IoT System for Monitoring and Managing Public Transport Data

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Abstract: - Public transport has a significant role in the economy and modern city development. Today, public transport systems face many problems which should be solved, like real-time monitoring, data management, passengers flow optimization and road accident prediction. The Internet of Things (IoT) is a promising technology for the development of the modern public transport management system. IoT systems combine a wide range of technologies, such as sensors, edge devices, and cloud computing. Also as well as many communication infrastructures which can be applied to develop robust and automated public transport systems. The transfer of information from devices to the cloud is the most important part of an IoT system. All devices should use network standards and protocols to allow physical objects to interact with each other and the cloud. Information transfer from IoT devices to the cloud is only possible if devices are securely connected to a communication network. Network protocols and standards are policies that comprise certain rules that define communication between two or more devices over the network. This article aims to evaluate the possibilities of using IoT for monitoring and managing public transport data in modern Ukrainian realities. Specifically, in this study, we analyze general industry protocols and standards that are used by IoT devices and meet requirements like bandwidth, latency, and power consumption. This work describes a specific device that transmits information from a transport unit to the cloud. Lastly, this paper proposes an IoT system architecture for the public transport data monitoring and management system.

Key-Words: - IoT, Public Transport, M2M communication, Data analytics, Intelligent transport systems, Smart City.

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1 Introduction

Public transportation refers to shared passenger transportation services such as buses, trolleybuses, trains, ferries, and express transportation like the metro. Design of an intelligent real-time Public Transportation Monitoring and Management System based on IoT systems, depending on several technologies, allows retrieving data from any transport node and managing and control of the transportation network.

IoT protocols are a crucial part of the IoT technology stack without them, the hardware would be rendered useless as the IoT protocols enable it to exchange data in a structured and meaningful way. IoT protocols and connectivity help in transferring pieces of data from which useful information can be extracted for the end-user and thanks to it, the whole deployment becomes economically profitable, especially in terms of IoT device management, [12].

Wireless protocol selection plays a major role in the above system design. The following are the critical parameter for the selection of the wireless protocol requirement to make it affordable, scalable, and efficient according to system needs:

- Effective Radio Distance/Data Rate.
- Operating Frequency Band.
- Network Deployment Models.
- Security Features Supported.

2 Literature Review

The development of intelligent transport systems is an important problem today. Over the past decade, many studies have been conducted on this topic, and many systems have been implemented in different cities and countries around the world. For example, in this paper, [7], the authors proposed an IoT tracking system for public buses. Also, a lot of studies are dedicated to the development of tools for drivers. For example, this paper, [8] considers an IoT navigation system for bus drivers. Also, a lot of studies are dedicated to the smart management of public transport. In [8] the authors develop a framework that allows the transport administration to manage resources more effectively.

[9], [10] provide a detailed analysis of research on the use of IoT for public transport systems. Overall,

most of the reviewed papers consider the transmission and visualization of public transport data, without analysis and training of models based on this data. In this paper, we propose a system architecture that can save, transmit, analyze, and build predictions based on public transport data.
Our study was written to evaluate the possibilities of using it for monitoring and managing public transport data in modern Ukrainian realities. This research focused on the idea of automated management of city bus routes without drivers. The idea has been put forward since 2010. Unfortunately, full implementation in world practice was not achieved.

3 Methods and Materials

This research combines analytical and experimental methods. It also includes the best practices of specific IoT systems realizations, which are described in the chapter "Literature review".
For each service is selected a set of possible technologies which are analyzed and compared by performance tests. The performance tests are executed on device emulators, which allows an effective compare the capabilities of the technologies.
Also, we analyze the feasibility and complexity of implementation into existing transport.

4 Results

4.1 System Requirements

The system can be divided into two main parts - data collection and data processing. The purpose of this paper is to analyze and select stable and secure communication channels between the above parts.
For data collection and transmission (Fig. 1) developed special modules, that are installed directly in the vehicle (Vehicle module). This module collects and builds packets for transmitting the following data: current geolocation data, information from passenger validators, and vehicle service data (from CAN bus).

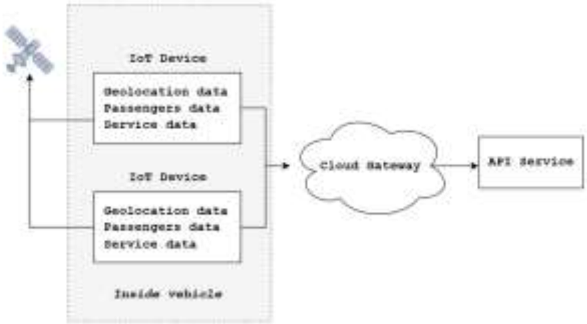

Fig. 1: Data transmission system structure
Source: Created by the authors

Data should be transmitted to the gateway in conditional real-time mode, with the maximum delay time equal to 1 min.

Table 1. Vehicle module data description

Data	Description	Size
Geolocation data	NMEA packages	The maximum length of each packet is restricted to 255 bytes.
Passengers data	Information about the number of successful validations at the stop. The package should contain the stop ID and passenger count. Data is received from the RS232 interface.	128 bytes.
Vehicle service data	Information about the vehicle's technical condition (for example, battery level, etc.). Depends on the vehicle type.	The maximum length of each packet is restricted to 256 bytes.

Source: Created by the authors

According to Figure 1, we also have two communication types: Device-Gateway communication and Gateway - API communication.
Device to gateway communication. It is the telecommunication connection between the Vehicle module and gateway nodes. Gateways are more powerful computing nodes than IoT devices. They have two main functions: to consolidate data from devices and route it to the relevant data system (API in our case); to analyze data and, if some problems

are found, return it to the device. For this connection type, we should consider IoT network connectivity.

Gateway – API communication. It is the data transmission from a gateway to the appropriate data system – API Service.

4.2 IoT network Connectivity

IoT connectivity technologies provide the network infrastructure and communication capabilities required by IoT devices to collect, transport, and exchange data over the internet and are remotely monitored and controlled.

IoT connectivity covers a range of communication technologies:

- Low-power wide-area network (LPWAN) technologies, such as LoRa.
- Cellular technologies, including 2G, 3G, 4G, and 5G
- Short-range wireless technologies, such as Wi-Fi, Bluetooth, Zigbee, and many others
- Satellite technologies, such as VSAT, BGAN, and the newest satellite-based LPWAN

The IoT network technologies specification are presented in Table 2.

Table 2. IoT network technologies specifications

Technology	Distance	Frequency	Rate	Power cons.
GSM/LTE	~10 km	Cellular	10 Mbps	High
BLE	~ 100 m	2.4 Ghz	1,2,3 Mbps	Low
WI-FI	~ 100 m	2.4, 5 Ghz	54 Mbps	Medium
ZigBee	~ 100 m	2.4 Ghz	250 kbps	Low
LoRa	~ 5km	sub-GHz	50 kbps	Low

Source: Created by the authors, based on, [1], [2], [4], [5]

Since data needs to be transmitted in real time over long distances, the most suitable technologies are – Cellular connectivity and LoRa.

Cellular networks are based on open, global industry standards, use licensed spectrum, and are always operated by wireless network providers.

A cellular network or mobile network is a communication network where the link to and from end nodes is wireless. The network is distributed over land areas called "cells", each served by at least one fixed-location transceiver (typically three cell sites or base transceiver stations). These base stations provide the cell with the network coverage which can be used for transmission of voice, data, and other types of content. A cell typically uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed service quality within each cell, [1]. In our case, we should review two generations of cellular networks – GSM (2G, 3G) and LTE (4G, 5G).

GSM is the second generation of Cellular networks. 3G and 2G Coverage is currently available in many cities around the world. With General Packet Radio Service (GPRS), 2G offers a theoretical maximum transfer speed of 40 kbit/s (5 kB/s). With EDGE (Enhanced Data Rates for GSM Evolution), there is a theoretical maximum transfer speed of 384 kbit/s (48 kB/s), [2].

LTE (Long-term evolution) - is standard for high-speed data transmission. It delivers download speeds of around 100 Mbps (theoretically could be raised to 150 Mbps) and upload speeds of around 50 Mbps. The main LTE advantage over 2G and 3G is that it is a promising technology that increases coverage in the world, and LTE will provide continuity for networks in the long term. Also, LTE provides special technology for IoT devices - LTE-M or LTE CAT-M1. LTE-M is a reduced LTE version designed especially for battery-powered devices. In this case, IoT devices can transmit/receive data over cellular networks with more power-efficient.

LoRa (from "long-range") is a physical proprietary radio communication technique, [4]. It is based on spread spectrum modulation techniques derived from chirp spread spectrum (CSS) technology, [5]. The technology covers the physical layer, while other technologies and protocols such as LoRaWAN (Long Range Wide Area Network) cover the upper layers. It can achieve data rates between 0.3 kbit/s and 27 kbit/s, depending upon the spreading factor, [6]. For the LoRaWAN network, we need to provide a special Gateway (corresponding to base stations in a cellular network) (Fig. 2).

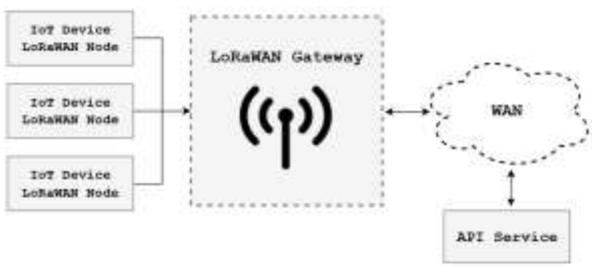

Fig. 2: LoRaWAN Network components.
Source: Created by the authors, based on, [4]

In our case, LTE is the preferred system because of the already existing infrastructure and high data transfer rates.

IoT data protocols
There are several protocols proposed for M2M/IoT communication, with a focus on mentioned constrained environments. The most frequently adopted protocols are MQTT (Message Queue Telemetry Transport), and protocols based on HTTP – CoAP or REST API, [3]. In this paper, we need to test the performance of the above protocols and compare them for our system scenarios. Results can help determine which protocol should be used. After a brief description of MQTT and HTTP protocol, testing results are presented.

4.3 MQTT

MQTT is a machine-to-machine Internet of Things connectivity protocol for use on top of the TCP/IP protocol stack which was designed as an extremely lightweight broker-based publish/subscribe messaging protocol for small code footprints (e.g., 8-bit, 256KB RAM controllers), low bandwidth and power, high-cost connections and latency, variable availability, and negotiated delivery guarantees. In the hub and spoke model of the Message-Oriented Middleware messaging server forwards messages from sensor devices to monitor devices. In such architecture, a device whose main task is to continuously produce and send data to the server is defined as a publisher. The MQTT broker collects messages from publishers and examines to whom the message needs to be sent. On the other side, every device which had previously registered its interests with a server will keep receiving messages until the subscription is disabled.

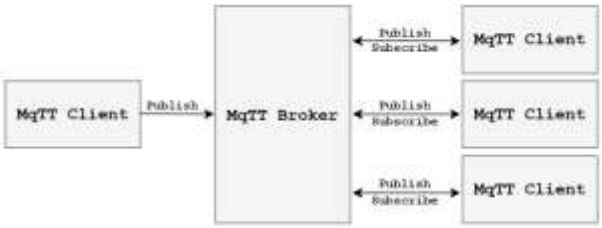

Fig. 3: MQTT Publish/Subscribe architecture
Source: Created by the authors, based on, [3]

Using this (Fig. 3) architecture, publishers and subscribers do not need to know each other, which is one of the major advantages of this protocol. Devices that send data need not know who are the clients that are subscribed for receiving data and conversely. Further to this, the publishers and subscribers do not need to participate in the communication at the same time and do not need to be familiar with each other. It is intended for devices with limited power and memory capabilities, where the network is expensive, has low bandwidth, or is unreliable. One of the key requirements of an Internet of Things concept is low network bandwidth used to send data and minimal device resource requirements.

4.4 HTTP

HTTP (HyperText Transfer Protocol) was invented as a component of the World Wide Web to transfer documents. It is most familiar to us as one of the enabling technologies that allow web browsers to work. HTTP clients can make requests: GET, PUT, DELETE, and POST, to name the most common (Fig. 4).

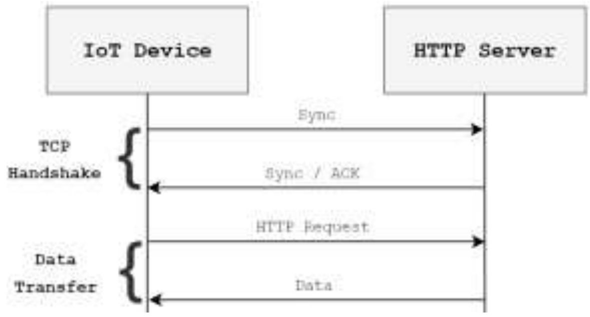

Fig. 4. HTTP Request/Response
Source: Created by the authors

In our case, the vehicle module will be sent a POST request with data described in Table 1. The data type will be separated by an appropriate HTTP path (Tab. 3). Moreover, the HTTP request for location of the data is presented in Table 3.

Table 3. HTTP request for location data

Method	Path	Data
POST	/API/v1/location	$GPGGA,092750.000,5321.6802, N,00630.3372,W,1,8,1.03,61.7,M,55.2,M,,*76
POST	/API/v1/battery	{ level: 75 }

Source: Created by the authors

Table 4 shows the main differences between the MQTT and HTTP.

Table 4. MQTT / HTTP Comparison

	MQTT	HTTP
Architecture	Publish/subscribe	Request/response
Underlying Protocol	TCP/IP	TCP/IP
Security method	TLS + username/password	TLS + username/password
Messaging Mode	Asynchronous, event-based	Synchronous
Message queuing	The broker can queue messages for disconnected subscribers	-
Message Size	256MB maximum	No limit
Content type	Binary	Text
Message distribution	One to many	One to one
Data validation	Software implementation	Software implementation

Source: Created by the authors based on, [3]

For the performance test, we develop a program that simulated a Vehicle module, which runs both an MQTT client and an HTTP client, and then measures the response time and tracks the packets sent over the wire. The test results are shown in Table 5.

Table 5. MQTT / HTTP Performance test

	MQTT Bytes	HTTP Bytes
Establish connection	5572	2261
Disconnect	376	0
For each message published	388	3285
The sum for 1 message	6336	5546
The sum of 10 messages	9829	55,460
The sum of 100 messages	44,748	554,600

Source: Created by the authors, based on, [11]

As MQTT was designed for IoT solutions, it fits many more IoT scenarios than HTTP. The only case where HTTP might be a valid choice is to connect devices that already have an HTTP client installed to a provider which has an HTTP option. But then only for low-volume data transmission, and without the option of sending control commands to the device. According to the above results, we can use MQTT for data transmission between the physical device (Vehicle module) and the Cloud gateway, and for the microservice communication, we can use REST API, [11].

4.5 IoT Network Structure

The proposed IoT network is shown in Figure 5. Information from physical devices is transmitted in real-time through cellular networks, according to the MQTT protocol. Between Cloud microservices, data is transmitted via HTTP.

The system (Fig. 1) is distributed and consists of the following modules:

1. Vehicle module – the device that collects and transmits data through the cellular network to the Cloud. This device is integrated with the onboard computer, a ticket validator, and has a GPS module.
2. MQTT Broker – a broker that receives messages from Vehicle modules (publishers) and transmits them to the clients (subscribers). API Gateway is a service that stores and manages stored data.
3. The API Gateway is the primary interface that provides access to stored data, analytics, and neural network-based prediction results. API Gateway also provides a Public API for third-party integrations.
4. ML (Machine learning) Service is a service for building neural network models based on stored data.
5. Analytics Service – a service for building data analytics.
6. Management Dashboard – control panel and data visualization. Allows tracking of the location of vehicles, the number of passengers, technical conditions, etc. in real-time.
7.

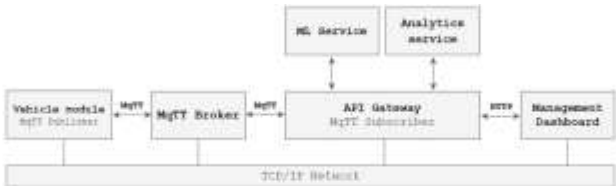

Fig. 5: Data flow structure

Source: Created by the authors

5 Discussion

The proposed system architecture is easy to integrate into and cost-efficient. The main advantage is real-time data transmission and processing. In this paper, the data transmitting is considered for Geolocation, Passenger, and Vehicle Service data. But the above dataset can be supplemented with any data, and this will not affect the overall system architecture. Also, the system is distributed and consists of separate microservices that are independent of each other. Therefore, we can add, remove, and scale each microservice without affecting the overall performance of the system. To implement the above system, it is necessary to install modules (Vehicle modules) in the vehicle. Each module will be integrated with an onboard computer and ticket validator. For the Cloud services deployment can be used infrastructure as code systems such as Terraform or CloudFormation.

As for the implementation of automated and robotic programs, they are implemented in cities with a fairly high density of buildings and a high population density (primarily Asian cities: Tokyo, Hong Kong, Singapore), [13], [14], [15] at the same time, in countries with a high level of GDP per capita. Therefore, due to the clear organization of traffic, such systems are effective and viable, because they allow optimizing the movements of transport and passenger flows, [15]. At the same time, they minimize expenses for the organization. As for European, primarily Ukrainian cities, such projects are only discussed, analyzed, and individual elements are implemented, [16]. There are quite a few reasons: it requires a complete reconstruction of the existing infrastructure and bringing highways up to international standards. As for the organizational aspects, Ukrainian cities still cope with numerous passenger flows due to the potential that was laid in the Soviet period through the concept of subways and electric transport. Today, from a practical point of view, this problem is not relevant due to a significant reduction of existing routes and diversion to the main city routes and the saturation of cities with their electric transport and their road transport. The main demographic condition is the reduction in the number of cities due to hostilities and displacement and migration flows of the Ukrainian population. Directly in the theoretical aspect, this topic is relevant from the medium-term perspective. Therefore, in the article, the scientific justification of the idea of automated movement of transport is carried out.

However, the idea itself may not be realized due to the innovative implementations of Chinese innovators, who successfully shape the movement of passengers in densely populated cities at the expense of motor drones and autodromes.

The advantage of the conducted research is that it reflects a unique approach to the architectural solution of the software complex, which is simple and relatively cheap, compared to other theoretical developments.

6 Conclusions

In this paper, we analyzed transmitting technologies and protocols which can be used for the city monitoring and management system. Based on the analysis and performance tests, we chose suitable technologies and proposed the IoT network architecture.

The proposed architecture allows to quickly implement effective collection, monitoring, and analysis of public transport data. Implementation of the above system will allow the monitor and therefore respond in time to potential problems in emergencies, problems with the technical condition, etc.

For data transmission, the system uses publicly available cellular networks, which do not require additional infrastructure.

The idea of introducing complexes for city vehicles is quite realistic. From a technical point of view, it is easily implemented, which is proven by research, because the city's IT infrastructural saturation system is quite significant and diverse (cameras, sensors, sound and signal traffic lights, barriers, etc.). Thus, the bandwidth of information channels is quite significant, which allows for quickly and fully implementing technical solutions. From an economic point of view, such a decision is relatively cheap and low-cost.

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Conflicts of Interest

The authors declare no conflicts of interest.

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