Estimation of the Available Bandwidth of the Cellular Network Connection with Android API

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Abstract: The speed at which mobile and wireless networks are currently developed continues to be astounding. The rate of data reception and transmission over a wireless network becomes a major factor for consumers and mobile phone service providers, as service providers compete with each other for leading positions in the quality of mobile communications provided. This paper describes the problem of available bandwidth estimation of the LTE network in dense urban environments under the TCP BBR Congestion Control protocol. For this, the open-source HTWK Signal Harvester app from the Leipzig University of Applied Sciences has been modified to estimate the available bandwidth of a connected 4G LTE network. The test results presented in the article show that the available bandwidth gathered from Android 11 API metrics are close to the results obtained by iPerf3, a stand alone utility for active measuring of maximum achievable bandwidth on IP networks, widely used in PC and server computers.

1 INTRODUCTION

Provision of a maximum possible available bandwidth (AvB) of a wireless network is currently a key issue for mobile communication operators. Currently, several tools are available to analyze available bandwidth on wired and mixed networks, already embedded in devices and allowing observation of changes in internet traffic. However, these applications have a structure hidden from the user, making it difficult to analyze and evaluate the factors affecting the quality of the connection. Several factors are known to affect wireless connection speeds, e.g. different weather conditions, technical (such as equipment workload), and landscape.

Examples of such weather conditions are a forested area [1] or rainy weather [2, 3]. Landscape [4] has also a major influence on the data transport speed, as the radio signal can pass through, be reflected, and be absorbed by obstacles. Also, there is the area of responsibility of the provider. Which includes such parameters as workload and channel capacity, quality of the equipment used, reliability and quality of the cable from the server to the customer's home, the network equipment that is leased to the customer. These are only some of the factors affecting signal quality. The main focus of this paper is on estimation of available bandwidth of the wireless network based on parameters obtained by the Android application on a mobile device.

To estimate the available bandwidth in LTE communication some specific transport parameters have been introduced such as BW, RB, RE, TBS, MCS, CQI, RSSNR. Hereby, BW - frequency range in a given band used for signal transmission. There and below, the concept of available bandwidth will be used to refer to data rates, and the concept of channel bandwidth will be used to define the frequency range in a given frequency band. Resource Block (RB) is a block consisting of a channel resource and includes 12 adjacent subcarriers occupying the 180 kHz band. During transmission, 12 adjacent sub-carriers are multiplied by 7 cyclic prefixes to form 84 RE resource elements (for the 7OFDM cyclic prefix case which is commonly used in LTE) which in turn forms one resource block. Adaptive Modulation and Coding (AMC) is used to increase the network capacity or downlink data rates. AMC stands for different Modulation and Coding Schemes (MCS). MCS defines different types of modulation, such as quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM). CQI - Channel Quality Index. The CQI channel-state report effect to change the modulation scheme in the subframe. This parameter may vary from manufacturer to manufacturer and is not consistent with each other.

RSSNR - Signal to Noise Ratio is used to determine the RSSNR-CQI relationship.

The main objective of this paper consists of two tasks. The first task is to propose an adaptive available bandwidth estimation scheme using the CQI prediction scheme proposed by the authors Alessandro Chuimento and Mehdi Bennis in [5]. We have implemented this estimation scheme into the android information monitoring application *HTWK Signal Harvester* which allows to perform and record LTE/5G NR measurements using the Android API. The app collects cell information, cell signal strength as well as location information from GPS. In the second task the estimation of trace data is recorded while driving in an urban scenario. In this, a laptop connected to the internet via a smartphone as a tethered device has been used. Work has been performed in Future Internet Lab Anhalt [6].

2 EXTERIMENTAL SETUP

The following equipment was used for tests and measurements here: OnePlus 8T 5G mobile device (Android 11.0, Qualcomm Snapdragon 865, 8RAM +128 ROM), Lenovo ThinkPad T430 laptop (Kernel: GNU/Kubuntu 21. 10 5.13.0-30-generic64bit equipped with Intel® Core i5-3210M CPU 2.5GHz, 8GB of RAM), the server was running on Linux 5.13.0-28-generic Ubuntu 21.10 SMP x86_64 and equipped with Intel® Core Skylake, IBRS 3.8GHz, 4GB of RAM, 128GB NVMe Storage. The testbed, used in this research is presented in Figure 1.

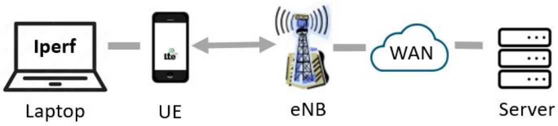

Figure 1: Network setup.

On the laptop - the sender runs the iPerf3 cross-platform sender-receiver console program [7]; on the other side the server opens the receiver side and starts writing data to a JSON file, and the smartphone runs the downlink data received from the connected base station and estimates the available bandwidth.

The main elements here are the OnePlus 8T 5G mobile device and the HTWK Signal Harvester [8] developed at HTWK University Leipzig. The HTWK Signal Harvester application is available as open source code at GitHub for information monitoring and analysis. The experiment was conducted along a closed route of the city of Köthen (Figure 2).

The wireless service providers were the local O2 provider and Alditalk provider as a virtual provider on the infrastructure of O2. The mobile device was connected to a laptop as an access point to the internet connection. The wireless link parameters were evaluated from a single UE served by the next eNB. The available bandwidth of the downlink is estimated at the MAC (Medium Access Control) level. The required TCP traffic load was generated using iPerf3. This was done in order to maximize the use of available bandwidth on the link. At the start of the traffic, both devices UE and Laptop started recording data in parallel. The route has been chosen so that there are a line of sight areas to the base station as well as dense urban areas with blind spots and areas with building obstacles and so with multi-path propagation scenarios.

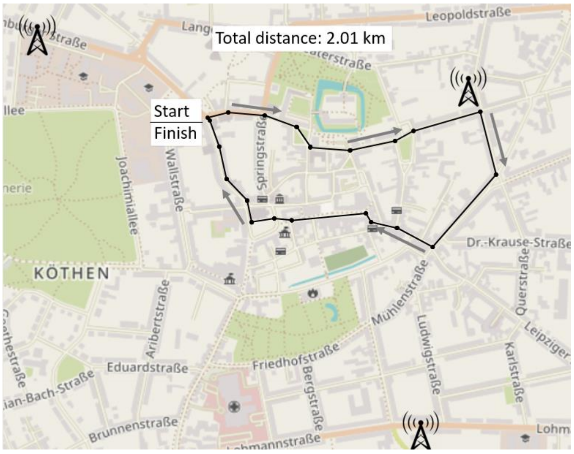

Figure 2: The route of the test scenario.

The mobile device also hands over to several different base stations along the route, which repeatedly changes the width of used LTE band and therefore changes the reception/transmission rate. After the metrics were collected, the results obtained by the mobile device and the iPerf3 throughput testing software were compared for verification of the results.

3 AVAILABLE BANDWIDTH ESTIMATION

The first parameter to look at when estimating the maximum available bandwidth is the CQI. This parameter cannot be calculated or in some other way determined from the information received from any

Android API. The CQI is vendor-specific, so no unambiguous value can be given. During the literature review, it was adopted to use the CQI indices and their interpretations are given from the official 3GPP TS specification [9] for reporting CQI based on QPSK, 16QAM, and 64QAM.

It is mentioned from the introduction that one resource block includes 12 subcarriers and 7 cyclic prefixes. The supported uplink-downlink configurations are listed in official 3GPP TS documentation [10]. Predominantly operators choose a configuration focusing on the downlink since templates with a predominant allocation to the uplink are only in demand by broadcasters or streamers. The resource blocks are allocated according to the appropriate channel bandwidth. That is, 50, 75, and 100 blocks are allocated for channel bandwidth 10, 15 and 20MHz respectively. The index of transport blocks for each specific case must then be calculated. These are determined by relating the CQI to the modulation scheme (MCS) (Table 8.6.1-1 3GPP documentation [9]). Using the transport block index in conjunction with the information already available, it is possible to suppose the number of transport blocks. To do this, it is needed to refer to the relevant section in the official documentation (Table 7.1.7.2.1-1 3GPP documentation [9]) and compare the I_{TBS} with the deferred number of resource blocks horizontally. In this way, we can construct a table of the number of allocated transport blocks size (TBS) for each modulation scheme in both directions (Table 1, Table 2).

Table 1: Downlink TBS allocation.

CQI	MCS	TBS Index	10MHz TBS	15MHz TBS	20MHz TBS
1	0	0	1 384	2 088	2 792
2	0	0	1 384	2 088	2 792
3	2	2	2 216	3 368	4 584
4	5	5	4 392	6 712	8 760
5	7	7	6 200	9 144	12 216
6	9	9	7 992	11 832	15 840
7	12	11	9 912	15 264	19 848
8	14	13	12 960	19 080	25 456
9	16	15	15 264	22 920	30 576
10	20	18	19 848	29 296	32 932
11	23	21	25 456	37 888	51 024
12	25	23	28 336	43 816	57 336
13	27	25	31 704	46 888	63 776
14	28	26	36 696	55 056	75 376
15	28	26	36 696	55 056	75 376

The resulting TBS size determines how much data (in bits) can be transmitted in one Transmission Time Interval (TTI) (=1ms). The last step is to multiply these values by 1000, thus obtaining the data rate in bits per second units. For convenience, the speed was further converted to Mbps. The correlation of the CQI values with RSSNR readings is carried out concerning the article [5].

Table 2: Uplink TBS allocation.

CQI	MCS	TBS Index	10MHz TBS	15MHz TBS	20MHz TBS
1	1	1	1 800	2 728	3 624
2	2	2	2 216	3 368	4 584
3	3	3	2 856	4 392	5 736
4	4	4	3 624	5 352	7 224
5	5	5	4 392	6 712	8 760
6	6	6	5 160	7 736	10 296
7	7	7	6 200	9 144	12 216
8	8	8	6 968	10 680	14 112
9	9	9	7 992	11 832	15 840
10	10	10	8 760	12 960	17 568
11	11	10	8 760	12 960	17 568
12	12	11	9 912	15 264	19 848
13	13	12	11 448	16 992	22 920
14	14	13	12 960	19 080	25 456
15	15	14	14 112	21 384	28 336

After the above steps, the implementation in the Android 11 API was carried out.

4 EXPERIMENTAL RESULTS

The suggested route of the mobile device in the city for taking LTE metrics has already been pointed out in Figure 2.

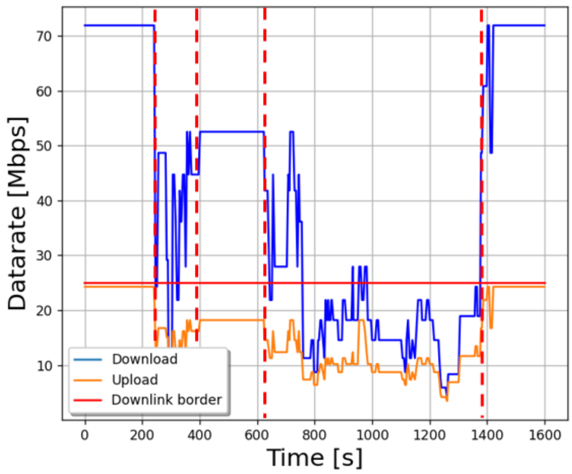

Figure 3: AvB estimation by android app.

The results of the metrics taken from Alditalk operator are presented in Figure 3. It must immediately be noted that the horizontal 'Downlink border' marks the maximum downlink speed set by the operator. As the ALDI operator has a data rate limit of 25Mbps - a comparison of the estimated data rate with the real rate would not give the required results. However, in comparison with the results obtained from the O2 operator, a general overlap of the estimated data rate over time areas separated by vertical lines can be observed. This is due to the fact that the ALDI operator does not have its base stations. The connection is provided by renting the capacity of the O2 operator's base stations. For the O2 operator, a brighter example can be observed (Figure 4), as the upper limit for download speeds is 225Mbps, which has not been achieved.

When defining the current SISO-MIMO scheme, difficulties were encountered in obtaining parameters using the Android 11 API. This parameter will be further estimated on base station locations and RSSNR values. MIMO in 4G LTE networks is primarily used due to spatial multiplexing that improves data rates by using multiple antenna elements that are physically separated in space on a transmitter or receiver.

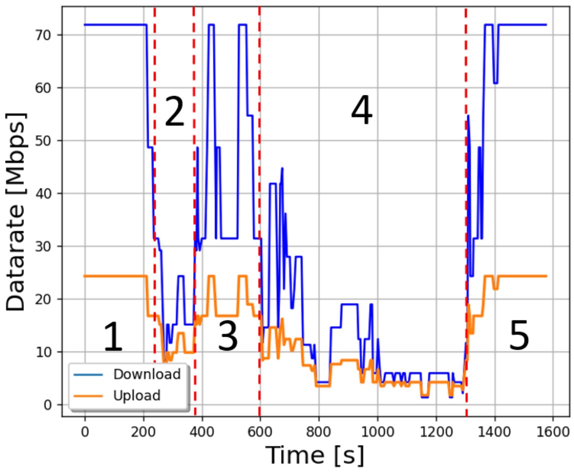

Figure 4: AvB estimation by android app.

To determine the connection scheme there are specialized software programs, e.g. SCAT: Signaling Collection and Analysis Tool or The Qualcomm Extensible Diagnostic Monitor (QXDM). The impact of MIMO on LTE link performance is described in detail in [11] and [12]. In our case, the spatial multiplexing pattern assumptions were determined based on the location of the nearest base stations and RSSNR values. Different MIMO schemes results in different data rates reached by Iperf3 below.

Figure 5 shows the iPerf3 receiver measurement results. The unstable throughput can be explained by measurements under TCP conditions and it's varying performance.

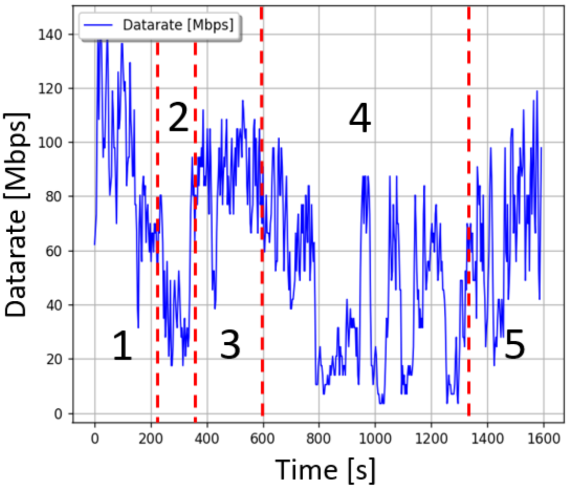

Figure 5: iPerf3 receiver side measurements.

During data analysis, it has been decided to divide the measurement area in Figure 4 and Figure 5 into 5 parts and evaluate them together. Measurements gathered during first time period on the Figure 4 correspond the situation of MIMO2x2 and the location of the base stations, which are determined by the eNB (eNodeB) ID. In the second part, there is a blind spot and the data transmission occurs by the reflection of the signal. The third zone shows a predominantly MIMO2x2 connection with medium signal strength. In the fourth zone, multiple switching between SISO and MIMO2x2 modes is observed due to the dense urban development and the close location of the base stations. In the fifth zone, there is a smooth transition to a stable SISO connection.

It is important to note that the measured values, presented in Figure 4 have been estimated for the SISO (Single Input Single Output) scenario. In a SISO system, a single antenna is used for transmission and reception. The required TCP traffic load with was generated using iPerf3 utility. By analyzing the graphs, it can be noted that the download speed has changed in the same time periods of the measurements. The occurrence of these areas can be explained by the blind spots along the route as well as by the time required for the mobile device to switch between base stations.

Trace was also taken in rainy weather conditions to assess the effect of weather conditions on internet connection speeds. An average deviation of 5-10% of the results against dry weather conditions has been found.

5 CONCLUSIONS AND FURTHER WORK

In this paper, a way has been described to estimate the available bandwidth based on cell information, cellular signal strength obtained by Android API for both uplink and downlink in SISO scenario conditions. Correspondence in the values of the estimated method with those of the trusted utility has been proven. The results gathered by android API are applicable for wireless network emulation in wired equipment for emulation but do not predict the actual available network bandwidth due to the complexity of determining the spatial coding method of the signal. The results and accuracy are expected and sufficient for our study. Subsequently, ideal experimental conditions can be reconstructed in the emulation. To precisely measure real AvB, it is necessary to determine the MIMO scheme, CQI metrics, the operator's network load as well as ideal weather conditions, and the absence of obstacles. The further work is to use this experience to emulate wireless channels in a wired environment to test the performance of the data transfer software in an Apposite Netropy [13] environment as a tool for datasets generation.

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