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A novel sensor-based architecture using 5G and Blockchain for remote and continuous health monitoring

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The healthcare sector strives to improve the quality of care delivered to patients, especially considering new digital technologies, such as sensor-based networks (SBN). The application of SBN can help to provide remote and continuous monitoring for patients that need continuous treatment and management. In this context, this research proposed a novel sensor-based architecture for healthcare monitoring including 5G as a recent technology for low latency data communication. Blockchain is another component that is integrated to prevent forgery, tampering, and enable more secure transmission. Furthermore, this study proposed a unique data architecture that is based on a new protocol that aims to transmit gathered sensor data over existing network architecture (for example, routers) without the need for intermediate devices such as mobile phones, PDAs, or tablets. The proposed data architecture is discussed for its application in healthcare through two case scenarios, continuous monitoring of chronic diseases and back pain.

Keywords
blockchain, continuous and remote monitoring, health informatics, sensor-based networks, 5G data architecture

1. Introduction

The term Internet of things (IoT) refers to a system of heterogeneous and homogeneous connected devices that can sense, process, and transmit gathered information. Examples of IoT devices include sensors, actuators, radio-frequency identification (RFID) tags, mobile phones, smart embedded devices, etc. Among other numerous applications (e.g., smart homes, smart cities, autonomous vehicles), IoT devices can be used in the healthcare domain to provide remote and continuous monitoring of patient's vital signs or other health-related information that medical specialists need [1]. Here are included sensor-based applications in the form of wearables or smart sensing systems, that can sense data related to a patient's body (e.g., heart rate, blood pressure, oxygen saturation, blood sugar, amount of sleep, physical activity, movement, muscle activity) and transmit gathered information to a point that is accessible from third parties such as healthcare professionals, family doctors, family members or other caregivers.

IoT plays an important role in remote monitoring for elderly care, patients diagnosed with chronic diseases, back pain monitoring, and similar cases where continuous monitoring is needed [2]. Consequently, many digital medical devices in the form of sensors, imagining, or diagnostic devices, present IoT smart devices installed within and outside the medical centres. According to previous research [3, 4], worldwide there are more than 100 million installations of IoT platforms designed for healthcare, and this number is estimated to reach 75 billion by 2025 [5].

Blockchain, on the other hand, is considered an emerging technology that can be applied in the IoT domain to safely process gathered sensor data [6]. Moreover, blockchain is considered a technology that has evolved beyond the financial area and currently is discussed about its implementation in the healthcare sector [7]. Blockchain features such as decentralization, tamper-resistance (data records cannot be changed) and traceability (each block contains the record of the previous block) ensure that gathered sensor information is processed in a reliable network and are safe from vulnerable attacks. This is further supported by previous research [8] that elaborated blockchain as a possible solution to develop secure IoT systems. Hence, the distributed messaging protocol and encryption technology

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that blockchain has, enables efficient data processing from IoT nodes to third party applications while maintaining data integrity [9].

Besides security, system designers should consider the transmission capabilities of the huge amount of sensor data that will be collected from IoT architectures. In this context, the advent of 5G (fifth generation of wireless communication standard) brought increased data rates, improved coverage compared to other existing wireless standards (4G or 3G), and reduced end-to-end latency [10]. All these factors are considered beneficial for the IoT applications in regards to communication and transmission requirements.

The purpose of this paper is to present a unique, scalable, and flexible sensor-based architecture that can collect health-related information in real-time through IoT sensors. Hence, the contribution of this study is twofold:

- It proposes a data-architecture based on 5G wireless standard and blockchain. The 5G is incorporated to handle large amounts of IoT data that are collected from wearables attached to a patient's body, while blockchain is used to encrypt and transmit gathered data and, in this case, it avoids forgery or tampering of the collected information through sensor nodes.
- It elaborates on a common data communication protocol that operates on the sensor-based platform and on the devices of the existing networking infrastructure, for example, routers.

Hence, the proposed data architecture is generic in the context of the sensed information and this means that it can scale up by incorporating various IoT devices designated for health monitoring. Another factor that makes the proposed architecture unique, novel, and cost-effective solution for real-time and remote monitoring, is related to the usage of existing network devices as relay nodes for transmitting information from sensor-based platforms to the blockchain network. This eliminates the need for mobile phones, PDAs, tablets, or other mobile devices, that were proposed as intermediate components on various architectures for health monitoring in the literature, as discussed in the following section.

2. Background

The internet of things (IoT) is considered as an evolving technology that has applications in different business areas. However, the rapid evolution of IoT is leading to security leaks or cyber-attacks which need to be considered carefully [2]. This is extremely important for the healthcare domain as gathered data may be a patient's vital signs or related recordings that may come from the sensors attached to a patient's body. To overcome these concerns, blockchain technology was discussed as a possible solution [11].

Blockchain is considered as a decentralized database that records every data transfer over a network. This technology is formed based on 4 pillars that include: consensus, it provides the proof of work and enables to verify the actions in the network; ledger, it provides details of all data transactions within the network; cryptography, this pillar ensures that all data transactions are encrypted and accessed only from authorized users; and smart contract, it provides verification and validation of the participants in the network. Hence, blockchain needs the coordination of blocks and a network to operate on. In this context, 5G is proposed as a suitable standard that enables data transmission for IoT devices.

The 5G wireless standard presents a technology that offers low cost, low energy consumption, and support for a larger number of devices. All these parameters are considered favourable for the IoT industry, blockchain, and their application in the healthcare area. Further to this, Dinesh et. al [7] confirmed the close relation of these technologies, and they declared that 5G enables us to connect to the Internet of things (IoT), while for having secured transactions, in this case, we will need blockchain. In this context, various studies [12, 13, 14] proposed an IoT platform that enabled continuous and remote monitoring of chronic diseases using 5G as a wireless mobile network. Similarly, in previous research [15], a diabetes constant assessment and monitoring system was proposed using 5G and IoT.

Various studies [16, 17, 18] presented research on the application of sensor-based platforms for healthcare monitoring. A study in [19] highlights the projects of well-known companies such as Microsoft, Google, Cisco, Intel, IBM, Qualcomm, and Apple, towards the application of IoT platforms for improving the delivery and management of healthcare services. Tito in [2] proposed a simplified version of a remote monitoring system for patients' wellbeing designated for regions with limited IoT infrastructure. The proposed architecture in [2] had three layers of data communication, namely data acquisition, data transmission, and data processing. Similarly, a study in [20] proposed a three-layered architecture (sensing layer, transport layer, and application layer) for monitoring heart diseases, and it was able to gather patient's data and send them to an Android-based application. The contribution of this work compared to previously mentioned ones was the proposal of four transmission modes for sending gathered sensor data to the server-side. Another three-tier architecture for health monitoring was proposed in [21]. In this architecture, (Tier-1) gathered sensor data were transmitted using Bluetooth technology to the local collector (for example a hub, PDA, or laptop), then (Tier-2) the collector used ZigBee/IEEE 802.15.4 to forward the data to the IP based network (Tier-3). Nevertheless, the proposed solution was evaluated in a small-scale testbed.

Gómez, Oviedo, and Zhuma [22] proposed a client-server architecture that was able to record health data and send them through a communication interface on the server-side. The server side included components such as detector context, reasoning engine, and knowledge (applied ontologies). A study in [9] used 5G and blockchain to propose an IoT architecture for air pollution measurement. Authors concluded that their proposed 5-tier architecture can help to overcome environmental problems caused by air pollution that affect peoples' health conditions too.

Most of the investigated studies proposed very similar sensor-based architectures consisting of three-layers that enabled gathered sensor data to be transmitted to a remote server for further analyses and processing. Furthermore, most of them included mobile devices as intermediary components that enabled the transmission of gathered sensor data to remote servers using various wireless standards. The aim of this research, on the other hand, is to propose a cost-effective solution that will use existing network infrastructure and eliminate the need for additional devices such as mobile ones (tablets, PDA or mobile phone). Hence, taking into account the benefits of 5G and blockchain technology combined with the direct network access method, as discussed above, this study proposed a novel data architecture that provides real-time and distance-based health monitoring over the existing network infrastructure.

3. Proposed 5G and blockchain-based sensor architecture

This study includes a sensor-based architecture that can collect health-related information in real-time through IoT sensors using 5G wireless standard and blockchain. The 5G is incorporated to handle large amounts of IoT data collected from wearables attached to a patient's body. The proposed architecture uses blockchain technology to encrypt and transmit gathered data and in this case, it avoids forgery or tampering of the collected information through sensor nodes. This section is divided to provide the general layered data architecture (3.1) and the proposed common data communication protocol between the sensor-based platform and existing networking infrastructure (3.2).

3.1 Data architecture

The proposed data architecture enables remote and continuous monitoring of the patient's condition through the sensors that can gather health-related information, for example, heart rate, blood pressure, oxygen saturation, blood sugar, amount of sleep, physical activities, movement, muscle activity, etc. The overall architecture consists of five layers as presented in Figure 1.

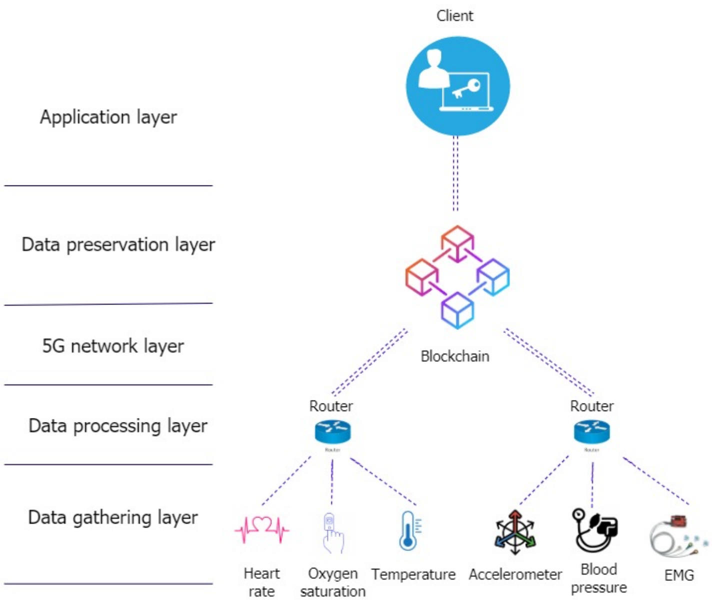

Figure 1 5G and blockchain-based sensor architecture for continuous and remote monitoring

The data gathering layer consists of medical sensors that can sense a patient's vital signs or other health-related parameters. The sensed information is converted into digital signals and is transmitted to existing networking devices, such as routers, through 5G wireless networks. As mentioned above, the proposed architecture is easily scalable, as system designers can attach various medical sensors to the existing schema, and the information will be further transmitted.

The data processing layer enables the analyses and further processing of the gathered sensors data that are transmitted from the data gathering layer. The communication between these two layers is managed through the proposed protocol in this study, the common data communication protocol (CCDP) elaborated in the next subsection 3.2.

5G Network layer is used to transmit a huge amount of data generated from sensors that are attached to a patient's body. 5G wireless standard provides high reliability, increased network speed, wide-coverage, and low latency, which all make suitable use cases for application in sensor-based architectures.

The data preservation layer is used to securely preserve transmitted data from the processing layer and further transmit them to the application layer. This layer uses blockchain to provide secure and private communication that prevents forgery and tampering of the gathered data. Blockchain technology incorporates encryption and its immutable timestamp ledger layer that enables storing and sharing of data in a distributed manner, without the need for a central authority (decentralized). Blockchain provides functionalities such as compatibility, sustainability, data sharing, and interconnectivity.

The application layer is used to present gathered information through a client, that can be a web-based application or mobile application, to its users. In this study, users of the proposed data architecture are considered healthcare professionals, family doctors, patients, family members, or other caregivers. Hence, the application layer uses the data that is already encrypted and preserved through the previous layers, to visualize and present the IoT application that fits the purpose. Various data analyses, reporting, configuration, and authentications are performed in this layer.

3.2 Common data communication protocol

A common data communication protocol is proposed in this study to enable the sharing of the information between the sensor-based platform and the existing devices in the network. The data protocol will be used to exchange gathered sensor information over an existing wireless area network, for example, routers inside a building, in case the patient is at his/her home or office; or wireless connection of a public network, in case the patient is outside a building and connected on a shared network. Hence, the proposed protocol is a software that will be installed in the proposed sensor-based platform and in the telecommunication devices that provide an internet connection, for example, routers, base stations, and similar.

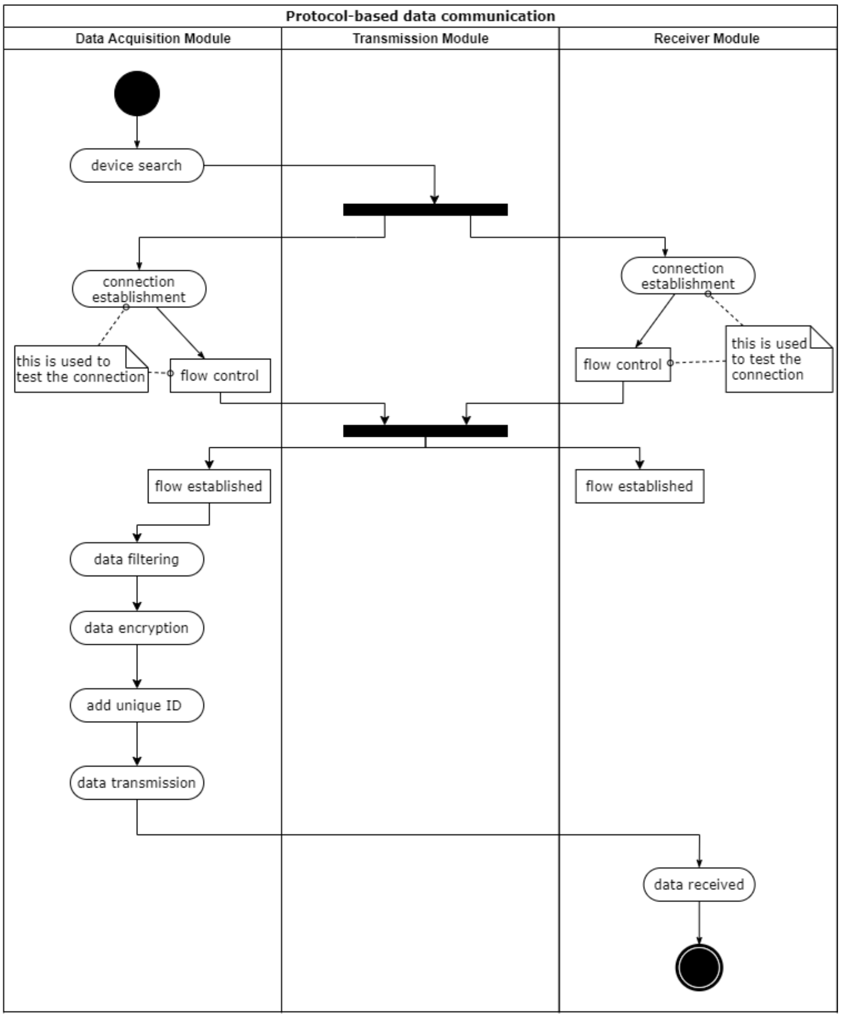

Figure 2 Activity diagram of the data communication protocol

Figure 2 shows a workflow diagram of the data communication protocol. The data acquisition module represents the sensor-based platform where different sensors (depending on the healthcare needs, for example, heart rate sensor, oxygen saturation sensor, proximity sensor, acceleration sensor, etc.) transmit the data. This module can be considered a microcontroller that has processing and transmitting capabilities. In this case, the data communication protocol will be installed and will enable the exchange of information with the receiver module, as presented in Figure 2. These two modules primarily need to agree on a communication standard that in this case will be the same data protocol, and establish a connection channel for data sharing. After setting up the communication bridge, the acquisition module will perform:

- Data filtering represents the process of cleaning the received sensor data from any noise or other unwanted information that can be merged during signal processing from sensors to the microcontroller or the sink device.
- Data encryption presents the process that protects gathered patient's information by encoding them and transforming in an unreadable format for the third parties that may want to access them. Hence, only authorized people can decode and read gathered information. This process is very important as it helps to prevent packet sniffing or other unauthorized access to the transmitted data packet over a public internet connection.
- Add a unique ID, this will serve to identify the sensor-based device that is transmitting the data.
- Data transmission, following all the above processes, the sensor-based device will use existing network architecture to transmit data (patient information) to the receiver module.

The proposed steps of the data communication protocol, follow a logical order that enables to transmit the gathered patient information (for example patient's vital signs) over wireless communication links to a storage module, that in this case is the blockchain.

4. Use cases

Digital technology in healthcare enables gathering and sharing of the information to people of different backgrounds (e.g., medical personnel, caregivers, family members, and patients). This implies access to the information and possible solutions, to minimize medical costs. Hence, IoT applications such as smart medication, assisted living, telemedicine, and remote monitoring (eHealth or mHealth), provide mechanisms to improve health delivery.

In this context, the proposed sensor-based architecture in this study enables users a remote and continuous monitoring tool that can be applied in various medical areas. As use case scenarios of the proposed architecture are considered:

- **continuous and remote monitoring of chronic diseases**, this means that in the proposed sensor-based architecture, system designers should include corresponding sensors that enable the monitoring of chronic parameters. Previous research [23] identified key vital signs such as blood pressure, pulse, temperature, heart rate, oxygen saturation, that healthcare professionals need to monitor continuously and, based on these, to provide reliable feedback to their chronically ill patients in distance. Hence, the inclusion of corresponding medical sensors would enable healthcare professionals and patients, in this case, to communicate and share information in real-time and remotely.
- **continuous and remote monitoring of back pain**, healthcare professionals usually need detailed information on the daily activities of patients with back pain, this includes also a patient's spine position. Hence, by incorporating corresponding sensors (motion, accelerometer, muscle activity) in the proposed architecture, it would provide useful information to medical personnel on the visualization of the position of the spine, to identify patient's posture problems and provide more accurate therapies and solutions to back pain problems.

These two cases provide just a few examples of the application of the real-time and remote monitoring offered through the proposed sensor-based platform. Continuous monitoring of health-related parameters enables enhanced healthcare services delivered to patients and their improved quality of life.

5. Discussion

IoT-based healthcare services tend to decrease treatment and management costs and improve patients' quality of life [2]. Gathered sensor-based information can be used for further reporting, better diagnosis, and emergent interventions in case of a patient's critical condition. Hence, this has an impact on hospitalization costs that may be reduced due to early diagnosis and more accurate therapy from a detailed report of measurements offered from continuous and remote monitoring [10].

From an initial research of the existing sensor-based architecture, it is noticed that mobile devices were used in most of these architectures as a relay node between sensor platforms and remote servers [20, 21, 12]. However, a study presented by Tito [2] discussed a direct network access system that enabled sensor platforms to transmit gathered information directly to network service providers without the need for any intermediary devices. A similar workflow was discussed also in [24], even though, there the authors used the term exchange service for the component that was collecting data from sensor nodes and forwarding them to storage services on the cloud. This approach was followed also in our study by proposing the common data communication protocol between the sensor-based platform and routers in the existing network infrastructure, to transmit gathered data and forward them to the blockchain network. Further to this, our proposed architecture used services to provide an interface between the application layer and its users, that in our case will be healthcare professionals, patients, caregivers, or family members. A similar approach was suggested also in [25] where services were used to link data objects in an enterprise architecture designed for healthcare.

5G is considered a recent innovation that has various advantages over previous wireless communication standards, such as 4G or 3G. However, 5G is still under consideration and discussion [26]. In this case, the proposed data architecture in this study can also work using the previous generation of wireless standards, however, for better latency and higher data transmission rates, 5G is proposed.

The intersection of 5G, IoT, and blockchain, on the other hand, is considered to provide more secure and private communication [7]. Further to this, Blockchain was proposed in various research studies [27, 28] as a privacy-preserving scheme for patient's data transmitted over the Internet. Blockchain's immutable timestamp ledger layer enables storing and sharing of data in a distributed manner, without the need for a central authority, in a peer to peer network. Nevertheless, according to [29], there are some challenges in applying blockchain as follows:

- overhead that is caused due to consensus operations either when adding a new block or when broadcasting transaction to all participants in the network,
- considering the scale of IoT applications, system designers should consider the low throughput due to the low number of transactions that can be recorded in the blockchain.

Besides these challenges, various studies [30, 31, 32] have adopted blockchain solutions for securely storing patients' healthcare data. In this context, a study in [33] proposed an architecture that declared to overcome some of the above-mentioned challenges and it enabled patients to choose who can access their data and how. This is considered beneficial and adds further value to data security and authorized access for healthcare information.

6. Conclusions

Considering advances in digital technologies, especially ones that include the IoT, this study elaborated on their application in the healthcare domain. Hence, based on the most recent and innovative platforms that are proposed in the literature and taking into consideration the needs of the healthcare domain, a novel sensor-based architecture was proposed.

The proposed data architecture consists of:

- 5G as a recent technology for increased data rates, improved coverage compared to other existing wireless standards and reduced end-to-end latency data transmission,
- blockchain as a secure data storage mechanism that avoids forgery or tampering of the collected patients' information through sensor nodes, and
- the common data communication protocol between the sensor-based platform and existing network architecture (for example, routers).

The proposed architecture in this study is scalable and such it enables various health-related sensors to connect to it. In this way, patients' vital signs or other related health information can be recorded and transmitted in real-time and remotely, to authorized parties that can access them. This was further elaborated through the two case scenarios for continuous and remote monitoring of chronically ill patients and those having back pain.

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