Study on CPU and RAM Resource Consumption of Mobile Devices using Streaming Services

Przemyslaw Falkowski-Gilski[a] and Michal Wozniak
Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology, Narutowicza 11/12, Gdansk, Poland

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Abstract: Streaming multimedia services have become very popular in recent years, due to the development of wireless networks. With the growing number of mobile devices worldwide, service providers offer dedicated applications that allow to deliver on-demand audio and video content anytime and everywhere. The aim of this study was to compare different streaming services and investigate their impact on the CPU and RAM resources, with respect to type of Internet connection. The paper consists of two parts: theoretical and research. The first part provides a description of current means of wireless communication, including transmission of multimedia in Wi-Fi and cellular systems, as well as principles of operation of popular streaming media available on the marked, including utilized coding algorithm and available bitrates. The second part describes the set of utilized consumer devices, including 50 smartphones, as well as tools, laboratory equipment, and research scenarios. Results of this study may aid both researchers and professionals involved in the digital mobile market, including content and service providers, as well as network operators.

1 INTRODUCTION

The continuous development of mobile devices and wireless networks has contributed to the creation of many services enabling streaming of audio and video content. Unlike traditional terrestrial radio or television, they allow each and every individual to choose the content he or she desires at a given moment, without being limited by a fixed broadcasting schedule (Kohli, 2020).

Streaming services allow us to consume content without having to download the entire file into the memory of a consumer device in order to play it back. In this case data are being downloaded from the server continuously in real-time. This is possible thanks to the increase in both throughput and network capacity (Muscat, 2019).

Like all data transmitted over the Internet, multimedia are divided into packets that are sent to the recipient, sometimes even via different routes and/or different access media. Even when a drop in quality of a connection occurs, smooth playback is maintained thanks to the existence of the so-called buffer. The buffer may be viewed as a queue that allows to download and process data in advance (Bouraqia, Sabir, Sadik and Ladid, 2020).

2 WIRELESS COMMUNICATION INTERFACES

Wireless networks enable to connect and share resources among multiple consumer devices located and operating on a predefined serving area (Kryvinska and Greguš, 2019). Currently, the most popular ones include Wi-Fi and cellular systems.

2.1 Wireless-Fidelity

Wireless-Fidelity is a proprietary name of the IEEE 802.11 family of standards, in which WLANs (Wireless Local Area Networks) are based. These networks are susceptible to interference, due to utilized frequencies. In order to minimize this effect, the allocated frequency range of 2.4 GHz has been divided into 14 channels in Europe and 13 in the USA, of 22 MHz width each. Whereas, the 5 GHz

[a] https://orcid.org/0000-0001-8920-6969

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band has been divided into 23 channels, each of 20 MHz width, respectively.

Over the years, many versions of the IEEE 802.11 standard have been introduced, subsequent ones were market with letters of the alphabet. Each new version brought improvements in the speed and range of data transmission.

The original version, introduced in 1997, allowed data transmission with a maximum speed of up to 2 Mbps in the 2.4 GHz frequency band. Its range (coverage) was equal to approx. 20 m indoors and approx. 100 m outdoors.

In 1999, two subsequent versions were issued, labelled as IEEE 802.11a and 802.11b. They both utilized SISO (Single-Input Single-Output) technology, however differed in operation frequencies and modulation techniques.

- 802.11a utilized 5 GHz and 3.7 GHz radio frequencies with channel width of 20 MHz, enabling data transmission with speeds up to 54 Mbps. The connection area ranged from 35 to 120 m for the 5 GHz variant, whereas for the 3.7 GHz variant it was equal to even 5 km outdoors. The utilized modulation scheme was OFDM (Orthogonal Frequency Division Multiplexing);
- 802.11b utilized the 2.4 GHz frequency range with channel width of 22 MHz. The transmission speed was up to 11 Mbps, and its serving area for both indoor and outdoor environments ranged from 35 to 140 m. In this case, DSSS (Direct Sequence Speed Spectrum) technique was used.

In 2003, the IEEE 802.11g standard was released, enabling transmission of data at speeds up to 54 Mbps with the 2.4 GHz frequency range. The serving area ranged from 38 to 140 m with SISO technology. It was compatible with both OFDM and DSSS techniques, depending on the user's choice.

The IEEE 802.11n standard, introduced in 2009, operated at either 2.4 or 5 GHz, and supported a maximum bandwidth of 150 up to 600 Mbps. The serving area ranged up to 75 m indoors and 250 m outdoors. This increase in maximum transfer speeds and range resulted from the introduction of the MIMO (Multiple-Input Multiple-Output) antenna array for both sending and receiving data. Additionally, this version enabled to increase the channel bandwidth from 20 to 40 MHz.

In 2013, the IEEE 802.11ac standard, operating within the 5 GHz radio band, enabled to select the width of the channel from 20, 40, 80, up to 160 MHz. It introduced MU (Multi-User) MIMO technology. This standard also brought a novel 256-QAM modulation scheme. Therefore, the maximum transfer speed ranged from 450 Mbps up to 1.3 Gbps, and the connection range indoors was equal to 35 m (Gast, 2005).

In 2018, the Wi-Fi Alliance concluded that the names of IEEE 802.11 standards should be more user-friendly. For this reason, a new nomenclature of standards has been introduced, as shown in Table 1, together with new logos, particularly designed and implemented for mobile devices (see Figure 1).

Table 1: Nomenclature of IEEE 802.11 standards.

Before 2018	After 2018
802.11b	Wi-Fi 1
802.11a	Wi-Fi 2
802.11h	Wi-Fi 3
802.11n	Wi-Fi 4
802.11ac	Wi-Fi 5
802.11ax	Wi-Fi 6

Figure 1: Updated Wi-Fi logos introduced by Wi-Fi Alliance.

A comparison of currently available IEEE 802.11 standards, including utilized frequency range as well as maximum throughput, is shown in Table 2.

Table 2: Comparison of different IEEE 802.11 standards.

Standard	Release date	Freq. range [GHz]	Throughput [Mbps]
802.11	1997	2.4	2
802.11b	1999	2.4	11
802.11a	1999	5	54
802.11g	2003	2.4	54
802.11n	2009	2.4/5	150-600
802.11ac	2013	5	400-1300
802.11ax	2019	2.4/5	1200-14000

However, Wi-Fi networks operate in the so-called ISM (Industrial, Scientific, Medical) band, which is open for other communication standards, including Bluetooth, etc. This issue, related with coexistence of multiple systems and/or standards, is an important topic, especially when talking about the IoT (Internet of Things) concept (Polak and Milos, 2020). This fact, quite the opposite to standardized cellular networks, may be a crucial differentiator when it comes to possible interferences.

2.2 Cellular Networks

The standardization of cellular networks begun in the 1970s and 1980s. However, the first generation (1G) standard, offering analog radio transmission, was focused only on speech and text services. The second generation (2G) system offered some type of multimedia transmission, namely MMS (Multimedia Messaging Service) with still pictures and audio. The breakpoint came with the third generation (3G), as the expectations of users started to grow.

The UMTS (Universal Mobile Telecommunications System) offered speeds up to 384 kbps, with video calls (aside from traditional voice calls), file sharing, Internet browsing and other multimedia services available so far only using fixed cable connections. The next step was the introduction of HSDPA (High-Speed Downlink Packet Access) and HSUPA (High-Speed Uplink Packet Access) protocols, which complemented each other creating the HSPA (High-Speed Packet Access). It provided transfers from 1.8 to 3.6 Mbps in the downlink and 1.4 Mbps in the uplink.

In 2014, LTE (Long-Term Evolution) as the fourth generation (4G) system was introduced. This standard increased the peak data rates up to 100 Mbps for downlink and 50 Mbps for uplink, with significant delay reduction and improved spectral efficiency related with flexible frequency allocation. LTE allows 6 different channel bandwidths, namely 1.4, 3, 5, 10, 15, and 20 MHz. Theoretically, with a 20 MHz wide channel and 4x4 MIMO antenna equipment, it allows speeds up to 326 Mbps for downloading and 86 Mbps for uploading data. With further improvements, referred to as LTE-Advanced, related with the growing number of active network subscribers, throughput can be increased even up to 3 Gbps and 1.5 Gbps, respectively (Meraj and Kumar, 2015; Shen, Lin and Zhang, 2020).

Currently, each and every network operator is focused on implementing the fifth generation (5G) network infrastructure. As the number of active users and their consumer devices continues to grow, throughput may be further extended to 10 or even 20 Gbps (Raca, Leahy, Sreenan and Quinlan, 2020).

Yet still, most people own and use 4G-compatible mobile devices. That is why this cellular standard, along with Wi-Fi connectivity, was evaluated.

3 MOBILE MULTIMEDIA DISTRIBUTION

The popularity of multimedia content distribution via the Internet started in the last two decades (Iwacz, Jajszczyk and Zajaczkowski, 2008). With the growing demands for transferring large amounts of data in a timely manner, the IETF (Internet Engineering Task Force) has developed the RTP (Real-Time Transport Protocol).

The RTP standard is dedicated to handle streaming of multimedia over IP (Internet Protocol) networks that enable to deliver audio and video packets with low overhead. It manages the streaming session between the server and clients with the RTCP (Real-Time Control Protocol). However, RTP has several disadvantages, such as: blocking packets by firewalls, no support for currently operating CDN (Content-Distribution Networks), difficulties when handling different receiving devices (e.g. processing power, resolution, etc.).

In order to overcome this, HTTP (Hypertext Transfer Protocol) was introduced. Unlike RTP, HTTP is compatible with CDNs and is not blocked by firewalls. Additionally, in HTTP the client is responsible for managing the streaming session, which eliminates the burden on the server. However, despite many advantages, HTTP cannot handle streaming different bandwidths for clients using diverse consumer devices. Therefore, HAS (HTTP Adaptive Streaming) was proposed.

HAS allows to adjust the quality of multimedia to the available network resources and technical parameters of the receiving device. This is possible by dividing multimedia files into short segments, which are then encoded at different data rates. Multimedia transmitted in such a way may contain both video and/or audio content, as well as subtitles in various languages.

The coded segments are available on the web server so that the client can download them on demand. Before starting the essential playback, the client downloads a MPD (Media Presentation Description) file, containing information about the streamed content, in the form of an XML (Extensible Markup Language). It contains information such as: start and end time of each segment, available transmission rates, URL (Uniform Resource Locator) for each segment.

Based on a set of parameters, including Internet connection, screen resolution of the consumer device, etc., a schedule for downloading subsequent segments is prepared. The schedule may be dynamically changed, based on network quality parameters, in order to provide the highest quality possible while maintaining smooth playback.

Currently, the most widely-known and utilized standard is MPEG (Moving Pictures Expert Group) DASH (Dynamic Adaptive Streaming over HTTP), utilized by a variety of streaming services, including Netflix and YouTube (Vetro, 2011; Gazdar and Alkwai, 2018; Hoßfeld et al., 2015).

4 MOBILE STREAMING SERVICES

This chapter discusses popular mobile streaming services (Falkowski-Gilski and Uhl, 2020; Falkowski-Gilski, 2020), including utilized codecs and available bitrates that were evaluated during this study.

4.1 Spotify

Spotify is a streaming service that allows to play audio files. It was first launched in 2008. As the first on the market, it offered both music pieces and podcasts on multiple mobile platforms. Currently, its library contains over 60 million songs. Its free version enables to: access the full library, and playback (interspersed with advertisements). Whereas, the premium version enables to: play content without advertisement, even offline, and with higher quality (bitrate).

Spotify supports different file formats for content distribution from creators, including FLAC (Free Lossless Audio Codec) and WAV. Then, audio files are encoded using either: Ogg Vorbis (bitrates of 96, 160, 320 kbps), AAC (128, 256 kbps), or HE-AACv2 (24 kbps). Premium users have the ability to choose one of the following bitrates: automatic (depending on the network connection parameters), low (approx. 24 kbps), normal (approx. 96 kbps), high (approx. 160 kbps), very high (approx. 320 kbps). With a dedicated application, mobile users can not only search for songs or create their own playlist, but also listen in a group session mode or even control playback on another compatible device.

4.2 Tidal

Tidal is a service containing over 55 million songs and more than 200,000 music videos and movies. In order to consume content, one needs to purchase one of the two available subscription versions: Premium or Hi-Fi.

Premium allows to play audio in standard quality that is either normal (depending on connection speed) or high (AAC at 320 kbps), as well as video in HD quality. Additionally, users can download content and play it offline. The Hi-Fi version offers playback in the Hi-Fi format (uncompressed music files at 1411 kbps) and MQA (Master Quality Authenticated) format (recordings from the studio). It offers similar capabilities as Spotify, except for remote control and group sessions.

4.3 Netflix

This platform is focused on audio-video content consumption, such as movies, series and other materials. However, the library is strictly dependable on the region in which the user is located. Content consumption in SD, HD and 4K formats is only possible with a subscription.

A dedicated application is available on a variety of consumer devices. Additionally, users can download content directly to their device and watch it while being offline. It offers a variety of user profiles and related suggestions based on similar and/or previously watched content, as well as a resume playback option when the viewing process was interrupted.

4.4 Twitch

This streaming platform was designed in order to connect the gaming and broadcasting industry. Currently, Twitch allows creators not only to upload and share content with others, but also earn money from ads and subscriptions. The displayed audio-video quality is dependable on current network conditions (auto mode). However, one can chose one of the following resolutions: 160p, 360p, 480p, 720p, 720p 60 FPS, and 1080p 60 FPS. The dedicated application enables to select from a variety of broadcast categories, including type of gameplay, individual creators. It offers the possibility to watch saved broadcasts or their fragments, adjust playback settings or even start a fresh live streaming session.

4.5 YouTube

This platform is available in a free version (with advertisements) as well as a premium one (no displayed advertisements). However, both version allow creators to earn money. The premium version enables to play audio and/or video with the screen turned off. The resolution ranges from: 144p, 240p, 360p, 480p, 720p 60 FPS, 1080p 60 FPS, even up to 4K. The application offers multiple search options, including movies, playlists, even channels broadcasting live.

5 ABOUT THE STUDY

The study was carried out using a set of 50 mobile devices coming from different manufacturers. Each terminal was running Android 10 and had a 8-core processor and 4 GB of RAM. The display resolution was equal to Full-HD. All consumer electronics were compatible with Wi-Fi 802.11 a/b/g/n/ac, as well as 2G, 3G, and 4G cellular networks.

The serving network infrastructure was realized with a typical Wi-Fi access point, with 2x2 MIMO antenna array, operating in the 2.4 GHz frequency range. After a preliminary benchmark, the Internet connection was set to the following throughput values:

- Download speed: maximum 300 Mbps, typical 225 Mbps, minimum 150 Mbps;
- Upload speed: maximum 40 Mbps, typical 30 Mbps, minimum 20 Mbps.

All data sourced from mobile devices, for monitoring as well as further processing purposes, were gathered in a wired manner, in order not to influence the wireless connectivity, using a custom Linux-based software. The current status was refreshed every second.

The streaming services were installed in the currently available distribution, sourced from the Android dedicated application market. The research campaign was composed of a set of scenarios, including both Wi-Fi and cellular connectivity, together with audio and mixed audio-video content, as shown in Table 3.

Table 3: Investigated research scenarios.

Name	Wireless interface	Type of content
Scenario 1	Wi-Fi	Audio-Video
Scenario 2	Wi-Fi	Audio
Scenario 3	Cellular	Audio-Video
Scenario 4	Cellular	Audio

In each of the four scenarios, we have predefined the initial throughput value, based on type of streaming services as well as quality (related bitrate). The list of settings, for each respective scenario, are shown in Tables 4-7.

Table 4: Initial parameters for scenario 1.

Approach no.	Streaming application	Content quality	Initial throughput [kbps]
1	Netflix	240p	1024
2	Netflix	480p	1024
3	Netflix	1080p	1024
4	YouTube	240p	1024
5	YouTube	480p	1024
6	YouTube	1080p	1024
7	Twitch	240p	1024
8	Twitch	480p	1024
9	Twitch	1080p	1024

In case of scenario 1, the content quality ranged from 240p up to 1080p, regardless of the type of utilized streaming application.

Table 5: Initial parameters for scenario 2.

Approach no.	Streaming application	Content quality	Initial throughput [kbps]
1	Spotify	Low	512
2	Spotify	Normal	512
3	Spotify	High	512
4	Tidal	Normal	512
5	Tidal	High	512

For scenario 2, the content quality ranged from low up to high for Spotify, and from normal to high for Tidal.

Table 6: Initial parameters for scenario 3.

Approach no.	Streaming application	Cellular network	Content quality
1	Netflix	3G	480p
2	Netflix	4G	480p
3	YouTube	3G	480p
4	YouTube	4G	480p
5	Twitch	3G	480p
6	Twitch	4G	480p

Scenario 3 was focused on investigating different audio-visual content distribution streaming applications, available in 480p resolution, via 3G or 4G terrestrial radio interfaces.

Table 7: Initial parameters for scenario 4.

Approach no.	Streaming application	Cellular network	Content quality
1	Spotify	3G	High
2	Spotify	4G	High
3	Tidal	3G	High
4	Tidal	4G	High

Whereas scenario 4 was aimed at investigating audio content distribution applications, available in high quality, transmitted via 3G and 4G as well.

In each of the four scenarios, we have performed typical user activities, including: moving forward and backward, skipping and selecting another material, selecting and switching to and from a playlist, turning full screen mode on and off.

6 RESULTS

Results, concerning all the aforementioned scenarios, user activities, as well as devices, have been averaged, concerning utilized CPU and RAM resources, are shown in Table 8.

Obtained data indicate, quite surprisingly that the quality of the consumed content itself does not affect the CPU usage. In case of RAM, the situation is quite the opposite. However, this increase is not linear with the rise of quality of media. This fact indicates that although RAM is more affected than CPU, the overall usage depends on a number of factors.

Additionally, larger deviations were observed during the 1080p content playback. This surely was related to data buffering, resulting from a seldom bottleneck in available bandwidth. Moreover, according to obtained results, the type of Internet connection did not directly affect the CPU and RAM usage.

When analyzing particular streaming services, it can be noticed that they strictly depend on the particular application. The Netflix mobile application consumed an average of approx. 40%, whereas YouTube and Twitch apps used approx. 35% and 50%, respectively. The average RAM usage was lowest in case of YouTube, resulting in approx. 8%, whereas Netflix and Twitch apps required a little more, namely 10% on average.

As expected, streaming audio files required less processing power than streaming mixed audio-video files. The Spotify platform used 30% of the CPU processing power, whereas Tidal required only approx. 20%. In case of both applications, the RAM usage oscillated around 8-10%.

7 CONCLUSIONS

The conducted research had shown that the mere change in quality of consumed content did not significantly affect the usage of CPU and RAM resources. In case of a dedicated mobile application, the type of Internet connection did not contribute to a significant change in the resource consumption as well.

Table 8: Overall results concerning CPU and RAM usage with respect to type of streaming service, type of content, and type of network connectivity.

Scenario	Approach no.	Avg. CPU usage [%]	Std. deviation	Avg. RAM usage [%]	Std. deviation
S1	1	38.79	18.38	9.44	0.80
	2	41.29	18.89	10.25	0.58
	3	40.74	16.53	10.20	0.50
	4	34.31	21.99	8.06	0.52
	5	35.01	20.19	8.05	0.35
	6	58.46	22.67	7.81	0.26
	7	50.47	11.31	11.95	0.28
	8	53.23	13.69	9.54	0.22
	9	75.56	22.16	8.83	0.24
S2	1	33.16	6.38	9.49	0.14
	2	29.71	8.00	10.27	0.15
	3	30.39	5.92	7.80	0.21
	4	16.64	10.57	10.45	0.43
	5	21.44	14.16	7.20	0.21
S3	1	34.25	18.40	7.89	0.70
	2	34.17	19.62	11.17	0.51
	3	32.82	24.92	8.90	0.33
	4	41.30	27.47	9.52	0.36
	5	43.10	13.81	12.36	0.59
	6	44.19	12.11	9.47	0.75
S4	1	27.55	10.44	7.18	0.22
	2	61.85	14.76	10.53	0.44
	3	19.39	19.73	7.51	0.67
	4	20.50	16.74	7.82	0.45

On the other hand, this research experiment also shown that high network bandwidth and stable connection enables high-quality media streaming without the need for buffering.

Streaming services encode the transmitted multimedia implicitly, which may result in the direct usage of CPU and RAM resources. This could be one of the reasons why did the resource usage of a mobile device differ. These differences may also result from the developers' approach to optimizing mobile applications, etc. Currently, a broad range of Android mobile devices is freely available on the market. That is why most developers try to make their products widely acceptable (e.g. due to the number of distributions of an operating system available on the market). The set of smartphones, utilized during this study, is new and up to date. This may be one of the reasons why the differences in resource usage did not significantly differ.

It seems that the question regarding code optimization, resource usage, network connectivity, etc., remains open. Future investigation may be related with a broader range of consumer devices, including a wide variety of manufacturers, different distributions of the Android operating system, as well as diverse Wi-Fi access point manufacturers and cellular network providers.

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