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OBJECTS' DETECTION IN THE CONTROLLED AREA BASED ON SIGNAL ANALYSIS USING PASSIVE LISTENING WI-FI NETWORK TRAFFIC

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Abstract. *Service functions of modern operating systems allow passive monitoring ("listening") of computer network traffic without the use of additional tools and additional equipment. Such functions can be used to control information security by detecting the appearance of new objects (both people and material objects) in the controlled area. The study is aimed at developing methods for detecting objects based on the analysis of channel state information (CSI) of the Wi-Fi network and creating appropriate hardware and software. The relevance of the work is emphasized by the potential of using such systems for non-invasive detection of dangerous objects in the environment. The study covers the process of detecting objects by analyzing Wi-Fi signals, focusing on CSI processing methods and algorithms for effective object classification and identification. A method for object detection based on network signal analysis is proposed. The change in CSI data depending on the material of the object that creates an obstacle is investigated.*

Keywords: *Information security, controlled area, Wi-Fi network, network traffic listening, channel state information (CSI), RSSI of signal, object detection, ESP32 module.*

Introduction.

The importance of researching a system for detecting objects based on Channel State Information (CSI) of a Wi-Fi network is explained by several factors. First, service functions of modern operating systems – including those based on which switching equipment firmwares are built – allow passive monitoring ("listening") of computer network traffic without the use of additional tools and additional equipment [1]. Such functions can be used to control information security by detecting the appearance of new objects in the controlled area. The existing infrastructure of wireless networks makes the implementation of such a system economically feasible and easy. Secondly, the use of radio frequency signals instead of conventional sensors or cameras allows for interference-free monitoring of the environment, which is especially important in certain conditions.

Thus, by listening to the traffic of network equipment, it is possible to detect not only people in the controlled area, but also some material objects (including dangerous ones), the appearance of which in the path of Wi-Fi signal propagation changes its CSI characteristics.

Aim.

Further development of methods for detecting and determining the type of objects based on the analysis of CSI information about the Wi-Fi network.

Materials and methods.

CSI (Channel State Information) is channel state data that characterizes the peculiarities of radio wave propagation in wireless networks. In Wi-Fi networks, CSI provides detailed information about the amplitude and phase of received signals on different frequency subchannels of OFDM (Orthogonal Frequency Division Multiplexing) technology [2]. This data plays an important role in detecting objects and tracking their movement within the coverage area of a Wi-Fi network.

The CSI structure of a Wi-Fi network includes the following main components (Figure 1):

a) Access Points (APs) – devices that provide wireless connectivity for client devices and collect CSI data [3];

b) client devices (e.g., laptops, smartphones) - devices that connect to access points to gain access to the network and can provide additional CSI data;

c) communication channel – a medium through which radio waves propagate between access points and client devices.

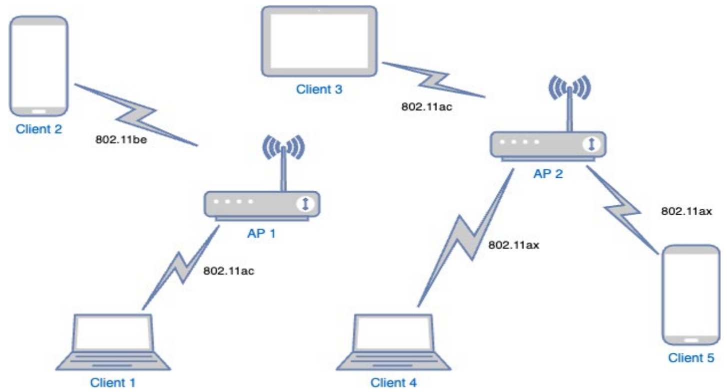

Figure 1 – The main components of the CSI network

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The principle of CSI in Wi-Fi networks is based on the analysis of radio wave propagation in the communication channel. The signals transmitted from the access point are reflected from various objects, such as walls, furniture, people, etc., and reach the client device via different paths. These multipath signal components interact with each other, causing changes in signal amplitude and phase on different OFDM subchannels. These changes are unique to a particular environment and depend on the location and characteristics of the objects in that environment.

CSI contains amplitude and phase information for each OFDM subchannel, which allows you to study the characteristics of the multipath environment with high resolution [4]. This information can be used to detect objects and their movement within the Wi-Fi coverage area by analyzing changes in CSI data as shown in Figure 2 [5].

CSI data is extremely sensitive to the slightest changes in the environment. This is due to the nature of radio wave propagation, which interacts with various objects and materials along the way. Even a slight movement or change in the position of an object can lead to noticeable changes in the amplitude and phase of the signal on different subchannels. The degree of refraction, reflection, and absorption of radio waves depends on the physical properties of the materials with which they interact.

For example, metal surfaces reflect radio waves strongly, while objects made of water or biological tissue can cause significant signal absorption. Obstacles made of dielectric materials such as wood, plastic, or brick can cause refraction of radio waves. The effects of radio wave refraction and reflection are most noticeable at higher frequencies, as the wavelength becomes comparable to the size of the obstacle. Therefore, CSI data acquired on higher frequency subchannels usually contain more information about small changes in the environment.

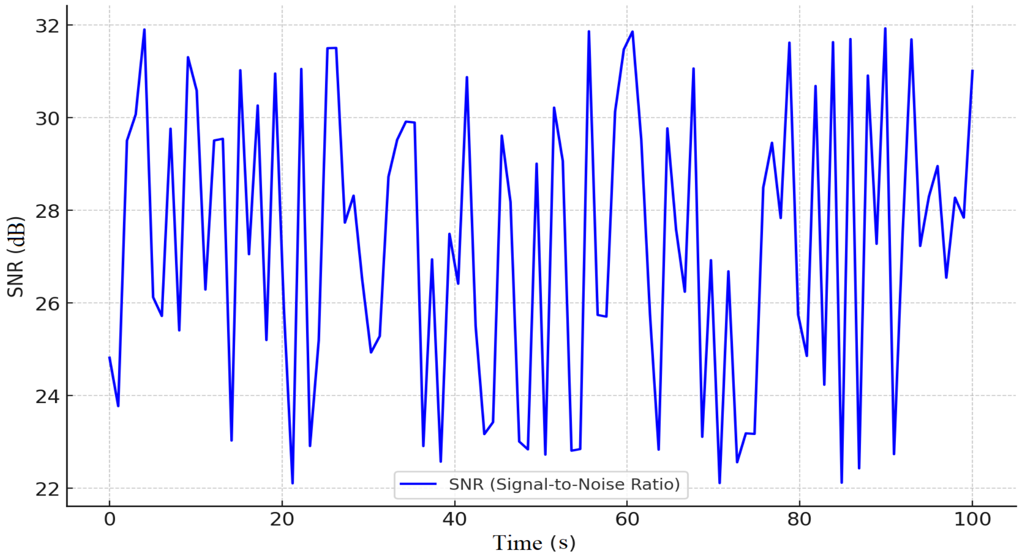

Figure 2 – Graph of signal/noise ratio in CSI

Source: [5]

In addition, the polarization of the radio waves also plays an important role. Vertically polarized waves are more sensitive to vertical obstacles such as people or furniture, while horizontally polarized waves interact better with horizontal surfaces such as the floor or ceiling. One of the key challenges in using CSI is the need to efficiently filter and process the huge amount of data coming from different frequency subchannels. This is often accomplished by using sophisticated machine learning algorithms that can detect patterns and trends in CSI data related to the movement or presence of objects.

Results and discussion.

The further development of the above object detection method consists in dividing the system into two main stages: collecting reference data and recognizing objects. Accordingly, there are also two main functions in the software:

1) The function of writing reference data to the database.

2) The function of comparing the input data with the reference data.

The function of collecting reference CSI data is implemented as follows: A timer is set for 60 seconds to determine the time interval for data collection. After that, continuous reading of CSI data from the serial port of the server begins, where it is transmitted from the Wi-Fi network within the coverage area of the object of study. The received CSI data is pre-processed by software to extract useful information. The reference CSI data is averaged together with a label identifying the object under study. After the 60-second timer expires, the collection of reference data stops, and the collected CSI templates for the object become available for use in the recognition mode.

Comparison of the incoming data with the reference data is performed by connecting to the serial port of the server to read the incoming CSI data. Next, the incoming CSI data is continuously read from the serial port in real time. The received CSI data is compared with all stored reference data. For each type of object, the corresponding reference CSI data is pulled from the database, marked with a label (marker) of this type of object.

The comparison process is as follows: each sub-carrier of the input CSI data and each sub-carrier of the reference CSI data is taken, and the similarity coefficient between them is calculated. If the average similarity coefficient of all sub-carriers is at least 95%, the object is considered to be detected. The similarity coefficient is calculated by comparing the amplitudes and phases of the subcarriers of the input and reference CSI data. The closer these values are for each subcarrier, the higher the similarity coefficient. If the similarity of all sub-carriers exceeds the threshold of 95%, the system considers that the current input CSI data corresponds to the reference data for a certain type of object.

The central hardware component of the CSI-based Wi-Fi object detection system is the ESP32 microcontroller from Espressif Systems. In particular, the ESP32-DevKit-V1 development board based on the ESP32 is used [6]. This microcontroller was chosen due to its high performance, low power consumption, and built-in Wi-Fi module, which makes it a good solution for CSI data collection.

The system will consist of an ESP32-DevKit-V1 microcontroller, a server with software, and a database for storing the CSI reference data. The interaction between these components is shown in Figure 3.

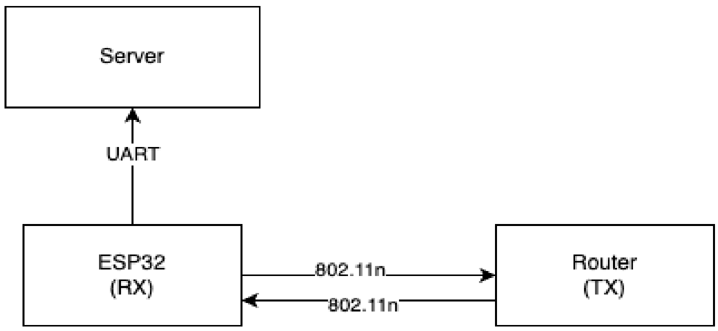

Figure 3 – Conceptual diagram

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The diagram shows the three main modules of the system: TX (Router), RX (ESP32) and Server, which analyzes CSI data.

The router acts as a transmitter of data packets over an 802.11n Wi-Fi network. The ESP32 microcontroller is connected to the same Wi-Fi 802.11n network and reads CSI data in real time.

The modified method is implemented as shown in Figure 4:

1. The ESP32 microcontroller continuously reads CSI data from the Wi-Fi 802.11n network and transmits it to the server via the UART interface.

2. The server runs an application that receives CSI data from the ESP32 microcontroller.

3. The application performs preliminary processing of the received CSI data and compares it with the reference data stored in the database.

4. The results of object comparison and recognition are displayed in the graphical user interface.

5. The database is used to store reference CSI data for different types of objects, which allows the system to learn and recognize new objects.

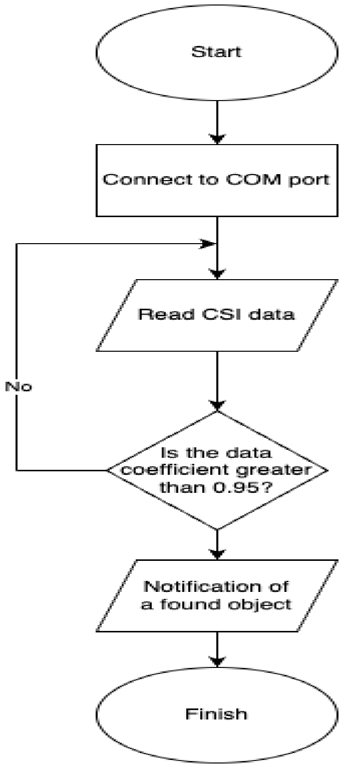

Figure 4 – Algorithm of the modified method of searching for an object by CSI

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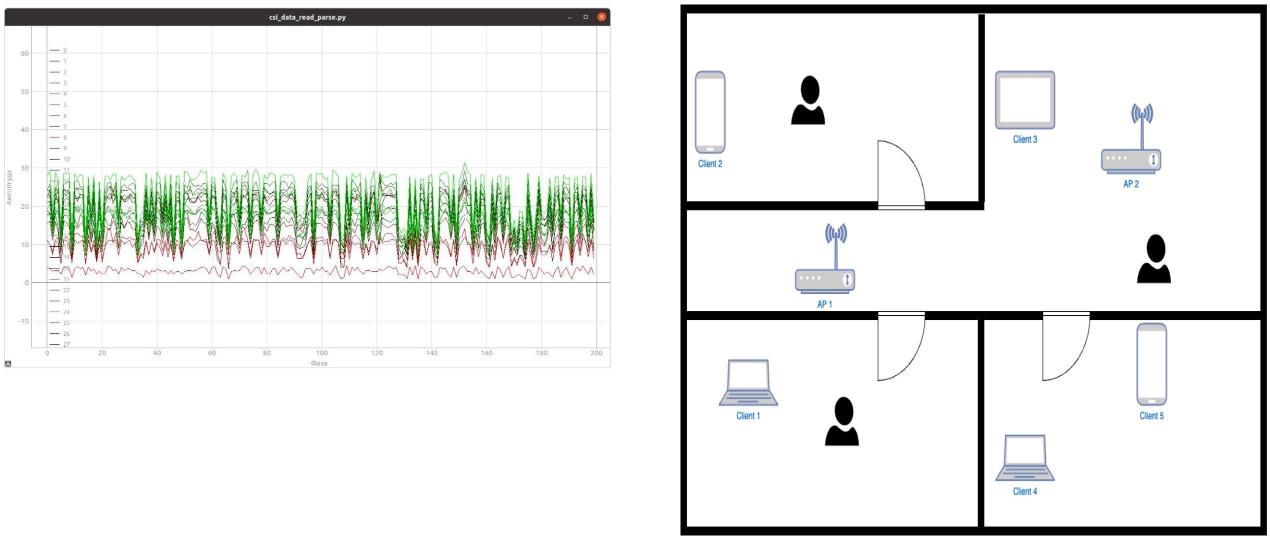
It is also possible to determine the location of a person by analyzing this CSI data, it is possible to localize a person in the room in use (Figure 5). CSI data can be integrated with other sensors and systems to create intelligent environments such as smart homes, smart offices, or smart cities [7]. Such integrated solutions allow collecting a variety of data about the environment and human behavior to provide automation, energy savings, and increased comfort.

The advantages of integrating CSI technologies into smart environments are the ability to create smarter, more convenient, and more energy-efficient systems.

CSI data provides valuable information about the presence and behavior of people, which allows you to automate processes and adapt the environment to their needs.



a. b.

Figure 5 – CSI-based sensing scenarios:

a – *accommodation of people in premises with Wi-Fi equipment*; **b –** *CSI signal data from premises*

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Summary and conclusions.

Further development of the method of using CSI data from Wi-Fi signals from standard equipment already installed on the territory of an enterprise in any industry to detect objects in the environment has significant advantages over existing analogues. These advantages include contactlessness, no need for additional sensors, the ability to detect objects behind walls, etc. The scientific novelty of this approach lies in the improvement of CSI processing algorithms, which increases the accuracy of classification and determination of the distance to objects. The results of this work make it possible to create cost-effective monitoring systems based on the existing wireless network infrastructure, which makes it particularly attractive for use in various industries.

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Анотація. *Сервісні функції сучасних операційних систем дозволяють здійснювати пасивний моніторинг («прослуховування») трафіку комп'ютерної мережі без використання додаткового інструментарію та додаткового обладнання. Такі функції можна використати для контролю інформаційної безпеки шляхом виявлення появи нових об'єктів (як людей, так і матеріальних предметів) у контрольованій зоні. Дослідження спрямоване на розвиток методів виявлення об'єктів на основі аналізу інформації про стан каналу (CSI) мережі Wi-Fi та створення відповідного апаратно-програмного забезпечення. Актуальність роботи підкреслюється потенціалом використання таких систем для неінвазивного виявлення небезпечних предметів у навколишньому середовищі. Дослідження охоплює процес виявлення об'єктів шляхом аналізу сигналів Wi-Fi, зосереджуючи увагу на методах та алгоритмах обробки CSI для ефективної класифікації та ідентифікації об'єктів. Запропоновано метод виявлення об'єктів на основі аналізу сигналів мережі та досліджено зміну CSI-даних в залежності від матеріалу об'єкта, що створює перешкоду.*

Ключові слова: *мережа Wi-Fi, мережевий трафік, інформація про стан каналу (CSI), RSSI сигналу, модуль ESP32, виявлення об'єкта.*

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