Improvement of urban mobility supported with IoT technologies

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Abstract

Urban mobility is one of the most significant factors in the successful development and sustainable future of large cities. The increasing demand for fast, safe, and eco-friendly transportation services is a trend in modern society. These requirements pose the challenge of finding corresponding solutions for efficient mobility of people in urban areas. However, many problems are caused by the increased traffic in cities, leading to high congestion, negative impacts on the environment, rising security challenges, etc. Therefore, the research community and other stakeholders have increased their focus on finding solutions for these issues. The Internet of Things (IoT) has enabled the development of efficient and cost-effective solutions to enhance urban mobility. Enabling IoT technologies has become a significant driver for smart mobility concept development. The continuous development of IoT has led to various applications focused on urban mobility improvement. This paper presents some IoT possibilities and potentials for developing solutions for smart urban mobility.

Keywords*: Urban mobility, Internet of Things, Smart city, Smart parking, Traffic light management, Bicycle rental*

1 Introduction

In recent years, the population of urban areas has continuously increased. Therefore, large cities are experiencing a major urban transition that leads to higher carbon dioxide emissions (up to 80%), increasing waste, environmental pollution, heavy traffic jams, traffic accidents, etc. [1]. Many of these issues have been addressed by using ICT-based solutions. These solutions aim to achieve efficient urban mobility (the movement of people in urban spaces in an organized manner). The concept of smart mobility implies the development of a connected, efficient, and flexible transportation system. This system is the basis for improving life in urban areas through better public transport, car and bicycle-sharing services, traffic light management, etc. Smart mobility provides more efficient movement of people, thereby improving their quality of life. ICT-supported transportation systems enable easier, faster, and more reliable travel of passengers by using public transport. Therefore, new approaches to solving problems related to urban mobility are mainly based on the concept of intelligent transport systems [2]. Most urban traffic management systems (TMS) allow real-time monitoring of public transport vehicle routes. In addition, many modern TMS enables monitoring of the entire traffic system including the number of vehicles on roads and parking lots, detecting traffic accidents, monitoring the use of alternative means of transport (e.g., bicycles and mopeds), etc. This information is used to manage traffic with a special focus on enabling unhindered and fast public transport and emergency services (e.g., ambulances, firefighters, and police). Also, there is a trend of promoting other forms of passenger transport in cities that suffer from traffic jams. Therefore, in a large number of cities, special focus is placed on the bicycle rental system. These activities seek to reduce congestion and negative environmental impact through the collection of various data on human movement. Thus, the concept of smart urban mobility implies a specially developed TMS.

Every TMS implies the need for data collection in the right place, at the right time, and the corresponding device. These processes enable the connection of various components and transportation system infrastructures. This data collection should be efficient with reasonable costs and the possibility of real-time processing [3]. One of the most efficient ways to develop a smart TMS is to apply the concept of the Internet

of Things (IoT). Therefore, IoT greatly contributes to the development and improvement of urban mobility [4]. This paper presents the IoT potential for urban mobility improvement. The first chapter describes the concept and indicators of urban mobility. The second chapter describes the benefits of using IoT technologies to enhance urban mobility for specific user groups. Certain urban mobility services based on IoT systems are described. The fourth chapter describes some of the most common applications of IoT technologies to enhance urban mobility such as traffic light management systems, smart parking, and smart bike rental systems. The fifth chapter contains concluding remarks.

2 Urban mobility

The concept of urban mobility represents the movement of people between sources and destinations, at different times, using different means of transport and modes of travel. Urban mobility is shaped by the demands for fast, efficient, safe, and economical transport. In earlier years, mobility was mainly associated with a product that included vehicles, physical infrastructure, and the fuels needed to move people. Today, mobility is increasingly seen as a service. Mobility enables people to provide basic living needs and contributes to improving the quality of life. In urban areas, the existence of high-quality mobility is essential for the success of other urban sectors and the creation of new jobs.

The urban mobility assessment aims to identify the weaknesses and strengths of the transport system as well as to identify the key and critical elements of the same. It provides a better understanding of urban mobility and creates a foundation for improving existing and creating new services. Procedures for assessing urban mobility depend on the information available on the transport system, which could be collected from a variety of sources. Most often, data is collected by public transport companies, road charging institutions, national statistical agencies, etc. In addition to the above data sources, one of the key ways to collect the necessary data is through sensors and cameras installed on traffic infrastructure. These are the most common components of modern information systems used for traffic monitoring and management. They are often used to develop these systems. Also, new data sources such as data from public mobile telecommunications networks and services such as Google Maps are increasingly being used. The primary function of these technologies is not to collect or generate data on urban mobility, but they can generate information that can be used to assess and improve mobility.

An indicator is a quantity that shows the state or change in the state of a system, or the course of a process. They enable the display of the system concerning the desired state and efficient and simple monitoring of system changes over a while. Indicators of urban mobility are formed and based on appropriate data from different segments of the transport system (Fig. 1).

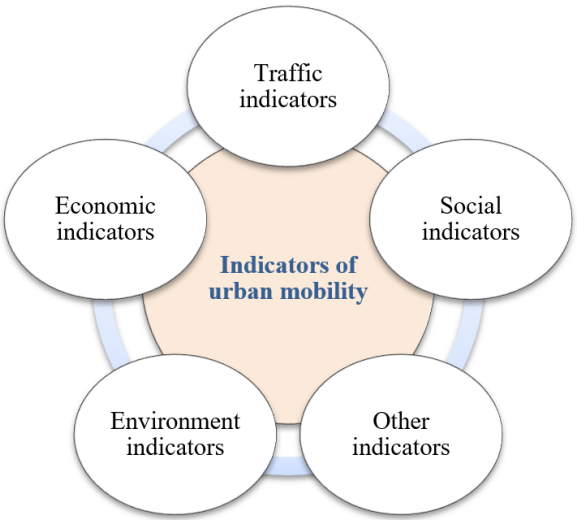

Fig. 1. Indicators of urban mobility

The traffic indicator shows urban mobility through categories related to the traffic aspect, eg. travel time and speed. The economic indicator shows the impact of certain economic components on urban mobility like as fuel prices and parking prices. The social indicator shows urban mobility through its social acceptability (e.g., number of traffic accidents, number of casualties, number of injured). The environmental indicator shows urban mobility through categories related to the environment and meteorological conditions, eg. emissions of harmful gases, and noise. Additional indicators are those that cannot be classified in any of the above categories, eg. the existence of regulatory frameworks, traffic management, and planning bodies, etc.

3 Impact of IoT technologies on urban mobility

Smart TMS development requires data collecting to enable an efficient decision-making. IoT technologies enable real-time data collection and provide seamless connectivity between various physical and virtual objects [5]. These services contribute to the improvement of urban mobility. Also, Green IoT (G-IoT) is a promising technology that will drastically improve the quality of life in smart cities and change our environment to be smarter, healthier, greener, and more economically sustainable [6].

The implementation of the IoT system improves the capabilities of traditional infrastructure by enabling the collection of data from physical infrastructure, their exchange between different components, and automated decision-making based on real-time data processing. Examples of IoT applications that have significantly improved certain aspects of urban mobility are adaptive traffic management systems, smart parking, smart public transport ticketing, pedestrian crossing control, travel planners, vehicle and bicycle-sharing services, etc. These solutions are the basis for the further development of smart urban mobility. Fig. 2 shows some of the most common IoT-based services that significantly contribute to the urban mobility improvement.

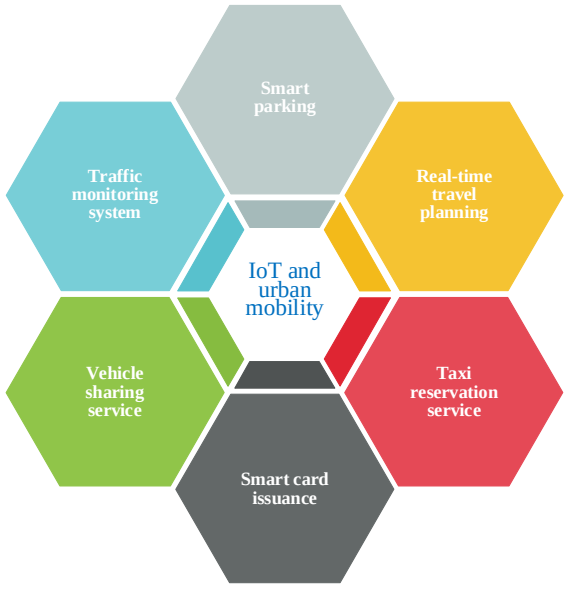

Fig. 2. IoT based services to improve urban mobility

Smart parking increases users' ability to locate free parking spaces which reduces waiting times, congestion, costs, negative impact on the environment, etc. Smart ticket issuance allows easier and faster payment for transportation services with the integration of different payment systems. IoT technologies enable efficient real-time travel route planning. Smart monitoring centers enable traffic data collection to enable efficient control and management mechanisms to improve safety, reduce congestion, etc.

The IoT also provides additional services to improve vehicle sharing systems (e.g., car-sharing and bicycle-sharing). For example, IoT-based bike-sharing systems improve passengers' interest in this alternative way of traveling and connecting. The usage of these smart systems reduces the number of vehicles on roads, which causes a congestion reduction as well as mitigation of negative effects on the environment. Also, IoT-based services used for taxi reservations allow easier access to taxi services with improved quality.

The following potential user groups have key benefits from using these IoT-based smart mobility services:

- Travelers - improving the travel experience in urban areas, improving travel reliability, reducing travel costs and time, etc.
- Transport operators - creating a balanced supply and demand, more efficient use of resources, reducing costs, planning a better supply, etc.
- City authorities - planning the development of infrastructure and the provision of transport services, ensuring a more environmentally sustainable transport system, traffic control to improve safety, etc.

Thus, some of the key benefits of applying IoT technologies to enhance urban mobility are reducing congestion and passenger frustration, improving safety, reducing travel time, reducing the negative impact of traffic on the environment, improving the travel experience, reducing costs, etc. Most IoT-based systems are based on real-time data collection to enable integrated services such as traffic management and control.

4 Examples of IoT application to improve urban mobility

IoT technologies are used a lot in transport systems for urban mobility improvement. These technologies contribute to more efficient traffic management and control, better use of available resources, integration of traffic and other systems, improvement of traffic safety, etc. These effects are achieved through efficient real-time data collection mechanisms that are the basis for quality decisions. Some of the most commonly used areas of application of IoT technologies that contribute to the improvement of urban mobility are adaptive traffic management systems, smart parking solutions, and bicycle-sharing systems.

4.1 Smart traffic light management system

The smart road concept integrates advanced IoT technologies and management algorithms to enable traffic flow prediction and management. This integration can improve travel time, and road safety, reduce congestion, increase vehicle throughput, etc. [7]. The improvement of the traffic management system is mainly based on the optimization of the work of traffic lights at intersections (Fig. 3). The smart traffic light system is an automatic vehicle management system that combines new technologies (sensors) and artificial intelligence techniques to control the flow of traffic at signalized intersections [8]. This system enables significant improvement of traffic congestion management through the implementation of a fully adaptable and dynamic way of decision making. Signaling schemes change according to the real-time traffic situation. In some cases, traffic conditions change abruptly due to an event, accident, or special situation. That is why smart systems based on IoT technologies often include the detection of road conditions such as weather conditions and unforeseen situations such as traffic accidents.

Traffic light management systems are mainly based on the use of microprocessors and usually, work on a pre-programmed algorithm. The system requires data collecting from sensors including microwave radars, laser radars, passive infrared sensors, ultrasonic and passive acoustic arrays, and special cameras. Most of traffic management models are based on similar processes of collecting data that is transmitted to the control unit to determine the current state of the traffic flow. The queue length and waiting time at each intersection are then calculated while the adaptive neuro-fuzzy system automatically estimates the duration of the traffic green/red light and the cycle time to minimize the waiting time. Thus, sensors installed at key locations collect data on high-traffic crossings and areas where cars are automatically diverted based on the current situation. This can be achieved by using IoT technologies. Long-term data collection can be used to create data warehouses. This data can be used for further analysis and optimization of traffic signaling.

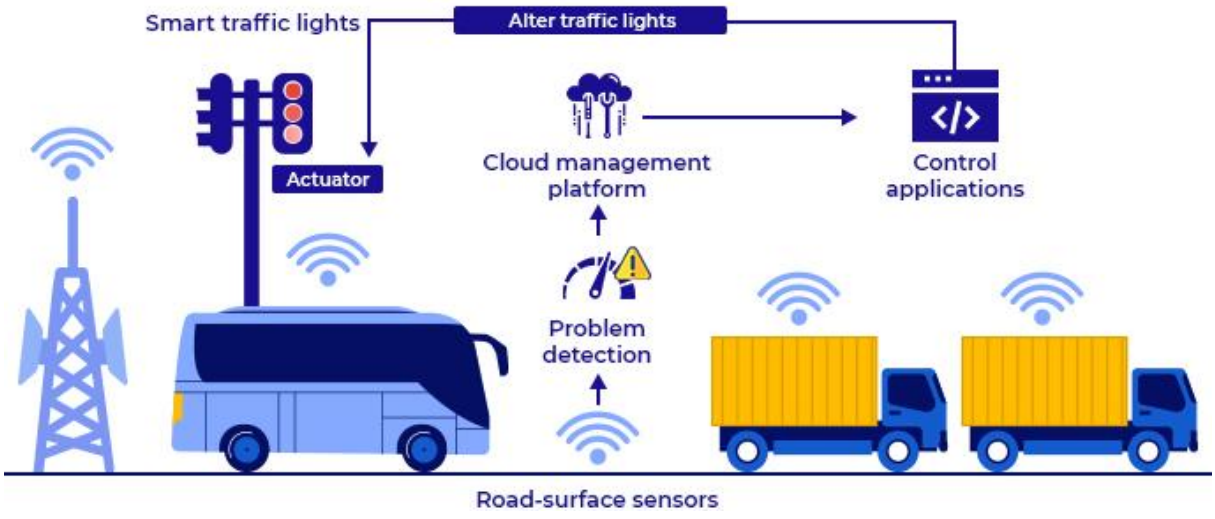

Fig. 3. Illustration of a smart solution for traffic light management [8]

Also, IoT technologies can be very useful for informing drivers and alerting them to road conditions in real-time. For example, the application of these technologies can detect collisions caused by collisions. Informing drivers is crucial to deciding on choosing an alternative route. When the driver is aware of a potentially dangerous obstacle on the road, he can drive carefully or choose an alternative route, avoiding a potentially fatal collision or preventing drivers from injuring people on the road. More advanced systems also allow proposing alternative routes based on available data. This can be done by using roadside displays or by sending information directly to drivers via in-vehicle info systems. This is especially useful for services such as ambulances, police, firefighters, etc.

4.2 Smart parking

Smart parking is a system that uses sensors to detect parking space occupancy. This information can be passed on to drivers to reduce the time it takes to find a suitable car park. In many cities, the number of vehicles has long exceeded the number of available parking spaces. To solve the problem of parking, it is necessary to consider all the factors that affect stationary traffic in a city such as the number of vehicles and parking spaces, geographical location and relief of the city, urban division of the city, gravity zones, etc.

The key goal should be a sustainable solution for stationary traffic terminals that will provide a sufficient number of parking spaces for all users in the long run. This goal can only be achieved by applying smart parking solutions. A large number of smart parking solutions include options for detecting free parking spaces as well as directing drivers to free parking spaces using the integration of IoT and GIS systems. Also, these solutions enable the development of the *Park and Ride* system, parking time restrictions, information in parking lots, etc. Thanks to these capabilities, smart parking systems are beginning to offer certain solutions to improve urban mobility. The application of IoT and sensor technologies enables the collection of data on parking availability and road conditions in real-time (Fig. 4).

These data enable traffic management, which results in reduced traffic, reduced emissions, shorter travel times, shorter parking time, etc. All these effects are significant indicators of the impact of IoT on improving urban mobility. IoT systems implemented in smart parking solutions can generate a large amount of data. The vast amount of data presents challenges related to their processing, storage, management, and manipulation. An effective solution to these problems is the application of Cloud technologies [9]. An example of the functioning of such a system is that data on free spaces in the parking lot is detected by sensors and then forwarded to Cloud servers. At the request of the driver, the data can be transmitted to the user via the web or mobile application.

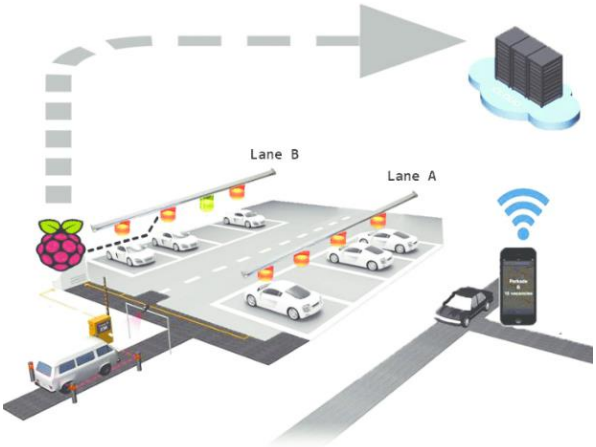

Fig. 4. Illustration of an IoT-based solution for smart parking [10]

4.3 Smart bike rental and sharing systems

Bicycle sharing and rental services in urban areas are growing rapidly in cities that are trying to solve the problems of traffic congestion and protection from the negative impact on the environment. The basic premise of the concept of smart bike-sharing and rental is sustainable transportation. Therefore, bicycle rental systems are being introduced to increase mobility choices, improve air quality and reduce congestion. IoT enables the development of an intelligent public bicycle management system using sensors, GPS, wireless technologies, mobile phones, object identification technologies (e.g., QR), etc.

The traditional way of implementing these services included subscription, using the screen terminal at the rental station, returning the bike to defined locations, and other rather

complicated processes. IoT technologies simplify these processes, which greatly influences their popularization among residents and tourists. Smart bike rental solutions make it easier and simpler to rent, use mobile phones instead of displays at rental stations, integrate with the public transport system, the ability to use different business models, etc. [11].

Many IoT-based solutions include a bicycle track, which is important for improving safety and the possibility of more flexible use of rented bicycles (Fig. 5). For example, the user can leave the bicycle at any location in the city, and not only at certain stations, as provided by the traditional bicycle rental system.

The most commonly used GPS tracker allows you to locate your bike in real-time. In addition, it is possible to create route records that can be viewed later to optimize locations for bicycle rental, theft protection, and other services. Thus, new systems are based on smart technologies and provide users real-time information on bicycle availability. This is enabled through various user-friendly platforms including web and mobile applications. These smart bike rental systems provide the missing link between existing public transport and desired destinations, offering a new form of mobility that complements existing public transport systems.

Nowadays, due to climate change, traffic congestion and many other facts affecting daily life a trend to use eco-friendly transportation ways has arisen. The idea of real time bicycle tracking has been around for a while. These systems have been greatly accepted in the different cities around the world. They are increasingly popular in cities world-wide as a sustainable, eco-friendly and flexible transportation mode [12]. Therefore, smart bike-sharing and rental systems are becoming as one of the world's most widespread public IoT applications.

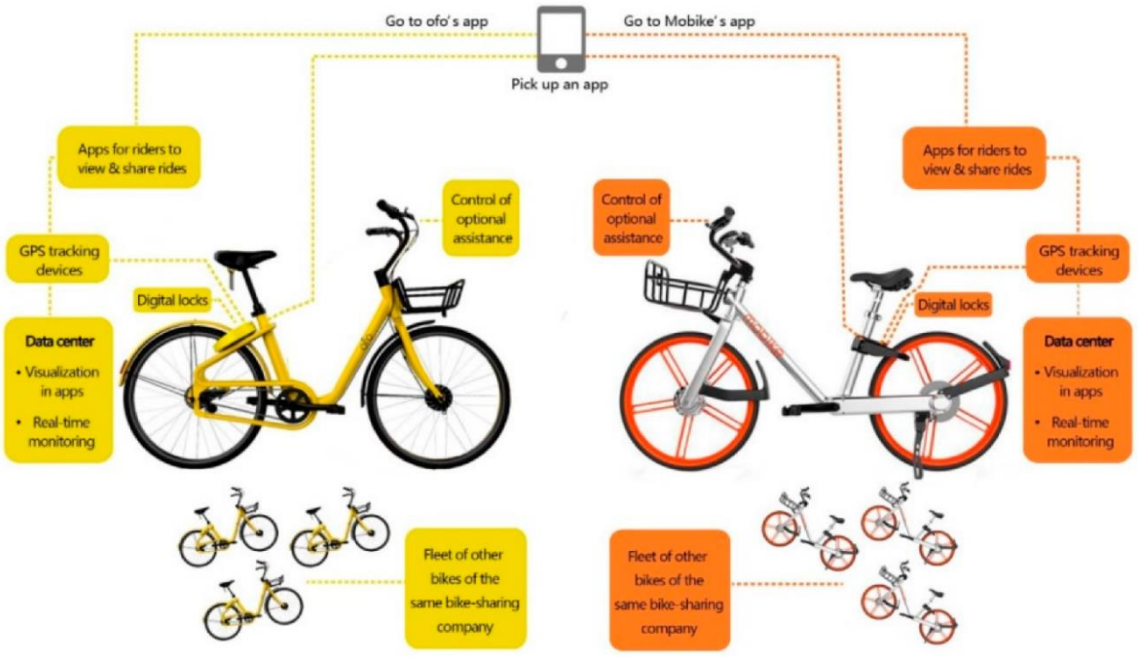

Fig. 5. Station-less bike equipment and devices [13]

5 Conclusion

Sustainable mobility aims to ensure efficient mobility, which means the rational use of available space and resources while reducing the negative impact on the environment. In this paper, we presented the importance of IoT for urban mobility improvement. We highlighted some advantages, benefits and potentials of the IoT-based solutions for sustainable urban mobility. Also, the paper presented some examples of these solutions for urban mobility systems including smart traffic light management, smart parking, and bike-rental system. The users of these systems are numerous and include residents, tourists, decision-makers, and other stakeholders. In an environment where urban congestion is growing every day, its residents can use smart solutions for urban mobility in various ways. One of the key benefits is the reduction of travel time and costs. Also, these solutions mitigate the negative impact on the environment, which significantly affects the improvement of the quality of life in cities. Tourists can get the necessary information and use optimal means of transport more simply. Planners and decision-makers can use the data generated by the IoT devices to make appropriate proposals and decisions to further urban mobility improvement. Also, new solutions can be integrated by connecting different information and passenger transport systems, which opens additional opportunities for further improvements in urban mobility. All these facts show potentials of the IoT for the urban mobility improvement. Therefore, this topic is interesting area for many stakeholders such as researchers, urban planners, traffic engineers, city authorities, etc.

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