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Cellular network quality evaluation at a university campus on the eve of 5G

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Abstract

Thanks to the availability of mobile devices and the spread of broadband access around the world, the number of network users continues to grow. This has raised user awareness when it comes to the quality of content they consume. Many service providers and operators focus on monitoring QoN (Quality of Network) and QoS (Quality of Service) parameters, particularly those influenced by bandwidth and latency. However, for most end-users, quality is understood as the subjective QoE (Quality of Experience), a mixture of several individual factors. This paper presents a QoN evaluation, carried out under real-time operating conditions at a university campus, considering the overall performance of the cellular network. The study involved 50 mobile devices, i.e., smartphones, used by students during their typical activity throughout a week. The results were gathered on the eve of 5G, using a custom-built Android application. This application enabled the acquisition of valuable data about the wireless link, including download and upload speed, latency (pink), the ID of the serving base station, and type of cellular connection. This approach can be used to detect the strengths and weaknesses of back-end networks.

Introduction

With the development of digital networks (fixed and mobile), the importance of their quality and the quality of services they provide increases. The first case is called QoN (Quality of Network), and the second is QoS (Quality of Service). When end-users are involved in determining the quality of services, it is called QoE (Quality of Experience). In recent years, many recommendations from international standardization institutions have been issued with regard to the quality of networks and services. In the ITU-T Rec. Y.1541 (ITU-T, 2011) recommendation, the QoS classes are defined, and the QoS parameters in individual classes for the IP network are also set. The recommendation ITU-T Rec. G.1010 (ITU-T, 2001) specifies the size of QoS parameters from the end-user point of view for an IP network. The ETSI TS 102 250-2 (ETSI, 2011a) recommendation identifies the size of QoS parameters for mobile networks. The ETSI TS 102 250-3 (ETSI, 2011b) recommendation defines procedures related to the measurement of QoS parameters in mobile networks.

The topic of QoS has also recently attracted attention in Brussels, and the negotiations conducted by the European Parliament led to the adoption of a communication package in November 2009. It contains two very important directives, Directive 2009/136/EC (JEU, 2009a) and Directive 2009/140/EC (JEU, 2009b), which were developed to ensure net neutrality and transparency throughout the entire telecommunications market of the European Union. With the publication of these directives, all EU Member States were obliged to implement them.

Today, the number of electronic services is growing rapidly. Some, especially video types, need a high bandwidth. High demand for services can quickly lead to a reduction in the amount of available resources in a network, increasing delays. In extreme cases, it can even block access to a service. Therefore, in practice, it is important to continuously measure network parameters and, if necessary, reconfigure the infrastructure. This approach forms the core of this work, by measuring selected parameters of cellular networks available at the campus using a custom-built Android application.

After a short introduction, the basic features of the Long Term Evolution and 5G Ready technology will be briefly presented. The next point will focus on quality content consumption. The subject of terrestrial networks and service providers will be shown in the next section of the paper. The network requirements will be discussed afterwards. The last sections will describe the measurement campaign, including the environment and utilized devices. The results and their interpretation will conclude this paper, along with a summary and guidelines for further research.

Literature review

Long term evolution and 5G ready

Currently, there are numerous mobile and wireless systems, including Wi-Fi, WiMAX, and LTE. The fourth-generation (4G) technology is an extension of 3G, with additional measures, services, and other advancements (Sule & Joshi, 2014). The main idea of OFDM (Orthogonal Frequency Division Multiplexing) is the distribution of narrowband subcarriers among users (Afolabi, Dadlani & Kim, 2013), depending on their channel characteristics (Jiang, Song & Zhang, 2010). The utilization of MIMO (Multiple-Input Multiple-Output), considering multiple antennas at both the transmitter and receiver side, increases the spectral efficiency for a given transmit power by adequately multiplexing parallel channels. Likewise, scheduling and dynamic resource allocation techniques ensure fair and efficient management of limited system resources (3GPP, 2005). This allows more users to consume high-quality content, increasing the system's total capacity (Letaief & Zhang, 2006).

With the exponential rise of audio-video traffic in cellular networks, there is a need to improve delivery mechanisms. Starting with 2020, it has been estimated that these services will occupy more than 70% of available bandwidth. The incoming 5G system offers many distinct characteristics. However, the simultaneous provision of numerous HD (High-Definition) video streams and other multimedia services will degrade the service quality. Maintaining a stable and reliable connection may be a significant challenge (Ibrahim & Khamiss, 2019). Nowadays, network providers describe themselves as not only 4G, but also 5G Ready. Nevertheless, they do not always enable the consumption of high-quality content.

Quality content consumption

Modern content delivery systems, particularly adaptive audio-video streaming services, have gained significant attention. To maximize quality and avoid re-buffering, the audio-video client itself predicts the future available bandwidth and then selects the appropriate bitrate for the content. Since network fluctuations affect the available bandwidth, bitrate selection algorithms have to work efficiently enough to provide smooth playback. One of the most popular algorithms is DASH (Dynamic Adaptive Streaming over HTTP) (ISO/IEC, 2014).

In DASH, the audio-video file is partitioned into multiple few-second segments, where each segment is encoded at different bitrates (quality levels). If the requested bitrate selected by a particular user is too high, it may increase the risk of buffer underflow (re-buffering). On the other hand, if the requested bitrate is too low, the quality will be judged as poor. To fulfill both QoS and QoE requirements, related to the available bandwidth and subjective judgments, the client should choose the bitrate that avoids buffer underflow and quality switching (Xu & Ma, 2015).

The paper (Hoppe & Uhl, 2020) describes in detail the effect of network parameters, type of utilized codec, coding speed of the image and its resolution, as well as the buffering in the end-user's device, on the quality of the video streaming service using DASH technology. The main characteristic of content transmission over wireless networks is the rapid availability of large amounts of data. Currently, the most popular coding standards include AVC (Advanced Video Coding), known as H.264, and

HEVC (High-Efficiency Video Coding), referred to as H.265.

H.264 is a widely utilized coding method for a variety of applications, from mobile devices to web applications and HDTV. In this case, the DCT (Discrete Cosine Transformation) operates at 4×4 pixels, rather than 8×8. It includes MC (Motion Compensation) blocks at various sizes, VLC (Variable Length Coding), a frequency distortion optimizer, weighted duplex forecasts, multiple reference frames, and many more.

H.265 has a similar structure to H.264, with many enhancements, including flexible division partitions, transforming block sizes, and multiprocessing support. The encoder produces structures that are captured inside units of data called a NAL (Network Abstraction Layer). The differences in hybrid video coding using H.265 include CTUs (Coding Three Units), CTBs (Coding Tree Blocks), CUs (Coding Units), CBs (Coding Blocks), PUs (Prediction Units), PBs (Prediction Blocks), TUs (Transform Units), quantization control, and many more. Additional information may be found in (Uhrina, et al., 2014).

Terrestrial networks and service providers

Currently, subscribers evaluate offered telecommunication services by comparing prices with declared network benchmarks, most often throughput and coverage. Due to increases in wireless Internet service usage, most plans come with unlimited voice calls and SMS/MMS (Short Message Service/ Multimedia Message Service), but not data. The main reasons are varying upload and download speeds, related with constantly changing serving environments.

In contrast to wired Internet access, mobile communications require relatively high initial capital investments and rigorous licensing policies. Of course, policymakers have issued various direct and indirect regulations, including entry permissions, to ensure that the market environment is sound. In fact, numerous countries have established regulatory and economic policies to prevent subscribers from being overcharged for mobile telecommunications services. In many cases, the price represents a point of conflict between the needs of consumers and service providers, and/or network operators.

As mobile technology develops and the demand for mobile telecommunications services continues to grow, telecom operators need to continuously expand their infrastructure to provide high quality levels to as many simultaneous active users as possible. However, the speed of such technological development and the demand for particular services differ from one area to another. As a result, there are great variations in service quality, including data transmission speeds and service coverage, among not only different countries but various cities within the same country, as well as numerous districts of a city.

According to the OECD (Organization for Economic Cooperation and Development), in 2012 the fastest advertised mobile download speeds averaged 59.7 Mbps, whereas the lowest ranged at approx. 4.8 Mbps. There is little relation between the advertised and experienced speed. Additionally, during the last several years, the price of mobile phones has increased significantly. Therefore, device manufacturers and service operators offer large subsidies to subscribers who agree to enter into a mandatory year-long contract. Of course, such subscription fees and subsidies can potentially have a large impact on the final price of mobile services. Additional information, considering a broad analysis of price and network parameters offered in 12 cities in 10 different countries around the world, can be found in (Yun, Kim & Kim, 2019).

Network requirements

Of course, network requirements based on Internet speed and latency depend on several factors, including connection type and type of medium (wired or wireless, copper or optic fiber), network architecture (cellular 3G, 4G, Wi-Fi, etc.), and the number of simultaneous users that share the same portion of available resources. Network requirements for basic everyday online activities are described in Table 1.

Table 1. Download speed requirements for everyday online activities

Activity	Typical download speed [Mbps]
Web browsing	1
Online gaming	1–3
Audio-video conferencing	1–4
SD content streaming	3–4
HD content streaming	5–8
4K content streaming	40
Large file downloading	50
Simultaneous web activities	100–200
Web browsing	1

In the case of online gaming, a low-latency connection is more important than the overall bandwidth.

Whereas for audio-video conferencing, at least a 1 Mbps upload speed is required. Most often, the allowable ping rate should not exceed 100–150 ms.

For the average user, download speed is more important than upload speed. Network providers tend to only advertise the download speed of their plans and some offer unlimited data transfer for particular online streaming platforms. For example, Netflix recommends at least 3 Mbps download speed for SD (Standard Definition) content, 5 Mbps for HD content, and 25 Mbps for 4K content.

Often the declared connection speed is split across numerous users, preventing a smooth high-quality stream. Additionally, Wi-Fi will always be slower than a hardwire connection due to numerous effects, including interference from surrounding access points. Moreover, the connection speed itself may vary by user location, including both indoor and outdoor environments (Chruszczyk & Zając, 2016; Qamar et al., 2019). In this case, the network planning process should take into consideration current and future locations to maximize quality while avoiding unnecessary multimedia buffering. Regardless of the type of service, the physical connection has to go somewhere central, e.g. the provider's office, joining node, or central switch. The distance between the user's equipment and these meeting points impacts the maximum speed of a service and QoS that a particular company can offer.

The increase in the number of users and new multimedia streaming services, including online games, surveillance, videoconferences, VoD (Video on Demand), VoIP (Voice over IP), and many more, generates significant traffic (Sequeira, Fernández-Navajas & Saldana, 2014). Many researchers have studied how network parameters, such as bandwidth, BER (Bit Error Rate), buffering, delay, and packet loss, affect the network QoS and user QoE (Uhl & Jürgensen, 2015; Leszczuk et al., 2016; Nowicki & Uhl, 2017).

Methodology

Research environment

Tests were carried out during a typical day of the week, just before the start of the pandemic, with many simultaneous active users. The aim was to investigate the current parameters of cellular networks operating near the GUT (Gdansk University of Technology) campus. Figure 1 shows the 2D map (left-hand side) and the 3D (right-hand side) of the GUT campus (GUT, 2022).

According to current statistics, the university has approx. 20 000 students, both full-time and part-time, as well as more than 2500 employees. The campus has a lot of open space, surrounded by several 1-story to 10-story buildings. This area, located in the center of a large metropolitan city, seemed an interesting environment to conduct this experiment.

Materials and methods

During speed tests, these metrics may range from link capacity to ABW (Available Bandwidth), i.e., the maximum bandwidth unused at a certain point, or BTC (Bulk Transfer Capacity), i.e., the maximum achievable throughput by a TCP (Transmission Control Protocol) flow. Furthermore, there are multiple measurement techniques, usually classified into three different groups: active probing, passive estimation, and mathematical model based (Prasad et al., 2003). However, such techniques and tools sometimes have complex user equipment and/or network condition requirements (Atxutegi et al., 2016).

Figure 1. 2D (left) and 3D (right) plan of the GUT campus

Table 2. Principle parameters of utilized mobile devices

Group	Released on the market	Supported cellular system	CPU	RAM	Android OS
1	Q2 2017	GSM, UMTS, LTE (single-SIM)	8-core, 2.3 GHz	4 GB	7.0 Nougat
2	Q2 2017	GSM, UMTS, LTE (dual-SIM – provider no. 1)	8-core, 2.3 GHz	4 GB	7.0 Nougat
3	Q2 2017	GSM, UMTS, LTE (single-SIM)	4-core, 1.3 GHz	2 GB	7.0 Nougat
4	Q2 2017	GSM, UMTS, LTE (dual-SIM – provider no. 2)	8-core, 2.3 GHz	4 GB	7.0 Nougat
5	Q4 2017	GSM, UMTS, LTE (dual-SIM – provider no. 1)	8-core, 2.0 GHz	3 GB	7.0 Nougat
6	Q3 2016	GSM, UMTS, LTE (single-SIM)	4-core, 2.2 GHz	3 GB	6.0 Marshmallow
7	Q3 2016	GSM, UMTS, LTE (single-SIM)	8-core, 2.0 GHz	3 GB	6.0 Marshmallow
8	Q4 2017	GSM, UMTS, LTE (dual-SIM – provider no. 2)	8-core, 2.0 GHz	3 GB	7.0 Nougat

The field tests were carried out outside in the open environment. They involved a group of 50 users, and each one was equipped with their own mobile device and a custom-built mobile application for this study. The mobile application was developed using Android Studio in the Java/Kotlin programming language. It could be used to obtain several data about the wireless link, including download and upload speed, latency (ping), the ID of the serving base station, and type of cellular connection. Each person performed his or her measurements at 10 unique points, with more than 30 measurements per point, evenly distributed throughout the campus. We achieved confidence intervals lower than 10% of the measured mean values, with a confidence level of 0.95. The obtained data were initially stored in the built-in memory of each mobile device. After ending the measurement campaign, data were transferred in a wired manner onto the hard drive of a desktop PC for further processing and analysis.

The utilized smartphones included mobile devices from various manufacturers, including Kurger & Matz, LG, Huawei, Samsung, Sony, and Xiaomi. Table 2 shows the main parameters of the utilized mobile devices, divided into eight groups (about the same size), taking into account both hardware and software features. For commercial reasons (competition), the brands of the end-users' devices used are not named here.

Results

Obtained results were all processed to determine the quality parameters of the mobile devices themselves and the base stations. These results were averaged (both into mean and median values) and divided into eight groups (related to a given manufacturer and/or smartphone model and/or parameters, etc.). The results for downlink (download), uplink (upload), and delay (ping), are shown in Figures 2–4.

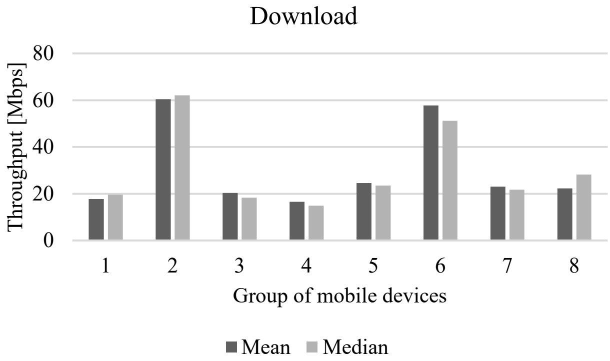

Figure 2. Download speed of operating mobile devices

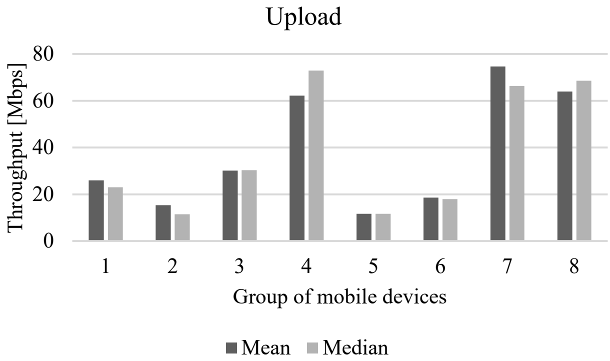

Figure 3. Upload speed of operating mobile devices

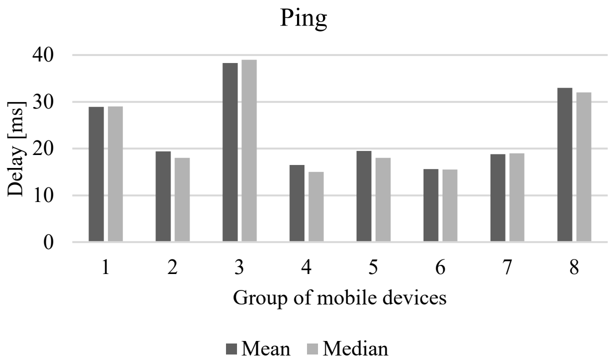

Figure 4. Ping of operating mobile devices

Although all devices were LTE-compatible, the range of obtained download and upload connection speeds was high, ranging from approx. 20 to 60

Mbps for a download, and from approx. 10 to 70 Mbps for an upload. The ping ranged from approx. 15 to 40 ms. The obtained results were more location-dependent than device-dependent. According to the obtained results, the area of the campus was served by six base stations. The results obtained for all evaluated base stations, including download, upload, and ping rate, are shown in Figures 5–7.

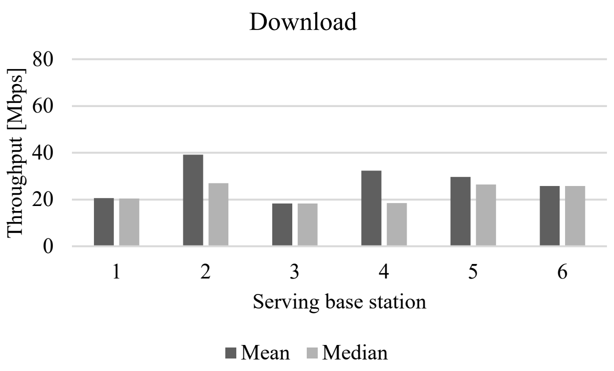

Figure 5. Download speed of serving base stations

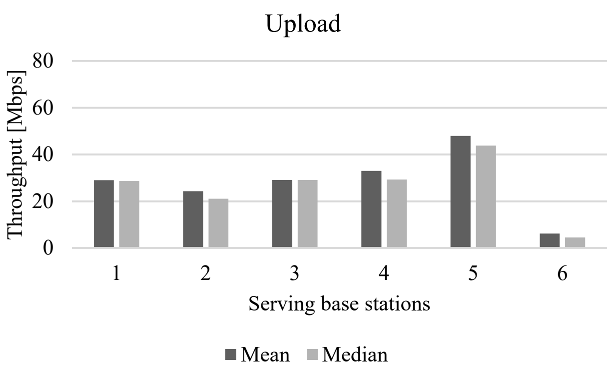

Figure 6. Upload speed of serving base stations

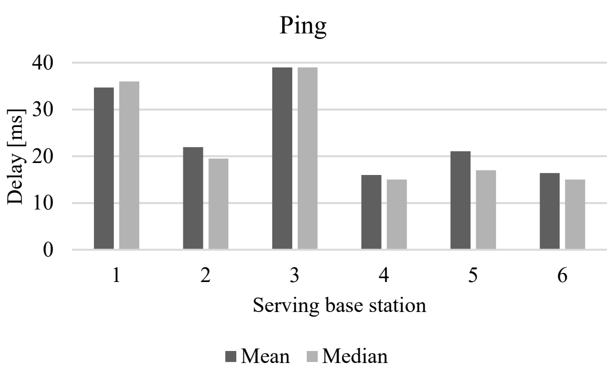

Figure 7. Ping of serving base stations

As observed, the throughput for download was quite even for each base station, ranging from 20 to 40 Mbps. Whereas, in the case of an upload, the results ranged from approx. 10 to even 50 Mbps. When it comes to the ping rate, the network's latency oscillated from approx. 15 to 40 ms. It should be emphasized that all mobile devices were served by base stations, which were sometimes shared between several operators. This fact may justify high transmission speeds in selected cases for some groups of end-user devices. It would be interesting to correlate the measured access bit rates with the utilization of the individual base stations. Unfortunately, this information cannot be obtained from network operators.

According to the obtained results, the current network conditions, particularly throughput in downlink and uplink, enable a stable reception and consumption of SD and HD multimedia content. As shown, observed network conditions are more location-dependent than device-dependent. However, when it comes to observed ping rates, very few real-time audio-video services could be applied.

Conclusions

This paper examined the quality of mobile networks (QoN) using a university campus as an example. The size and development of this site seemed to be a good environment for such a study. All measurements were performed with our own custom-built application, installed on 50 mobile devices. The obtained measurement results allow us to state that the current qualitative parameters of the tested terrestrial cellular network infrastructure allow users to consume content using popular web browsers, carry out audio-video conferences, and consume streamed multimedia content in SD and HD quality in real-time. On the other hand, 4K content would certainly require significant buffering.

Overall, the relationship between the observed network speed and ping rates are important parameters that cannot be neglected when planning a network deployment. Furthermore, multimedia applications are becoming popular in mobile environments, where resources are limited. Of course, the term "resources" can be understood as a combination of factors, including the processing capacity and power consumption of a mobile device, as well as the bandwidth and latency of a network.

Moreover, it is vital to properly balance the interests of consumers and service providers in the mobile market. As shown, both bandwidth and latency may vary, depending not only on the consumer device but also on current environmental conditions and network load. The network quality assessment approach provided in this paper is a pragmatic method that could be effectively used in practice. It should be mentioned that activities related to user mobility, and thus the connection handover, significantly impacted the obtained results. Subsequent research could include different techniques for assessing both the QoS and QoE of specific services.

As expected, the demands and preferences of mobile users tend to change (Boz et al., 2019; Falkowski-Gilski & Uhl, 2020). Thus, it would be interesting to compare results obtained pre vs post-coronavirus pandemic. Future works are planned in this direction. Similar observations should be taken into account by content providers and network operators, who intend to deliver good-quality audio-video signals to their customers. Development in the field of video coding continues, and announcements of the new H.266/VVC standard have already been made. Image resolution is also constantly being increased, as 2K and 4K screens seem to be the new standard. With the advancements of such QoS models, the procedure presented in this paper could be applied. Therefore, further work is also planned in this direction. Additional sources of inspiration may be found in refs. (Dymarski, 2020; Jeena Jacob et al., 2020; Leszczuk & Janowski, 2021; Wasilewska, Bogucka & Kliks, 2022).

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