

# Overview: Operating Systems of Modern Terminal Devices

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**Abstract**—Development of technology and expansion of different types of sophisticated terminal devices resulted in an increase of the variety of operating systems. Besides classical devices like personal computers or smartphones driven by conventional operating systems, a number of modern categories of devices with built-in newly developed unconventional operating systems emerged. A classification of terminal devices followed by a comprehensive overview of all the types of OS and an analysis of the trends in their further development were required. This paper provide an overview of the operating systems of smart vehicles, smartwatches, smart TVs and smart home speakers, as well as their global market shares.

**Keywords** - *unconventional operating systems; classification of terminal devices; history of operating systems; smart assistants*

## I. INTRODUCTION

The offering of different operating systems passed the past half a century through various states and in moments was very complex with the availability of a large number of different platforms, and in other periods very simple with the offer of two or three systems.

Until recently the term Operating System (OS) referred to a small number of possible software solutions. Microsoft Windows dominated most of the world markets, followed by Linux and Mac OS. The list of terminal devices (TD) requiring an OS for their functioning was limited to personal computers, laptops, servers and some gaming consoles.

However, in the recent past the number of devices driven by their own OS has been gradually growing, causing a diversification in the field of OSs. New OSs are being developed by either modifying the existing OSs like Android, iOS or Linux, or by creating new software solutions for specific types of devices.

Operating systems that can be categorised as “Conventional” (MS Windows, Mac OS and Linux for computers and Android and iOS for smartphones) are very well covered in a large number of publications. However, a comprehensive overview of other OSs that may be categorised as “Unconventional” is not that easy to come by. Unconventional are all the OSs developed for modern TDs which traditionally did not require an OS. This paper offers a general overview of the current situation in the field of OSs of TDs, with an emphasis on Unconventional OSs.

## II. OPERATING SYSTEMS IN GENERAL

### A. Terms and Definitions

According to [1], Operating System can be defined as software that acts as the connection between computer users and computer hardware; or as a set of programs that control how computer resources are used and how programs are executed.

*Casting* is a service that enables the delivery of multimedia from a computer, tablet or smartphone to the screen of a TV or other type of TD without using a physical connection. There are two types of casting: *mirroring* and *streaming* [2].

*Virtual Assistant* (VA, also called *Digital Personal Assistant*, or *Voice Assistant*) is a cloud-based software service that uses artificial intelligence (AI) platforms in order to respond to users' requests or queries. The most common functions performed by VAs include voice recognition and text-to-speech, which allows users to dictate their queries or listen to their e-mails while driving [3]. VAs are being used in almost all of the TDs that are considered “smart”, which means that most of the OSs in use today have at least one VA application integrated.

VA services may even be considered to be a simple kind of an OS, due to the ever-increasing range of functions that they perform and due to the fact that some of them also manage and control other devices. As a consequence, it may seem that to some software companies the main priority isn't so much if a TD is running their OS, just as long as it has their VA integrated. Recently TDs have appeared with more than one VA installed, taking advantage of the most successful function of each of the VAs [4]. The most significant limitation of the VAs is still the small range of supported control languages. However, the number of languages effectively used keeps growing and it's safe to believe that rather soon voice controlled VAs will be common in homes and vehicles worldwide.

### B. Classification of Terminal Devices

TDs are defined as devices located at the ends of the communication channel, which convert various forms of information into electrical signals suitable for transfer through the channel, and vice-versa [1].

TDs may be classified in many different ways, but for this paper the most suitable classification is to “Classical” and “Modern” devices. Classical TDs with OSs are personal computers, servers, smartphones and tablets.

Modern TDs can be defined as those that already exist in some form, but just recently became complex enough to require an OS to properly function. Thus, modern TDs include, but are not limited to smart vehicles, smart TVs, smartwatches and smart home speakers.

Figure 1 shows the increase in the number of connected devices between 2015 and 2017, as well as the projected increase between 2018 and 2025. There are many reasons for the increasing expansion of TDs with their own OSs, one of most obvious being rapid development of technology that enables mass production of connected devices capable of performing multiple tasks [6].

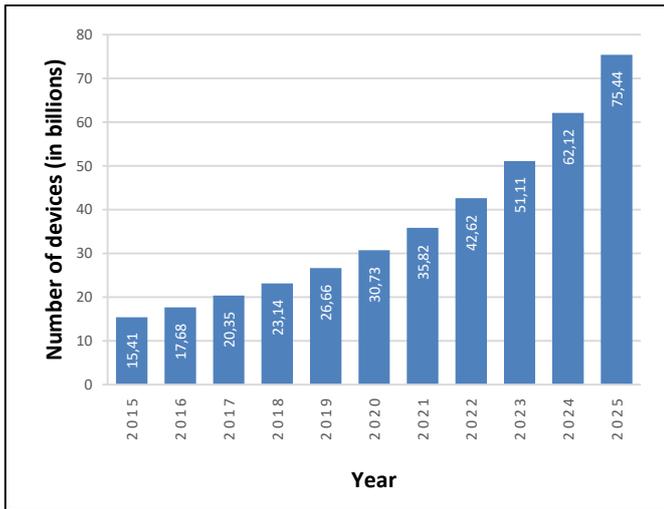


Figure 1. Increase in the number of connected TDs [5]

Current trends point to the fact that further expansion of different types of OS powered TDs should be expected, especially after full implementation of 5G technology.

### C. Smart Vehicles

Modern vehicles are equipped with numerous devices and sensors. Traditionally vehicles are not considered as TDs, but the fact that they are almost always connected to some network (e.g. mobile network, navigation system, FM radio etc.) justifies their inclusion into this category. Newer models often have several OSs installed, each controlling a certain component of the overall system. *In-Vehicle Infotainment (IVI)* is a common name for software that controls all those components and also provides various information and entertainment to the driver and passengers. The more complex systems are referred to as *Automotive Infotainment Operating System*.

Development of a new vehicle model is a process that usually takes from three to five years, with different departments within the company developing separate components. Not surprisingly, many times new vehicle models are presented with already obsolete IVI systems without the option of being updated [7].

Another challenge related to IVI systems is effective integration of all the vehicle sub-systems in a safe manner that

provides the driver and passengers with all the required information, using the available hardware (e.g. to display navigation information, AC information and currently playing FM radio station on an 8-inch screen without unnecessarily distracting the driver).

New trends in the development of electric and hybrid vehicles, development of self-driving vehicles, and introduction of the 5G technology that will enable constant connectivity of all the traffic elements will have significant impact on future software solution for vehicles [8].

Currently, IVI systems are expected to offer many options, which include:

- Integration of the IVI with other systems in the vehicle;
- Connectivity through Wi-Fi and LTE;
- Modern navigation with updated traffic information;
- Bluetooth connectivity with Hands-free devices and with other TDs (Machine to Machine);
- Integrated VA with voice commands and gesture control;
- Integration with smartphones;
- Multimedia casting from smartphones to IVI displays.

### D. Smartwatches

First types of “smarter” watches were introduced in the 1970s in the form of digital watches [9]. In the following decades several attempts of developing wrist-computers that could connect with PCs or mobile phones failed due to various reasons **Chyba! Nenašiel sa žiaden zdroj odkazov.. Pebble watch** from 2012 is considered as the first smartwatch that managed to reach significant popularity and start a new trend in this type of TDs.

Smartwatches are mainly used as an extension of the smartphone, although some newer models function as stand-alone smart devices. A smartwatch is expected to provide many functions, which include:

- Connectivity with smartphones (via Bluetooth);
- Displaying notifications (e.g. incoming calls or messages);
- VA support with voice commands;
- Establishing and conducting voice calls and messaging;
- Direct connection to Internet via Wi-Fi (and LTE for supported devices);
- Installing third-party applications;
- Tracking body functions via built-in sensors (e.g. heartrate, counting steps, etc.);
- Navigation (some devices have built-in GPS);
- Contactless payment via Near Field Communication (NFC) technology;
- Image and video recording via built-in camera.

Two significant functionalities stand out among other smartwatch features [10]:

- *Fitness* – smartwatches have proved to be very good fitness trackers due to their built-in sensors that track various body function parameters, combined with navigation and other sensors in smartphones;
- *Health* – smartwatches can use their built-in sensors to constantly track various medical readings and send data directly to a physician, limiting the need for personal contact.

#### E. Smart TVs

TV sets are an essential part of almost any home for over 30 years, but recently their functionality has extended beyond simple reception and display of multimedia from aerial antennas or cable networks. By connecting to Internet and other TDs their possible functions grow rapidly and their complexity requires development of specialised OSs [12].

Currently a number of software solutions are available and mostly their functions include:

- Connectivity to Internet via Ethernet cable or Wi-Fi;
- Possibility of controlling the TV with a smartphone;
- Connecting various devices (e.g. keyboard and mouse) via Bluetooth;
- Integrated VA with voice or gesture control options;
- Displaying multimedia content from a home network using the DLNA (*Digital Living Network Alliance*) standard;
- Streaming multimedia content directly from Internet (e.g. *Netflix, YouTube*, etc.);
- Casting multimedia from a smartphone or tablet;
- Installing third-party applications;
- Surfing the Internet;

Some companies have opted to develop their own specialised OS for their smart TVs, and others chose to modify existing solutions (e.g. Android).

#### F. Smart Speakers

The most recent category of “smart” TDs is the smart speaker (also called *smart home speaker*). Their main purpose for the users is to simplify and speed up some common daily activities. Most functions of smart speakers are based on VAs controlled by voice commands.

The smart speakers market is rapidly rising, not only by number of different models, but also by the number of different functionalities. Initially they were expected to recognise voice commands, access music files and play the desired content. However, desired functions of modern smart speakers include:

- Internet connectivity via Wi-Fi;
- Voice-operated VA installed (at least one);

- Text-to-speech functionality;
- Establishing and conducting voice calls;
- Multimedia reproduction (including videos for models with screens);
- Managing other devices (smart home functionality);
- Alarm and reminder;
- Online shopping or booking.

Since smart speakers are expected to run various applications and access online services, but also to manage other devices, their operation is controlled by some kind of OS. In some parts of the world the smart speakers are very popular. According to [13] almost 20% of US citizens own a smart speaker.

Due to the fact that smart speakers depend in their work on the voice recognition abilities of the installed VA(s), their main limitation remains the number of supported languages.

### III. CLASSIFICATION AND MARKET SHARE OF OPERATING SYSTEMS

Operating systems may be classified in different ways and based on various criteria. A common distinction is between proprietary and non-proprietary OSs.

For the purpose of this paper the most significant distinction is to conventional and unconventional OSs. Unconventional are all the OSs developed for modern TDs which traditionally did not require an OS.

Conventional OSs are those used on classical TDs like personal computers, servers, smartphones and tablets [1].

A certain pattern can be observed when studying the history of OSs for a certain type of TDs. In first few years a relatively large number of different OSs emerge, and after a period of competition two or three solutions manage to prevail while others mainly disappear.

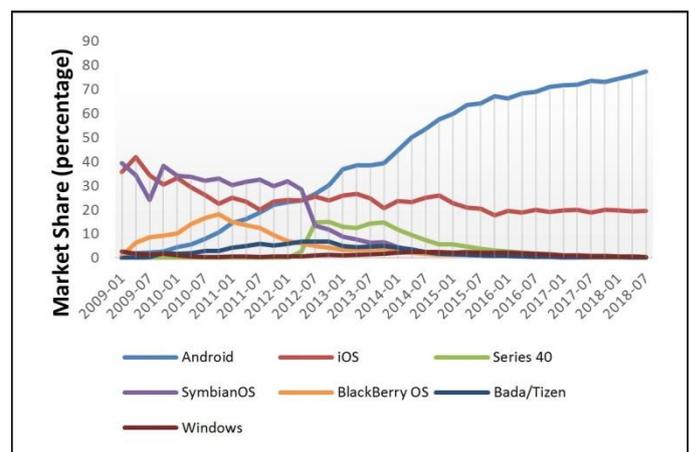


Figure 2. Market share of Smartphone OSs [5]

As depicted on Figure 2, the market share of smartphone OSs within previous 10 years follows the above mentioned pattern.

OSs for all types of modern TDs currently seem to be going through the phase of many available solutions, and time will show if in those cases the end state will be as in conventional OSs for classical TDs.

Software companies seem to be addressing the issue of developing new OSs in a different way. One of the obvious options is to modify the existing OSs (e.g. Windows or Android) to adapt them for a certain type of TDs. However, this approach hasn't always proved to be a good choice, like when the first attempts of using Android in vehicles resulted in drivers being too distracted, thus affecting safety.

Another approach is to develop a new OS, mainly based on Linux kernel which can be used free of charge. An example of this tactics is Samsung and their *Tizen OS* separately developed for smart TVs, smartwatches and other connected devices.

The third option is to join forces and create associations of companies with the goal of developing, maintaining and promoting software solutions. An example is the *Genivi Alliance* which brings together more than 100 various companies to a common project of developing vehicle IVI systems [14].

#### IV. UNCONVENTIONAL APPLICATION OF CONVENTIONAL OPERATING SYSTEMS

Major software companies have mainly recognised the need to develop versions of their OSs for the newly emerging modern TDs. They have been reminded to do so by several examples from the recent past where some leading companies lost their primacy or even completely vanished because they failed to keep up with changes (e.g. Nokia or Blackberry smartphones).

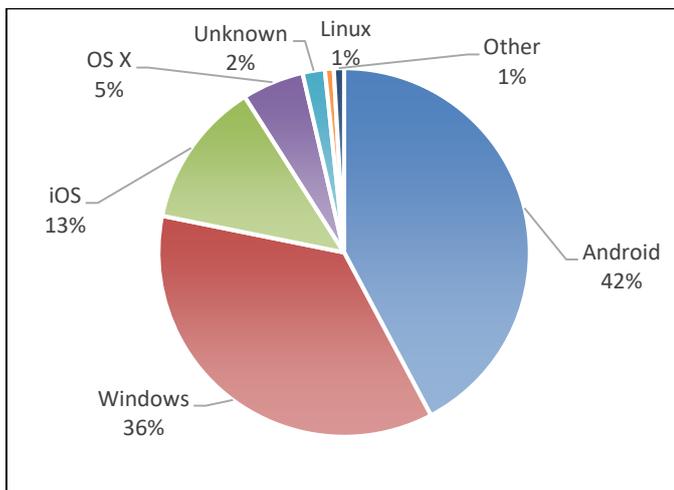


Figure 3. Global market share of Operating Systems (July 2018) [15]

Figure 3 shows the global market share of all the OSs. The domination of the three above mentioned companies is evident and each of them is in their own way trying to maintain or increase their share.

##### A. Apple

Apple is a company that bases their business plan on closed software and cloud solutions and closed connection between their hardware and software. Their products are almost always priced way above average and in many cases very limited in

usability, however by strong advertising and achieving the "must have" with their costumers they manage to maintain high sales.

- *Apple CarPlay* is not an OS, but an application that integrates the iPhone with the supported vehicle's IVI system, thus bringing some OS functionalities to the vehicle [16].
- *WatchOS* has been developed specifically for Apple Watch, which is the usual practice of the company [17]. Regardless of many limitations (e.g. the full functionality of the watch can only be achieved in combination with an iPhone or iPad) their market share is currently highest of all the smartwatches.
- *Apple TV* is a multimedia device (*TV Box*) with the primary function of streaming content from Internet to a TV set. It practically brings smart TV functionality to any compatible TV [18]. It is controlled by a modified version of iOS called tvOS.
- *HomePod* is a smart speaker with the *Siri* VA installed. As usual for Apple, it is only functional in combination with an iPhone or iPad [19].

##### B. Google

*Google* has a business plan completely opposite from Apple. It is based on free and open software, with all the revenue coming from advertising. Also, the company is very active in creating, but also in taking advantage of new technologies.

- *Android Auto* is an application for android smartphones which connects the smartphone with supported vehicle's IVI system and brings smart car functionality to the vehicle, e.g. the *Google Assistant* VA [20].
- *Google Wear OS* is a modified version of the *Android OS* for wearables, mainly smartwatches. More than 20 different watchmakers incorporate Wear OS into their watches [21]. Installing third-party applications and *Google Assistant* VA are supported.
- *Android TV* is a modified version of the *Android OS* developed by Google for smart TVs and multimedia devices (*TV box*) [22]. The platform is fully integrated with the *Google Assistant* VA, enabling voice control either through a microphone integrated to the remote control or via a smartphone.
- *Google Home* is an OS developed from *Chrome OS* specifically for smart speakers and *Chromecast* devices. It has the *Google Assistant* VA integrated **Chyba! Nenašiel sa žiaden zdroj odkazov..**

##### C. Microsoft

*Microsoft* had been dominating the OS segment for years and still dominates in the personal computers' domain. It has not been too successful in creating new trends, and has had several major failures in the recent past (e.g. windows mobile).

Recently the focus of their business plan has started shifting towards cloud solutions, mainly related to *Office 365*. However, a set of software products called *Windows IoT family* (previously

known as *Windows Embedded*) is available for integration into various TDs [23].

Windows Embedded Automotive 7 (from 2010) is the latest version of their OS for vehicles. Ford has been equipped with this solution for some time. It is based on their hybrid kernel that is developed for all Embedded versions of Windows OS.

Microsoft has not so far developed versions of the Windows OS for the purpose of wearable devices such as a watch or for smart TVs.

## V. OVERVIEW OF UNCONVENTIONAL OPERATING SYSTEMS

There is a large number of different companies or alliances with software solutions which fall into the category of unconventional OSs. Therefore it is more practical to provide an overview by types of TDs.

### A. Smart Vehicle Operating Systems

Vehicle infotainment systems are becoming more and more complex. Automobile companies have for years been searching for solutions that will successfully incorporate all the demands for security and reliability on one side, and connectivity and entertainment on the other. Many companies have given up on developing their own solutions and accepted already existing software products. Thus, currently the IVI segment is being dominated by *Blackberry QNX*, *Android*, and various projects based on the Linux kernel (e.g. *Tesla UX* based on *Ubuntu Linux*).

Another example of a Linux-based solution is the *Rimac IVI* system, developed by the company *Rimac Automobili*. The OS has been developed from the *Boot2Qt framework*, which is based on the *Yocto project*<sup>1</sup>.

### B. Smart TV Operating Systems

*My Home Screen*, *Roku TV*, *Tizen OS* and *WebOS* are the most commonly used software products, alongside the already mentioned *Android TV OS* and *Apple tvOS*. Each of those platforms has some unique features and the complexity of this segment is best shown by Figure 4.

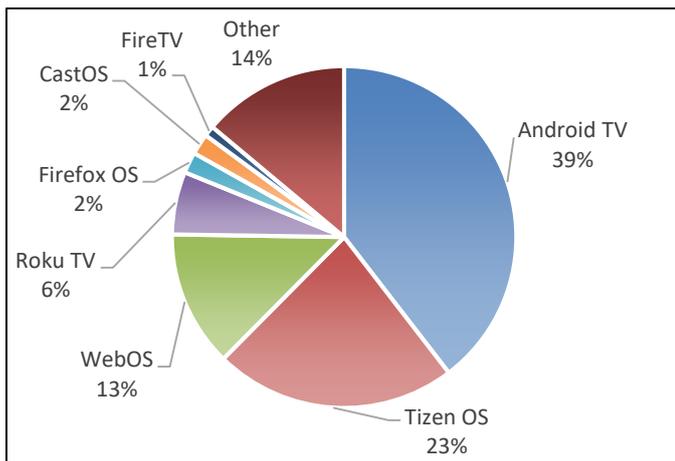


Figure 4. Smart TV Operating Systems market share [25]

<sup>1</sup> *Yocto Project* is an open-source project for development of tools for OSs based on *Linux*

### C. Smartwatch Operating Systems

The most commonly used solutions are *Tizen OS* and *Fitbit OS*, besides the already mentioned *Google Wear OS* and *Apple WatchOS*.

*Fitbit* has mainly focused on fitness products, keeping battery life as one of the main priorities. They have developed their own OS exclusively for their smartwatches and smart bracelets.

Samsung has been using their own *Tizen OS* for their smartwatches, which use the ring around the screen for navigating the interface, thus minimising the need to use the touchscreen. *Tizen OS* has been adapted for this feature, and has the *Bixby VA* integrated.

### D. Smart Speakers Operating Systems

Smart speakers are expanding at a fast rate, which is mainly limited by the number of supported languages. Besides the already mentioned *Apple HomePod OS* and *Google Home OS*, the most common product is *Amazon Fire OS* [13].

*Fire OS* for smart speakers is based on the VA *Alexa* and it is being used by many companies. Functionalities are partly limited by the features available on the speaker, as some have built-in screens and may display multimedia.

## VI. CONCLUSION

The overall market of operating systems is currently very complex, partly due to the increased number of various TDs requiring OSs for their operation, and partly also as a result of the ongoing battle between different software companies or alliances for domination. Significant development of several technologies within the past decade has influenced the way new TDs have been emerging and the speed of their expansion.

One of the common elements for all the TDs covered in this paper has been the virtual assistant, as a manifestation of artificial intelligence. Combined with the ever-growing number of connected devices, increased number of built-in sensors, growing capacities of all networks and increased storage capacities and data-processing power, the artificial intelligence is the overall factor that is most likely going to have the most significant impact on the further development of technology and many industries.

VA applications are not only becoming more effective and able to successfully complete more and more functions, but they are also controlling more and more other devices. Having in mind that the OS can be defined as the interface between users and the hardware, which coordinates the work of all components of the TD, but also manages other software, the virtual assistant can undoubtedly be considered a kind of OS. This also explains why currently most software companies focus on improving the functionalities of their VAs and why they care more about having their VA integrated in as many TDs as possible regardless of which OS runs the device. For now the major limitation of the global expansion of the VAs is their limited number of supported languages.

A majority of the described TDs use battery as their energy source. Smart TVs and vehicles are exceptions, although evidently the development of energy storage technologies will play a major role in the future of the car industry. The research of possible alternative energy-storing technologies has intensified and this segment will also have a major influence on the future of modern TDs.

All the changes that are currently ongoing in the segment of vehicle production due to gradual expansion of electrical vehicles and improvements in the field of autonomous vehicles, a certain transformation from a vehicle equipped with gadgets to a gadget on wheels can be observed. Tesla Company has made a unique approach to developing a new vehicle as a single electronic device rather than a set of different components, and has developed a unified OS for that vehicle, which may become a widely accepted approach in the future.

Every few years the TV producers introduce some new feature attempting to persuade users to buy a new device. Several years ago that feature was 3D, which failed to achieve any significant popularity. Currently the users are offered ever-growing screens with higher and higher screen resolution, as well as growing number of smart TV functions.

The segment of wearable devices grows more complex by years, with smartwatches and smart bracelets being only a part of that segment. The number of built-in sensors keeps growing, and the battery life keeps getting longer, which brings the wearables closer to a stand-alone autonomous device which will not require a smartphone for full functionality.

Smart speakers have seen a fast expansion in the English speaking countries, and the same can be expected in other parts of the world as the number of supported languages keeps growing. This expansion will be closely tied with growing functionalities of VAs and improvements of voice-recognition algorithms. Additionally, as the number of connected devices in our (smart) homes keeps growing, the smart speaker make it as a possible choice for the component which will control and manage all those devices.

Current trends in the technology development and new breakthrough that the 5G is most likely going to bring will result with a further complication of the OS segment and an increased number of terminal devices controlled by an operating system.

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