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Research Paper

On the Consumption of Multimedia Content Using Mobile Devices: a Year to Year User Case Study

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In the early days, consumption of multimedia content related with audio signals was only possible in a stationary manner. The music player was located at home, with a necessary physical drive. An alternative way for an individual was to attend a live performance at a concert hall or host a private concert at home. To sum up, audio-visual effects were only reserved for a narrow group of recipients. Today, thanks to portable players, vision and sound is at last available for everyone. Finally, thanks to multimedia streaming platforms, every music piece or video, e.g. from one's favourite artist or band, can be viewed anytime and everywhere. The background or status of an individual is no longer an issue. Each person who is connected to the global network can have access to the same resources. This paper is focused on the consumption of multimedia content using mobile devices. It describes a year to year user case study carried out between 2015 and 2019, and describes the development of current trends related with the expectations of modern users. The goal of this study is to aid policymakers, as well as providers, when it comes to designing and evaluating systems and services.

Keywords: audio coding; broadcasting; mobile devices; multimedia; signal processing; streaming services.

1. Introduction

Nowadays, due to the presence of numerous multimedia streaming services, e.g. YouTube, YouTube Music, Apple Music, Google Play Music, Netflix, Spotify, Twitch, etc., content streaming is a crucial application. It should be also noted that social media, such as Facebook, can also be used for content distribution. Their success, together with web browsers, is the focus of attention of numerous researchers interested in a variety of aspects, ranging from energy optimisation and network planning to recommendation systems. The main reason is the process of streaming itself, performed using wireless networks, since current mobile devices use a lot of power for constant decoding of multimedia content in order to present them via speaker or display. Rich content distribution among handheld devices, such as smartphones and tables, is becoming more and more popular every year. With the outcome of online streaming services, including VoD (Video-on-Demand) and other cloud based solutions, numerous service providers sometimes face bottlenecks, resulting in stalling or buffering. This paper describes a survey carried out over a period of 5 years.

2. Mobile streaming services

Over the last decades, the music industry continues to adapt to constant changes in technology. The breakthrough came in 2017, when streaming and downloading revenue outweighed physical music sales, such as CDs and vinyl. Mobile streaming services are not uniform themselves. They are comprised by streaming sociomusical platforms (e.g. Spotify), musical social systems (e.g. last.fm), music distribution services (e.g. Soundcloud), as well as millions of users that generate income, both from subscription and advertisement.

What is worth mentioning, streaming takes place at the expense of downloading music from the Internet. Surprisingly, it was the leading driver of revenue for the U.S. music industry, whereas downloading albums, compared to 2016, decreased by approx. 15%. On the other hand, vinyl sales increased by 20% compared to 2016, which accounts for 10% of all physical media sales (Christman, 2017). The list of most popular terrestrial broadcasting as well as online streaming services, along with primary information concerning utilised codec and bitrate, is described in Table 1.

Table 1. Popular terrestrial broadcasting and online streaming services.

Type	Service	Codec	Bitrate [kbps]
Terrestrial broadcasting	DAB (Digital Audio Broadcasting)	MP2	64–192
	DAB+ (Digital Audio Broadcasting plus), DMB (Digital Multimedia Broadcasting), DRM (Digital Radio Mondiale), DRM+ (Digital Radio Mondiale plus)	HE-AAC v2	48–128
Online streaming	Amazon Music	FLAC, MP3	up to 256
	Apple Music	AAC-LC	128–256
	Deezer	HE-AAC v2, MP3	24–128 (HE-AAC v2) 64–320 (MP3)
	Google Play Music	MP3	64–320
	Netflix	H.264	Audio: up to 768 Audio-Video: up to approx. 16 000
	Pandora	HE-AAC	up to 192
	Spotify	Ogg Vorbis	96–320
	Tidal	MQA	up to 1411
	Twitch	AAC-LC, H.264	Audio: up to 160, recommended 96 (AAC-LC, H.264) Audio-Video: up to approx. 8000 (H.264)
	YouTube	AAC-LC, H.264	Audio: up to 192 (AAC-LC) Audio-Video: up to approx. 16 000 (H.264)
	YouTube Music	HE-AAC v2	48–256
	Web streaming (various)	AAC-LC, HE-AAC v2, MP3, Ogg Vorbis, Opus	32–320 (AAC-LC, Opus) 24–128 (HE-AAC v2) 64–320 (MP3, Ogg Vorbis)

One must note that in the case of the majority of online streaming platforms, especially those focused on audio content distribution, the codec and bitrate, being closely linked with end user perceived quality, are strictly dependent on the type of service. Most often, the highest quality is reserved only for those consumers who pay a monthly premium subscription fee. When it comes to terrestrial broadcasting services, e.g. DAB+ digital radio, quality remains the same for each consumer. In the case of Poland, the bitrate of audio services ranges from 64 to 128 kbps, whereas e.g. in the Czech Republic it ranges from 48 to 80 kbps (Zyka, 2019). At the same time, additional value-added data services are available at 16 kbps. It is also easy to notice how online multimedia streaming can affect the battery life of a mobile device.

2.1. *Energy consumption*

During the last years, a wide range of solutions has been proposed to optimise energy consumption of multimedia streaming clients. They include operation at different layers of the Internet protocol stack, at different endpoints in client-server communication, etc. These solutions, applicable to commercial consumer mobile devices, are most often limited to networking technologies, such as Wi-Fi, 3G, and LTE. Some of them propose application layer techniques using SVC (Scalable Video Coding), transcoding and content selection. These solutions differ from the others, since they modify the actual multimedia content to reduce energy consumption of the mobile client (Hoque *et al.*, 2014).

In (Vallina-Rodriguez, Crowcroft, 2012), the authors look at smartphone energy management techniques from the following perspectives:

1) energy-aware operating systems,
2) efficient resource management,
3) impact of users' interaction patterns with mobile devices and applications,
4) wireless interfaces and sensors management,
5) benefits of integrating mobile devices with cloud computing services.

Of course, some factors can be linked with wireless communication aspect, particularly issues related with network planning and network monitoring.

2.2. Network planning

In (Havinga, Smit, 2001), the authors focus on MAC (Medium Access Control) layer solutions and energy-efficient error control techniques. Extensive power aware mobile multimedia was surveyed by (Zhang *et al.*, 2009), where the authors investigated adaptive technologies for video coding and transmission.

In (Cao *et al.*, 2004) the authors provided an overview of network-aware applications for mobile multimedia delivery. However, they excluded energy-aware multimedia delivery techniques. Software strategies that are applicable to portable computer energy management were surveyed in (Lorch, Smith, 1998). The study covers all components of a portable device, including wireless interfaces.

Another paper by (Kennedy *et al.*, 2012) also addressed energy consumption of different components of a mobile device during multimedia streaming. As far as the networking interface is concerned, the authors mostly focused on link layer solutions, as well as cross layer multimedia delivery mechanisms. While most studies analyse multimedia streaming in the regular client-server architecture, a survey on the research on QoS (Quality of Service) for peer-to-peer media distribution was presented in (Xiong *et al.*, 2011). However, that survey did not discuss energy consumption required for multimedia streaming.

In (Počta, Beerends, 2015), the authors investigate the perceived quality of current audio-based services; (Uhl *et al.*, 2017) and (Brachmański, 2018) describe quality evaluations of speech signals. Biases encountered in modern audio listening tests are discussed in (Zieliński, 2016). In (Leszczuk *et al.*, 2013) and (Uhl, Paulsen, 2014), both QoS and QoE (Quality of Experience) aspects related to video streaming services are investigated. Additional information on multimedia broadcasting and multicasting, particularly in mobile networks, may be found in (Iwacz *et al.*, 2008).

Another paper, by (Gilski, Stefański, 2016), talks about the possibilities, limitations, and user expectations related to analogue and digital services. After an extensive literature review, no surveys were found on the topic of consumption of multimedia content using mobile devices. That is why this year to year case study was carried out.

3. Survey

In order to evaluate current trends in the multimedia content consumption, a survey had been carried out. This user-oriented study was performed over a five year time period, from 2015 to 2019, on a group of 50 people each year, respectively. Those individuals were all students of the Gdańsk University of Technology, aged between 19 and 25. It was interesting to learn how their expectations changed over the time, with the outcome of numerous portable devices as well as streaming services available online, which undoubtedly had an impact on today's digital society.

The study was divided into 4 groups, namely:

1) consumption of multimedia content;
2) consumer devices;
3) processing and storing content;
4) Internet connection.

The survey consisted of closed and opened questions, in order to ensure the best possible feedback from each individual and freedom of expression.

3.1. Consumption of multimedia content

The first part was devoted to the consumption of multimedia content. Figure 1 shows the percentage of users consuming this type of content, whereas the popularity of online streaming platforms is shown in Fig. 2.

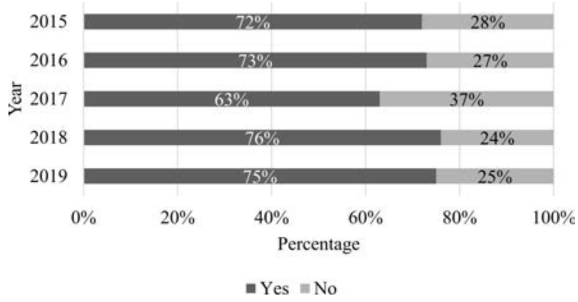

Fig. 1. Consumption of multimedia content.

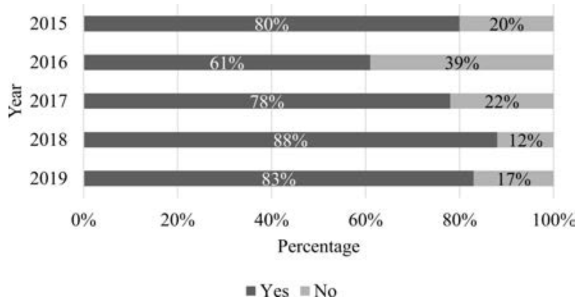

Fig. 2. Usage of streaming platforms.

As it can be seen, the majority of users are interested in consumption of multimedia content. The percentage of active users exceeds 70%, with an exception in 2017, where a slight decrease was observed. The main cause for choosing streaming platforms, and not traditional terrestrial networks, including digital terrestrial television DVB-T, as well as terrestrial analogue FM and digital DAB+ radio (Gilski, 2017a), was the need for a broader programme offer.

An overall definition of online streaming services is that they are created by separate components, including songs, albums, metadata, etc., in a way that helps to meet the user's needs and expectations. After a closer look on the characteristics and functionality of these services, two categories can be distinguished:

1) traditional streaming services – high availability of music pieces, radio stations, music recommendation, along with the ability to add friends and watch them, create and share playlists, subscription fees, etc.;
2) sociomusical services – webpages of artists, albums, songs, events, with the ability to track music listened by other users, have discussions with them, even receive recommendation based on an individual's taste, comparing one's music taste with other users, providing statistical data, along with distribution services intended mainly for debuting artists.

The preferred type of used streaming platforms, either payable or free, is shown in Fig. 3.

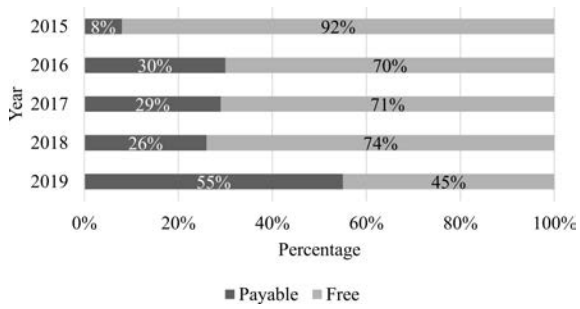

Fig. 3. Preferred type of streaming platform.

Not surprisingly, users favour free services instead of payable ones. It is worth mentioning that when it comes to quality, some of them offer only a limited bitrate, most often equal to 48 kbps for audio content. Higher bitrates, ranging up to 128 kbps or even 320 kbps, depending on the codec used, are available only for those who buy a premium account or make a payment and/or monthly subscription. Surprisingly, after 2015 there was a significant increase in the number of users who wanted to consume premium high-quality content. Most often this option was also related with less and/or no advertisements, including commercials launched at the beginning, end, or after a part of material. In 2016, the percentage of payable services reached 30%, and remained at this level up till 2018. Since 2019, a huge increase can be observed. The share of the most popular services is shown in Fig. 4.

The leading streaming service, Spotify, has over 60 million active users and 15 million subscriptions. It is available on the most popular operating systems, including: Android, iOS, Windows, and BlackBerry. Spotify operates on two layers: general map of relationships between songs and personalisation layer.

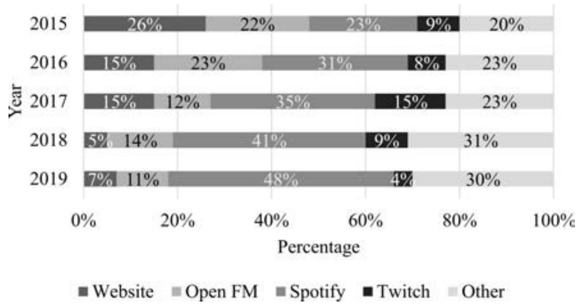

Fig. 4. Most popular streaming platforms.

The first one analyses all playlists of all Spotify users, how they choose them, which songs are played and how they use other functions of the application. This enables a continuous analysis inside the cloud-based service in order to learn the interconnections between users and songs. In the second layer, all conclusions from the first analysis are confronted with the user's musical preferences. This means not only what a particular user listens to, but what songs he or she likes to combine. Processing these two sets of dependencies results in a weekly playlist. On this basis, a recommendation playlist for each individual user is released every week. This list of albums and artists is not a random selection of an algorithm. It results from a careful analysis prepared by music journalists, people who know what new and noteworthy pieces appear on the market.

Other applications include TuneIn (with 4% in 2015 and 0% after 2015), Apple Music, launched in 2015 (with less than 10% between 2017–2019), and YouTube Music, launched at 2017 (with less than 5% between 2017–2019).

The dedicated platform for iOS, Apple Music, is an integrated system that combines streaming and Internet radio with a social platform in order to track the activity of one's favourite artist. However, the feature of creating and sharing playlists is not available.

Other platforms, considering those not indicated in this study, include Deezer and Google Play Music. Deezer is the largest library of recordings, comprising over 35 million songs. The service differentiates between subscribers. The premium version enables one to access higher-quality music files, with bitrates ranging up to 320 kbps. It is available for downloading files and streaming recordings and can be used on e.g. TVs and car audio systems.

Google Play Music has more than 20 million songs. Each user can create a personalised music collection, even up to 50 000 songs. The music recommendation system itself is based on a number of factors, including playback history, social media activity, and activity in the service application. This service enables users to add their own recordings and buy additional songs in the Google Play store (Kostek, 2018).

3.2. Consumer devices

Even though listening to music using portable multimedia players is opposed to listening to live music, a trend can be observed. Currently, as shown in Fig. 5, over 80% of users utilise this kind of devices in order to consume content. The biggest leap was observed in 2016 and 2019, where 99% declared possessing and using portable players.

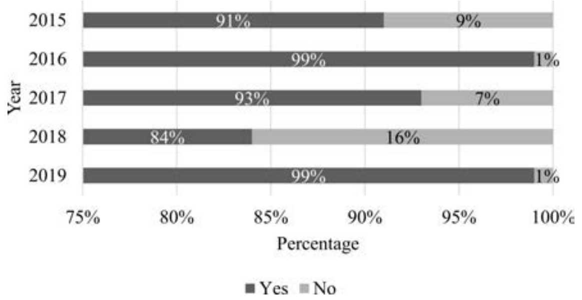

Fig. 5. Usage of portable multimedia player devices.

As indicated in Fig. 6, the smartphone remains the most popular device. Not surprisingly, the laptop comes at the second place, since it combines the productivity of a desktop device with the mobility of smaller portable ones. The third device of choice is a classical MP3/MP4 player. Other included e.g. a CD player (with 2% in 2015 and 0% after 2015), E-book reader used by people to listen to audio files (with 1% in 2015 and 2% in 2018 and 2019), as well as a tablet (with 6% in 2015 and 3% in 2018 and 2019).

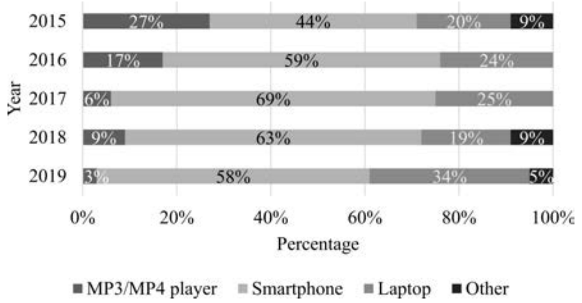

Fig. 6. Most popular portable multimedia players.

With the outbreak of numerous portable devices, their availability, including different operating systems, as well as light weight, users tend to favour multimedia consumption on portable, rather than desktop devices, as shown in Fig. 7.

When it comes to defining the most popular portable device, as shown in Fig. 8, after 2015, the smartphone is undeniably the first choice, the laptop comes in second, whereas the tablet has a fairly stable group of fans.

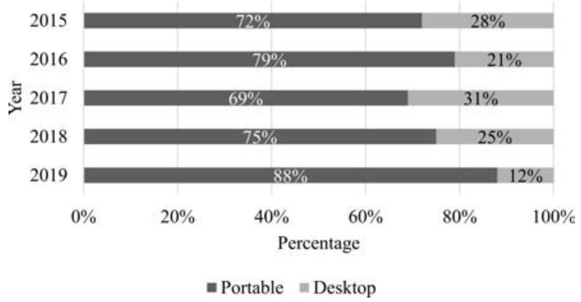

Fig. 7. Preferred type of device for content consumption using streaming platforms.

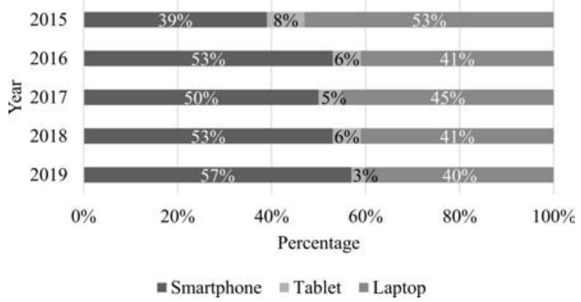

Fig. 8. Preferred type of portable device.

As indicated by the users, digital content has one main advantage, which is annotation. Annotation is generally understood as associating any element of musical content, such as lyric, title, music genre, with some additional information, i.e. comments. However, when talking about labeling pieces of music, playlists, radio channels, etc., the problem is still far from being solved, or even optimised. Music is very complex and exhibits a significant amount of variation. Different genres or styles can overlap, making metadata extraction more difficult.

3.3. Processing and storing content

In modern devices, having the display on while decoding multimedia content can consume a large part of energy. Of course, the energy required to decode audio or video content depends on the computational complexity of the codec and/or compression algorithms used for encoding. Researchers discovered that H.263+ (Cote *et al.*, 1998) is the least energy hungry, whereas MPEG-4 (Koenen, 2002) and Windows Media are the most energy hungry codecs or compression techniques (Lin *et al.*, 2010). However, many research efforts improve battery life time of mobile devices by introducing different techniques while decoding, such as dynamic voltage scaling (Simunic *et al.*, 2001), CPU register, or cache optimisation (Asaduzzaman, Mahgoub, 2006), traffic concealing at the network interface (Wang *et al.*, 2011), OS or application level optimisation (Mohapatra, Venkatasubramania, 2003). Display optimisation for multimedia streaming to mobile devices also had been studied in (Hsiu *et al.*, 2011).

According to the obtained results, as shown in Fig. 9, users still favour lossy compression algorithms for offline multimedia consumption. Despite the outbreak of newer and more efficient coding techniques, as shown in Fig. 10, MP3 is still the leading format, FLAC came in second, whereas WAV came third. Other, including the AAC (Advanced Audio Coding) and Ogg Vorbis format, did not exceed 12%. Quite surprisingly, neither of the aforementioned formats exceeded 2%. However, it should be pointed out that the results from Figs 9 and 10 refer only to the offline multimedia consumption.

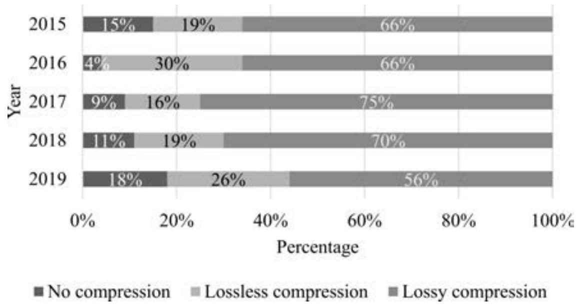

Fig. 9. Preferred type of compression method.

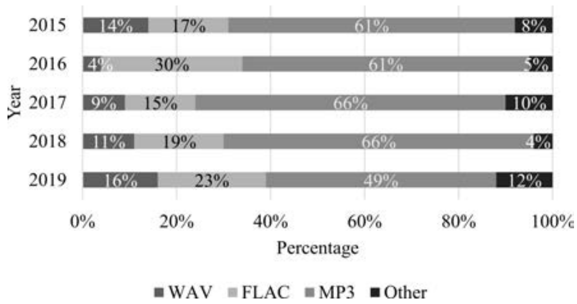

Fig. 10. Preferred audio format for storing audio files.

A very fundamental question remains open whether quality of music is still important. One may have an impression that this is no longer an issue, as millions of users download and stream music of low quality, most often in order to cope with limitations of a mobile data plan. On the other hand, live music events, both concert performances and reinforced events, gather thousands of people and this brings new technology to live reinforced music. Not surprisingly, whenever users have a choice, they choose the highest bitrate available, as shown in Fig. 11. Only in 2015 users declared a bitrate lower than 128 kbps.

The process of assigning appropriate bitrates is not trivial and takes a lot of time, especially when managing with limited resources (Gilski, 2017b). Tagging music data is most often carried out manually and requires a person with a musical background. Currently, service providers lean to the conclusion that social tagging, carried out by users themselves, will help music services to describe their cloud content more precisely.

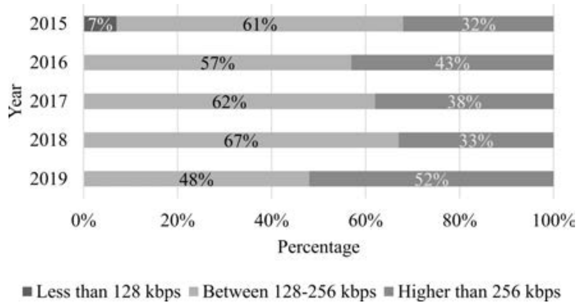

Fig. 11. Preferred bitrate of audio content.

3.4. Internet connection

Although display and decoding are often responsible for a large part of energy consumption, wireless interfaces can equally deplete the same amount of energy while running audio or video streaming applications on mobile devices. The type of preferred Internet connection is shown in Fig. 12, whereas the consumption of multimedia content with a mobile data plan is shown in Fig. 13. According to the obtained results, the biggest overbalance was observed in 2015. Since 2016, the network load of both fixed and wireless connections, i.e. cellular or Wi-Fi, tends to balance. Currently, over 90% of users regularly consume multimedia content using a mobile data plan.

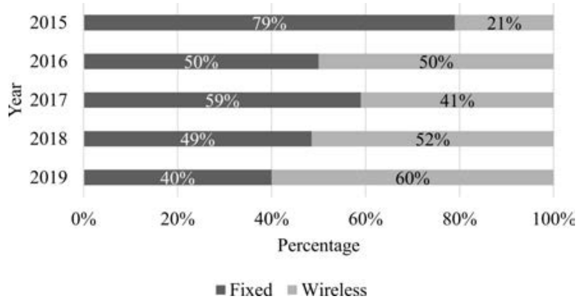

Fig. 12. Preferred type of Internet connection.

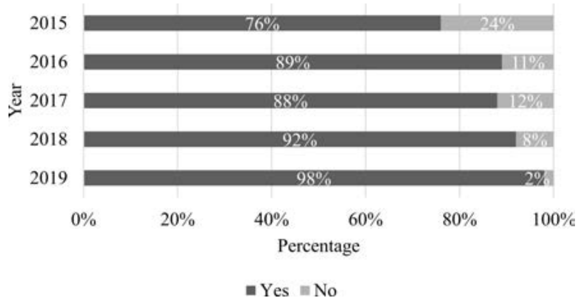

Fig. 13. Consumption of multimedia content using a monthly mobile data plan.

Just a few years ago, as shown in Fig. 14, in 2015 the majority of users had a data plan limit of 2 GB and less, with approximately a quarter even less than 1 GB. From 2016, this situation changed dramatically, where the majority of people have a data plan of more

Fig. 14. Data limit of a mobile data plan.

than 2 GB. However, still less than 10% of users have an unlimited data plan.

According to the studies, surprisingly, Wi-Fi can use roughly three times the energy required to decode audio or video content, whereas 3G interface requires around five times the audio decoding energy (Hoque *et al.*, 2011; Chandra, Vahdat, 2002). The reason for such high energy consumption is the continuous flow of network traffic, which forces these wireless radios to be powered up most of the time during streaming. Although these wireless technologies operate at the physical layer (PL), their power consumption highly depends on the wireless interface usage or management at the upper layers of the Internet protocol stack, such as at link layer (LL), network layer (NL), transport layer (TL), and application layer (AL). Therefore, these upper layers should be included in the energy consumption optimisation process. As it is shown, the aspect of network planning and management, particularly related to energy efficiency in wireless communication, for both audio and video multimedia streaming toward mobile devices, is still a wide topic, with different optimisation technologies still to come.

4. Summary

In order to consume multimedia content, one has to be connected to the Internet. With the outbreak of numerous devices with access to the web, referred to as IoT (Internet of Things), usage to music technology enables to perceive the whole music ecosystem as an inventory controlled by computer based technology, which includes not only music but also its user. One should be aware that our music taste, mood, what we share, things we download or stream, are all tagged. Thus we constitute an integral part of this ecosystem.

Undisputedly, new means and ways of delivering multimedia content have changed the way we perceive information. Currently, thanks to the global web, people can easily consume and exchange digitalised data. With the outcome of new mobile devices and streaming services, users changed their preferences. Currently most of us do not use physical drives to store music or video files. Online streaming platforms are doing this for us.

As it has been shown, there is a constant change in demand for devices and services. This forces new means and ways to emerge, especially when it comes to creating, processing, and delivering multimedia content, which has a significant effect not only on users or individuals but above all device manufacturers and network providers. The constant change for higher user revenue is joined with continuous efforts to maintain stable, reliable, and high-quality services.

In fact, next generation wireless technologies have put a significant emphasis on supporting distribution of rich media content and video-on-demand services. However, energy consumption in the handheld wireless devices is a major bottleneck that hinders the growth of mobile device based rich media services. The biggest problem today in the mobile world is that mobile devices are battery driven and battery technologies are not matching the required energy demand. It can be argued whether constant staring at the screen is the best way to take advantage of convenience that modern technology brings.

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