameters worth to be examined separately. The main, QoS-related KPIs for our measurements are throughput, latency, packet inter-arrival time, jitter and packet loss – which are described in Section IV and their results are presented in Section V.

B. Higher layer measurements

There are further, more subtle measurements that can be carried out at higher Open Systems Interconnection (OSI) layers, which can reflect further aspects of user experience. Some examples are the following.

1) *The iPerf tool*: A popular application for throughput measurements is iPerf – and its updated version, iPerf3 [7]. It can be used for both Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) transmission, even to create dynamic traffic load for a system. Furthermore, iPerf output can be compared easily, even for significantly diversified systems.

2) *Internet Control Message Protocol (ICMP) - related measurements*: Sending ICMP packets is a common method to examine network latency. Such applications can be found on almost any x86-based system, but the output and features are very poor for detailed analysis. Furthermore, latency can increase for many network applications in case of the high traffic load; for such cases, ICMP is not able to provide proper insights. A small improvement can be achieved with individual settings, but it is still not an entirely adequate solution.

3) *Application-specific measurements*: During the transmission of huge files, latency and throughput can be analyzed at the same time. While this method may provide information on retransmitted packets as well, their application-specific nature is a major drawback.

4) *Tools for operator measurements*: Before a service is allowed to go live, it is worth examining how the network performs within complex traffic scenarios. For this purpose, targeted measurement tools can be used such as IXIA solutions [8] or Cisco TRex [9]. Since most features we require are freely available with TRex, we utilized it for our analysis – but any other system can be used to repeat the measurements with properly calculated parameters.

III. OUR 5G TESTBED CONFIGURATION

The fundamental architecture of 5G networks is defined by the 3rd Generation Partnership Project (3GPP) Release 15 standard set [10]. Many of its network elements currently operate in live, previous-generation mobile networks. The Core network is responsible for Authentication, Authorization, and Accounting (AAA) functions, service mobility management, besides, it ensures connectivity with the Internet Protocol (IP) network. Another crucial part of the 5G architecture is gNodeB (gNB), which is responsible for the radio attachment between UE (the end-device) and the Core network's interfaces in case of 5G media. For the basic understanding, Figure 4.2.3-1 on [10] depicts the generic 5G architecture, where the main elements are also defined.

A. The 5G Testbed

The testbed we used is a standardized architecture shown by Figure 1, and known as "migration path to Non-Standalone Next Generation Radio with LTE assisted mode connected to

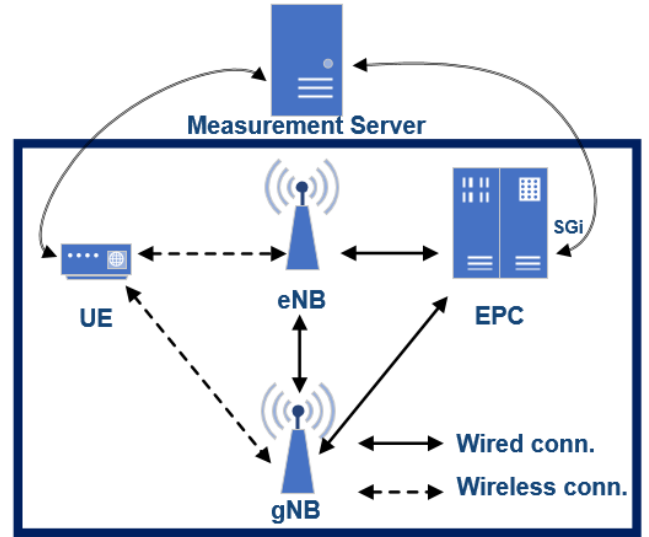


Fig. 1: The architecture of our 5G testbed – as Option 3X

Evolved Packet Core (EPC)", or "Option 3X" [11]. In here the Core network is pre-5G, while the access network includes 5G gNB.

In this setup, the UE connects primarily to a 4G anchor point, and the core elements authenticate it on the 4G network. After the attachment, the 5G NR (New Radio) base station builds a data connection providing a high *downlink* bandwidth. It is worth to stress that the client uses 4G radio for uplink and 5G NR is only used for downlink data transmission.

As an initial validation for the testbed, we analyzed fundamental technical promises of 5G, such as peak data rate in up- and downlink, and latency. Table I shows a comparison on expectations against earlier 3GPP standards – where 5G is supposed to outperform all others.

B. 5G User Equipment

The first 5G capable device [12] category has been published in 3GPP Release 15. To fulfil the standard's requirements, a 3.6 GHz frequency band, 256-QAM (Quadrature Amplitude Modulation) and even 100 MHz bandwidth are also needed [13]. It is worth to mention that at this stage, asymmetric network configuration is recommended. For downlink 5G network's 100 MHz bandwidth and 256-QAM are used – but for uplink and signalling transmission 4G network is preferred.

In the 3GPP Release 8 [14] a device type have been published, being capable of co-operating with 4G data networks [16]. Cat 3 radio devices were standardized mostly for low budget modems and mobile phones – but they did not spread widely. LTE category 12 have been published in 3GPP Release 11 [15], and is currently representing the top category of the 4G capable devices. This was the first standard using 256-QAM, so 600 Mbps downlink throughput can be achieved.

TABLE I: Expected parameters of the examined technologies

	Cat 3 [14]	Cat 12 [15]	5G – Option 3X [11]
3GPP Release	Release 8	Release 11	Release 15
Downlink Peak Data Rate	100 Mbps	600 Mbps	1500 Mbps
Uplink Peak Data Rate	50 Mbps	100 Mbps	100 Mbps
Latency (typical)	40 ms	20 ms	5 ms
Bandwidth	1.4–20 MHz	1.4–80 MHz	100 MHz and 20 MHz
Used technology	4G only	4G	4G and 5G

IV. MEASUREMENT SETUP

Our measurement took place within laboratory circumstances, while only our devices operated, transmitted data and generated background traffic. Radio input and output power could be configured arbitrarily, so it can be considered constant for the measurement process.

Based on DoNUT models, different transmission directions can be tested – as shown by Figure 1.

A. Testbed elements

1) *4G, 5G UE and Subscriber Identity Module (SIM)*: Our UE supported 256-QAM using 2 transmitter and 4 receiver antennas in the testbed. SIM cards had the same authorities as the simple 4G SIM cards, and 5G data bearer also had the same authorities during the building process as on 4G. In order to have reference measurements on 4G, we used a Cat 3 and a Cat 12 device as well.

2) *Radio Access Network (RAN)*: The 4G frequency band was on 1800 MHz with 20 MHz bandwidth in Frequency Division Duplex (FDD) mode. The 5G bearer was on 3.6 GHz, as we mentioned, only in downlink transmission could attach to the user with 100 MHz bandwidth, using 32 Transmitter, 32 Receiver antennas and 256 QAM.

3) *Mobile Core*: The network was built by the 3.X reference model with the standardized S1AP and S1U [17] interfaces towards to 4G eNB and 5G gNB. However, the inner architecture was built fully virtualized by the 5G standard. So the Mobility Management Entity (MME), Serving Gateway (SGW) and Packet Data Network Gateway (PGW) functions' resources can be varied based on the load of the network traffic. The infrastructure base was an off-the-shelf x86, with CentOS 7 (1810), with 64 Central Processing Unit (CPUs) and 128 GigaByte (GB) Random Access Memory (RAM). There were 16 CPUs actively connected to the Core network.

B. Expectations on measurement parameters

1) *Throughput*: High throughput is achieved with increasing bandwidth, different coding and better modulation. In downlink direction even 100 MHz bandwidth can be used; the theoretical throughput limit is 1.5 Gbps. Naturally, throughput can be tuned with the number of receiver and transceiver antennas as well.

TABLE II: Aggregated (median) results of measurements

	4G- Cat 3	4G- Cat-12	5G - 1 UE	5G - 2 UE
Downlink Peak Data Rate	75 Mbps	420 Mbps	885 Mbps	1465 Mbps
Uplink Peak Data Rate	22 Mbps	87 Mbps	92 Mbps	91 Mbps
Latency (one-way)	13 ms	12 ms	3.71 ms	4.96 ms
Packet Error Rate	0.3%	0.2%	0.39%	0.67%

2) *Latency*: A key promise of 5G is that latency experienced with 4G will be reduced drastically to around 1 ms; furthermore, latency can be kept low even if the traffic load is high in the network.

3) *Packet Error Rate (PER)*: The data connection layer of the radio channel should correct the transmission errors if packet loss has occurred. We measured PER at a higher layer, so we expected to detect PER only when lower layers were not able to restore packets. Our results confirmed this.

C. Measurement methodology

In our setup, the 5G network was treated as a Device or Network Under Test [18]. One part of the server connected to UE with cable, while the other one to EPC SGi interface (Figure 1). From the sent and received packets, the server could easily calculate latency, throughput and (Packet Error Ratio) PER values. To measure latency, throughput and PER, primarily iPerf, iPerf3 [7] and Cisco TRex [9] were used. The results were validated by Wireshark. We measured UDP and TCP stream transmission, and with the help of TRex, IP packets had been sent with high frequency. It became clear that one device can not exploit the whole bandwidth alone, although by using multiple devices, we managed to reach the DoNUT transmission limit. The critical link located between the UE and radio equipment, which was the first to reach its capacity limit.

V. RESULTS

The following findings are the results of a series of 5G non-standalone measurements. For reference comparison, we have carried out similar measurements on 4G. Table II summarizes our measurement results, which shows that for 5G, even 1 UE downlink peak rate massively outperforms the 4G values. However, 5G uplink transmission is an exception as it has similar performance as 4G. As expected, latency is also significantly lower at 5G than at 4G.

A. Latency results

We examined how the DoNUT affects 5G latency deviation with 100 Byte and 1000 Byte packets. During the tests, the time between sending packets was between 10 ms and 1000 ms, in 4 different scenarios. After these tests, we measured latency with continuous background traffic, with its volume being approximately 50% of the network's capacity: 700 Mbps. One-way latency results are shown by

Figure 2, when the background traffic took 50% of the link capacity, and with *no* background traffic.

A *very important finding* is that even the severe background traffic does not significantly affect the targeted latency values.

B. Jitter results with background traffic

When analyzing the variance of packet inter-arrival times during transmission, the examined packets were 100 Byte and 1000 Byte and also in 4 different frequency scenarios between a packet per 1 and 0.1 seconds. Since we were controlling the ratio of packet sending in multiple dimensions, we can calculate not only the variance of the packet arrival time but also the variance difference between the expected and real arrival. The Equation 1 we used is very similar to calculating variance. However, we replaced the mean " μ " with the packet sending interval as 1 sec to 0.1 sec, x_i is the i th packet inter-arrival time; and n is the number of sent packets.

$$\sigma^2 = \frac{\sum_{i=1}^n (x_i - \mu)^2}{n} \quad (1)$$

Figure 3 shows the received packet interarrival times with 0.1 and 1 s packet sending periods (in-between packets), and Figure 4 shows that at 10 and 20 ms packet sending periods the jitter is fairly minimal. The further (average) results are shown in Table III. A *highly interesting finding* is that in case of the cell is loaded with 50% background traffic, the jitter is slightly but remarkably lower than in case of an "empty" cell.

TABLE III: Packet inter-arrival time variance (jitter) σ^2 [msec]

Packet size	100 Byte		1000 Byte	
Sending interval	1 sec	0.1 sec	1 sec	0.1 sec
No background	0.0160618	0.232781	0.0222247	0.371
50% background	0.01724	0.2157	0.0194	0.3426

VI. CONCLUSION

This paper aims to provide some insights into 5G and 4G network capabilities. After a brief introduction of the non-standalone 5G architecture, Option 3X – the paper presents

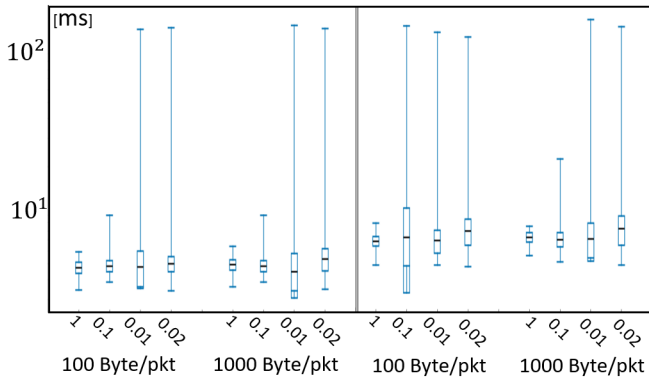


Fig. 2: Latency of 5G links, measured with different transmission intervals [0.02 - 1 ms] – with background traffic (left) and without background traffic (right)

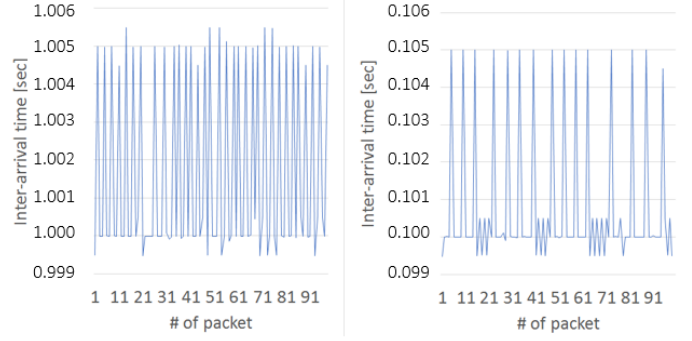


Fig. 3: Jitter results (left): 100 Byte packets, 1000 ms sending period, (right): 100 Byte packets, 100 ms sending period

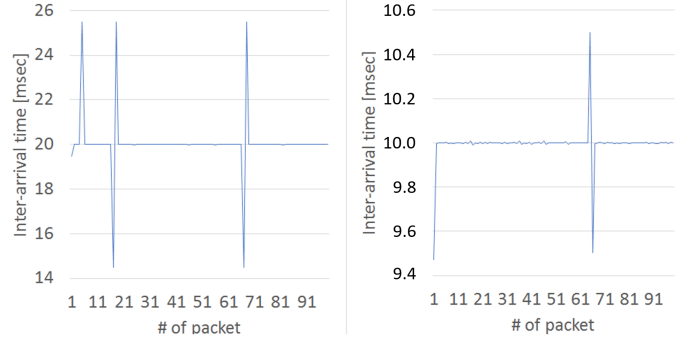


Fig. 4: Jitter results (left): 100 Byte packets, 20 ms sending period, (right): 100 Byte packets, 10 ms sending period

the created testbed containing both 4G and 5G base stations, an EPC, and various user devices.

As the main contribution for understanding and validating practical 5G capabilities, the paper presented multiple, end-device-originated measurements. These fundamental parameters that were compared against the widely advertised expectations were throughput, latency, the variance of packet inter-arrival times (jitter) and PER.

After the basic measurements, detailed analysis of one-way latency and packet inter-arrival times variance was carried out regarding 5G networks' main attributes.

As expected, 5G data transmission latency is significantly lower than it is for 4G – although sub-millisecond results require further tuning. As a further result, latency and jitter values with traffic load are not increasing significantly on the examined, practical 5G network testbed.

REFERENCES

- [1] Digitaltrends, Mark Jansen, "5G smartphones are on the way," <https://www.digitaltrends.com/mobile/5g-capable-phones/>, 2019.
- [2] 3GPP, "3GPP system standards heading into the 5G era," https://www.3gpp.org/news-events/1614-sa_5g, 2019.
- [3] Q. Zhang and F. H. Fitzek, "Mission critical IoT communication in 5G," in *Future Access Enablers of Ubiquitous and Intelligent Infrastructures*.
- [4] 3GPP, "The path to 5G: as much evolution as revolution," https://www.3gpp.org/news-events/1774-5g_wisearbour, 2016.
- [5] P. Varga, G. Kún, G. Sey, I. Moldován, and P. Gelencsér, "Correlating user perception and measurable network properties: Experimenting with QoE," in *International Workshop on IP Operations and Management*.

- [6] X. Lu, W. Cao, X. Huang, F. Huang, L. he, W. Yang, S. Wang, X. Zhang, and C. Hongsong, 2010.
- [7] iPerf, *iPerf - The ultimate speed test tool for TCP, UDP and SCTP*.
- [8] Ixia, "Ixia validate the performance of your networking solutions," <https://www.ixiacom.com/solutions/network-test-solutions>, 2019.
- [9] Cisco.com, "TRex, Realistic traffic generator," trex-tgn.cisco.com, 2019.
- [10] ETSI, "System Architecture for the 5G System, TS 123 501 V15.2.0," Tech. Rep., 2018-06.
- [11] GTI, Ericsson, ZTE, Nokia, "5G Network Architecture White Paper," <https://www.3gpp.org/keywords-acronyms/1612-ue-category>, 2018-02.
- [12] 3GPP, "User Equipment (UE) radio access capabilities, 3GPP TS 38.306 version 15.3.0 Release 15," 3GPP, Version 15, 2018-10.
- [13] —, "Physical channels and modulation, TS 38.306 version 15.3.0 Release 15," 3GPP, Version 15, 2018-10.
- [14] —, "Technical Specifications and Technical Reports for a UTRAN-based 3GPP system, TS 21.101," 3GPP, Version 8, 2008-12.
- [15] —, "Technical Specifications and Technical Reports for a UTRAN-based 3GPP system, TS 21.101," 3GPP, Version 11, 2013-03.
- [16] 3rd Generation Partnership Project, "LTE UE-Category," <https://www.3gpp.org/keywords-acronyms/1612-ue-category>, 2016.
- [17] 3GPP, "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)," 3GPP, 36.413 Rel. 8, 2016.
- [18] P. Orosz, P. Varga, G. Soós, and C. Hegedűs, "QoS Guarantees for Industrial IoT Applications over LTE - a Feasibility Study," in *IEEE International Conference on Industrial Cyber-Physical Systems*, 2019.