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PAPER

Delay of Transmitted Data in the Remote Patient Monitoring System through AMQP and CoAP

Filip Tsvetanov(✉), Martin Pandurski

South-West University, Blagoevgrad, Bulgaria

ftsvetanov@swu.bg

ABSTRACT

Remote Patient Monitoring (RPM) is a healthcare solution that uses technology to monitor patients outside conventional healthcare settings. It is especially useful for people with chronic conditions or needing regular monitoring. One of the main reasons for the increase in the number of deaths each year is the increase in cardiovascular diseases, including hypertension. Online blood pressure monitoring offers many advantages but also potential challenges. This work reviews the key communication technologies and research challenges in the real-time transmission of measured blood pressure data. Delay in these systems is not tolerated as it involves human lives. To conduct the experimental studies, a prototype of an experimental intelligent system was created to study the delay and processor load of the RPI4 gateway. The measured blood pressure data is sent to the Things Board cloud using the AMQP and CoAP protocols. The experimental results are particularly useful for RPM system designers. The results of this research facilitate an informed decision on the choice of protocol that transmits the data from the gateway to the cloud in the process of designing remote patient monitoring systems.

KEYWORDS

Remote Patient Monitoring, delay, sensor networks, AMQP, CoAP, clouds, integrations

1 INTRODUCTION

In recent years, people have mainly developed chronic diseases due to old age, unhealthy diets and stressful lifestyles. Unfortunately, the overburdening of the treatment system for such diseases significantly affects the modern healthcare infrastructure, resulting in an increased demand for hospital resources such as beds and medical staff. The alarming data about Bulgaria's critically reduced medical staff compounds this challenge, as doctors, nurses, technicians and engineers must work harder than ever to provide the same quality of patient care. The need to find a robust solution to deal with such excessive pressure on healthcare institutions while continuing to provide quality services in outpatient and inpatient wards is increasingly evident. One suitable solution to the problem is to move traditional clinical settings into people's homes,

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with the collected health data being transmitted wirelessly to the healthcare provider. Using this type of telehealth, physiological data such as heart rate/pulse, breathing rate, body temperature, blood pressure and blood oxygen saturation, blood sugar, etc., can be measured and transmitted by building wireless body networks [1], [2].

RPM (remote patient monitoring) is one common approach that helps doctors monitor patients with chronic or acute illnesses in remote locations, older adults in home care, and even hospitalised patients. The development and implementation of RPM systems play an important role in improving and increasing the efficiency of health care; the patient experiences greater physical mobility and is no longer forced to stay in the hospital. WBAN is a sensor network with a unique purpose, providing continuous monitoring of a person's parameters through specific biological sensors without any restrictions on their daily activities. Sensors are attached to clothing or the body or implanted under the skin. The wireless essence of the network and the wide variety of sensor devices offer many new, practical and innovative applications to improve healthcare and quality of life [3].

The Internet of Things is a popular technology, offering an impactful solution for the effective treatment of chronic patients. These solutions include remote monitoring and predictive maintenance and play a key role in managing such WBAN systems by offering real-time services [4]. RPMs perform well in self-management of chronic diseases, remote monitoring and clinical care by health professionals for patients who are restricted to staying at home due to disability or to avoid exposure to infection [5].

Arterial hypertension is among the main risk factors for cardiovascular diseases on an international scale. Currently, the public health challenge related to mortality, morbidity and complications of cardiovascular, cerebrovascular and renal diseases caused by hypertension is largely unsolved worldwide [6]. The number of hospital patients who need regular blood pressure measurement by medical staff is increasing yearly. That leads to a heavy workload of medical staff in some hospitals due to routine examinations and an increased need for such staff. Here comes the need to simplify the process of monitoring important indicators of treated patients. IoT systems for monitoring blood pressure and other indicators facilitate and automate these processes. The authors in [7] confirm that blood pressure monitoring at home and 24-hour ambulatory monitoring, used as self-monitoring by patients, is essential for confirmation and long-term treatment of hypertension. According to them, there is strong evidence that home BP monitoring allows the detection of intermediate hypertension phenotypes (masked white hypertension and coat hypertension) and is superior to conventional measurements in predicting cardiovascular events. Over the past decade, hypertension guidelines worldwide have increasingly supported the widespread use of blood pressure monitoring in clinical practice.

Although online blood pressure monitoring offers many advantages, there are also potential challenges and problems associated with this approach, such as new measurement technologies [8], device validation and calibration [9], [10] high energy consumption, availability of fewer resources and security issues [11], transaction time, throughput, different design priorities such as latency, mobility, cost and size, QoS requirements based on traffic type, data quality, quality of device and network metrics [12], the medical data routing protocols. To improve the QoS of health data transmission, the authors in [13] developed and tested a multi-hop enhanced cluster routing protocol (MRCRP). The cluster head is selected using an energy-efficient approach for improved utilization of hardware resources. Min-max is applied normalization to transform the original data into meaningful data for further analysis. According to the authors, the proposed routing technique provides efficient data transmission. A multipath routing protocol simulation study is presented in the work [14], where three modifications for a multipath routing protocol are implemented. To solve the routing problem, the authors build a DCell simulation network. Dijkstra's algorithm finds the shortest path in a data transaction. The results show that the proposed modification provides good results in saving time, cost and data transactions.

In ref. [15], the results of experiments in which the delay between sending a request and an RPM system's response were measured were published. The data is sent to three servers—a local server, a cloud on the ThingSpeak platform and the servers of the company Hostinger. The results show that the data latency with the ThingSpeak cloud is about seven times higher for the same network performance and experiment conditions. The ability of systems to deliver critical data without any delays is of utmost importance to reduce any complications, especially in emergency patients.

In ref. [16], the health monitoring system during the operation procedure, which determines the critical human conditions, such as heart rate, blood pressure, sugar, oxygen and other parameters, has been proposed and experimented. The surgeon can send audio and video through the server, and the heart rate and temperature sensors connected from the Raspberry through the microcontroller can send the physical parameters to the online specialist in real time. The digital data in the cloud web server can be accessed by professionals anywhere in the world via smartphones and other monitoring devices. Therefore, systems in the healthcare industry must offer real-time communication with a guaranteed delay to provide feedback to patients in the event of an emergency.

We can summarise that there is an increased interest from the research community to solve this significant problem. Numerous studies have been and continue to be conducted to improve the effectiveness of monitoring for various diseases. There are still many challenges facing these systems. One such challenge is network latency, which defines the end-to-end delay in a communication network. End-to-end delay in a communications network can be broken down into several main components. Each of these components can contribute to the overall delay of transmitted data. End-to-end delay is generally measured in milliseconds or even microseconds, depending on network characteristics and application requirements. Delays in these networks are not tolerated as human lives are at stake, and feedback must be given immediately. Choosing an appropriate data integration protocol is important for RPM system designers as it facilitates informed decision-making when designing remote patient monitoring systems.

The present work aims to investigate this component of data transmission delay in a gateway-to-cloud-generated communication network in a patient monitoring system. To achieve this goal, an experimental network was constructed, and the impact of network gateway to cloud data integration protocols AMQP and CoAP on the transmission delay of the measured data from the blood pressure device was investigated.

2 RELATED WORKS

2.1 Characteristics of patient monitoring systems in general

RPMs are being developed to solve the problem of patient monitoring regardless of time and place. The design of these networks must address mobility, data rate, and network coverage [17]. For example, building RPMs using fog or cloud computing can provide mobility capabilities, low latency, and low bandwidth consumption [18]. RPM enables physicians and patients to communicate over long distances, facilitating care, advice, reminders, awareness, remote intervention, and telemedicine services such as diagnosis and appropriate medical follow-up when the patient is in a rural area without transportation or inability to move, lack of funding, or lack of staff [12]. Accuracy for diagnosing diseases is also important with these systems.

The authors in [19] applied fuzzy set theory in bio-measurement medicine and its behaviour through a fuzzy logic model. The proposed design uses three different types of sensors and a microcontroller. The fuzzy logic model is designed and practically tested. The results show that it is an effective tool for accurately diagnosing heart rate, blood pressure and temperature measurements.

RPMs are critical to healthcare and must be developed and used with a strong focus on security to ensure patient health status data's confidentiality, integrity, and availability. Increasing the security of these systems, as well as preventing potential vulnerabilities, requires adopting some specific security measures, which we summarise as follows:

- Encrypt data transmitted between monitoring devices and the central system to prevent unauthorised access to patient's personal and health information.
- Authentication and authorisation to access the monitoring system to prevent unauthorised access to patient data.
- Physical security, protecting physical access to monitoring devices, such as through access control and video surveillance.
- Network security, using security measures such as a network with firewalls and filters to prevent unauthorised access to the monitoring system via the network.
- Regularly update and patch monitoring devices' software and operating systems to fix known vulnerabilities.
- Isolation of patient data by storing and processing in separate and secure environments from other systems to reduce the risk of compromised personal information.
- Staff training and awareness of security, potential threats and security procedures.
- Security and incident monitoring by building a continuous security monitoring and incident response system to quickly detect and respond to potential threats.
- Training staff to be careful when handling information and to recognise social engineering attacks.
- Ensure that the communication channels connected to the monitoring devices are protected from attacks such as Man-in-the-Middle.

We can summarise that the main challenges in the construction and exploitation of sensor networks involved in RPM are related to the need to operate at extremely low power, lightweight, avoiding implantable sensors, maintaining security and privacy, reliable transmission of vital patient data, real-time connectivity over heterogeneous networks, low complexity and latency, standardisation, interoperability, low cost and better quality of service (QoS).

2.2 RPM system communication capabilities

The main communication models used to facilitate IoT communication between doctors and patients are Request/Response or Publish/Subscribe. Communication protocols are classified into short-range, medium-range, and long-range protocols [20]. Communication links between devices in RPM are usually short distances, and we may consider them in several aspects. Communications are from the medical devices to the network coordinator, from the coordinator to the gateway, and from the gateway to the cloud. An analysis of network communication protocols in IoT-based healthcare monitoring systems such as HTTP, CoAP, MQTT, and AMQP has been done in work [21]. The authors also consider using RFID technology in the intelligent health system. In work [22], a remote healthcare monitoring system was built using the MQTT protocol for data communication. Ref. [1] analysed the applicability of appropriate communication protocols between application layer devices such as Bluetooth,

Bluetooth Low Energy, ZigBee and WiFi. According to the authors, Bluetooth is particularly attractive because it can connect and communicate with an almost unlimited range of Bluetooth devices without needing the device to be in direct sight of another device [23]. Both data and voice can be transmitted when connected. According to the standard, there are three types of devices, each with transmission power and coverage ranging from 1 to 100 m and up to 3 Mbps data rate. In [24], a real-world environmental monitoring system was built, including the XBee sensor network and ThingSpeak cloud. Data transmission between them is carried out with the following protocols: MQTT, MQTT-SN, HTTP and HTTPS. The impact of the parameters of the transmitted packet on the delay, the load on the processor, and the RAM of the gateway was studied. The results give advantages of MQTT over the other investigated protocols in terms of data rate, CPU and RAM load when working with XBee sensor modules and integration between WSN and cloud structures. A comparative analysis between CoAP and MQTT in healthcare is done in [25]. Based on an analysis of the capabilities of the two protocols, the authors conclude that the protocol choice depends on the type of application in which the protocols will operate. If an application needs TCP, MQTT should be chosen, and CoAP is the better choice for UDP messages. In [26], a CoAP-based group mobility management protocol called CoMP-G is proposed. It has been observed that the CoMP medical data transmission delay for a group of sensors is high. The authors propose a scheme where one of the sensors function as a coordinator and exchange all control messages with the web-of-things mobility management system (WMMS) on behalf of other sensors. It is analytically proven that the proposed scheme with the CoAP-G protocol gives better performance and less message delay regardless of the number of sensors in the network compared to the CoMP protocol.

An analysis of the performance of HTTP, CoAP, and MQTT under different scenarios is performed in ref. [27]. The authors prove that MQTT is lightweight and faster in data delivery. In [28], a real-time RPM system was proposed, with data forwarded to the website using the MQTT protocol to reduce signal transmission latency. In [18], Wi-Fi, Zigbee, Bluetooth, and BLE are discussed as short-range communication technologies in remote patient monitoring systems. Interoperability issues of various application layer protocols such as HTTP, CoAP, and MQTT are covered in ref. [29]. The author's work [30] notes that real-time applications often require fast data transmission from IoT devices. However, quickly obtaining the latest data from end nodes is difficult due to network delays and link failures. These issues can be worked out using ML machine learning, which is recommended. According to the authors, applying ML to an IoT application layer creates intelligent protocols, reduces redesign overhead, and limits human intervention. Ref. [28] performed a performance and packet loss test for the MQTT protocol. It is found that with QoS1, the packet delivery time is less compared to QoS. Based on the literature research in Table 1, we systematise the expediency of applying data transmission protocols to a cloud structure in RPM systems.

Table 1. Applicability of communication protocols in cloud data integration

Protocol	Feasibility of Implementing Cloud Data Integration Protocols in Remote Patient Monitoring Systems
HTTP/HTTPS	When security is a concern, HTTPS should be used to encrypt data in transit. This protocol is suitable for scenarios where real-time communication is not critical because it works on the TCP protocol. Working with this protocol has higher hardware requirements for the end devices, which makes the systems more expensive.
MQTT	Designed for low bandwidth, high latency or unreliable networks. Establishes communications between remote devices. It has a notification mechanism when an unusual situation occurs. It allows for minimising network traffic by reducing transport costs and protocol exchanges. It is suitable for transmitting data from health monitoring devices to the cloud in IoT applications.

(Continued)

Table 1. Applicability of communication protocols in cloud data integration *(Continued)*

Protocol	Feasibility of Implementing Cloud Data Integration Protocols in Remote Patient Monitoring Systems
CoAP	Designed for devices with limited resources, less data transfer, and lower network load levels, making it suitable for IoT applications. It is specifically designed for low-power devices and runs on UDP, making it well-suited for scenarios where energy efficiency is critical. CoAP provides quality of service (QoS) and message acknowledgement mechanisms that provide fine-grained control over communication, especially in poor connectivity situations. Enables operation in multi-network environments such as IPv4, IPv6, Bluetooth Low Energy (BLE) and more.
AMQP	It is suitable for scenarios requiring reliable and asynchronous communication and sending and receiving messages in real time. AMQP is often used in healthcare applications to transmit data between devices and the cloud. It supports different messaging models and configuration options, enabling application flexibility and scalability. There are options for data encryption and authentication of the identity of the participants in the communication, which ensures the security of the information. AMQP is supported by numerous libraries and tools for different programming languages and platforms.
WebSockets	Suitable for real-time applications, allowing a continuous data flow between the device and the cloud. They are used in scenarios where low latency is critical. It is suitable for various applications, including audio and video text and binary data streaming.
Bluetooth, Bluetooth Low Energy	Designed for short-distance communication between devices. It is used in health monitoring devices that transmit data to a nearby gateway device, which then forwards the data to the cloud.

Table 2 shows the protocols studied in this work and their main characteristics.

Table 2. Characteristics of app layer protocols [28]

Characteristics	CoAP	AMQP
Communication model	Request/Response or Publish/Subscribe	Request/Response or Publish/Subscribe
Design goal	Reducing the header and thus limiting the need for fragmentation	To transmit business messages between apps and connect them to different platforms.
Protocol Type/Connectivity	One-to-one and many-to-many communications, P2P	Point-to-Point or Peer-to-Peer
Message mode	Asynchronous and Synchronous	Synchronous and Asynchronous
Architecture	Client/Server or Client/Broker	Client/Broker or Client/Server
Transport protocol	UDP, SCTP	TCP, SCTP
Reliability. Quality of Service	Confirmable Message (similar to at most once) or Non-confirmable Message (similar to At least once)	Settle Format (similar to at most once) or Unsettle Format (similar to At least once)
Header size	4 – Byte	8 – Byte
Security	DTLS, IPSec	TLS/SSL, IPSec, SASL
Bandwidth consumption	Involves lowest	High consumption of bandwidth
Encoding format	Binary	Binary
Licensing Model	Open Source	Open Source

2.3 Data types and volumes

Research shows that the size of medical data can significantly depend on the type of data and the specific context [31]. Medical data contains a wide range of information, including electronic health records (EHRs), medical images (such as X-rays and MRIs), genomic data, clinical trial data, and more. Data characteristics are important for accurate assessment and interpretation when measuring blood pressure. These include the measurement of systolic and diastolic pressure. Systolic pressure is the higher of the two numbers, representing the pressure in the arteries when the heart beats. Diastolic pressure is the lower of the two numbers, representing the pressure in the arteries when the heart rests between beats. Pulse pressure is the difference between diastolic and systolic pressure. Usually, the blood pressure is measured in millimetres of mercury (mmHg). Digital blood pressure measurement is performed with electronic devices to automatically measure diastolic and systolic blood pressure. This process usually involves electronic cuffs (belts) connected to a digital device. The data obtained from these devices usually includes the following information: Systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate, and date and time of measurement. Some digital devices may provide additional or irregular heart rate information and a user name. Digital devices with irregular heartbeat detection technology are also available, which can provide an alert if such irregularities are detected and notify of battery status. Conducting real-time telemedicine transactions implies that two parties exchanging information are simultaneously present and communicating interactively.

The volume of data generated in digital blood pressure measurement is usually tiny because blood pressure and heart rate values are numbers with limited bits. Typically, these devices use small bytes to store individual measurements. Here are approximate data sizes that could be recorded for each measurement:

Systolic and diastolic blood pressure: Fixed-decimal numbers are usually used (e.g., 120.80), which require relatively few bytes.

Pulse rate: Like blood pressure, this can also be represented by numbers with a fixed decimal point.

Date and time: Standard date and time formats are used to record the date and time, which usually require more significant bytes.

Additional parameters: If the device supports additional functions such as recording average values, detecting irregular heartbeats and others, this data can also be part of the recording.

In general, the size of a measurement can be in the range of several kilobytes. It is important to note that, most blood pressure measurement data do not take up much space. When devices support multiple measurement storage functions, the data size may grow with the number of records.

The amount of data in a digital blood pressure measurement can vary depending on several factors, including the specific device used, the measurement frequency, and the data format. Digital blood pressure measurements are generally not very large in data volume. A digital blood pressure measurement can be stored in kilobytes (KB) or smaller units. For example, a measurement can be several kilobytes of data, which can vary. The author's work [31] estimates how much medical data can be included in developing telemedicine applications. It should be noted that the data shown in Table 3 may have a higher or lower value depending on the duration of data collection and compression and storage methods.

Table 3. Medical data size [31]

Data Type	Data Size
Digital blood pressure monitor	1 Kb
Digital thermometer	<2 Kb
Oxygen saturation meter	<21 Kb
Electrocardiogram	<141 Kb
Ultrasound	100 Kb – 2 Mb
X-ray	2 – 4 MB
Magnetic resonance (MR) (whole body)	58 – 164 MB
Video conference	<600 MB
Patient's medical records	<100 KB

Exact information on the data size of digital blood pressure measurements can be obtained from the device manufacturer, as they are not specified in the published specifications [32]. As technology and medical research advance, medical data will likely increase. Managing and analysing large volumes of medical data poses storage, processing power, and security challenges. Advanced and progressive technologies such as cloud computing and big data analytics are increasingly used to address these challenges.

3 RESEARCH METHOD

3.1 Scheme of the experiment

This project consists of software development and hardware implementation. The overall system is controlled by Raspberry Pi 4, which collects data via Bluetooth transceiver embedded in a blood pressure device similar to Omron X4 Smart upper arm blood pressure monitor with Bluetooth, sends those data to the cloud via AMQP and CoAP, and at the same time, performs stress test of those protocols via code, that has been developed for this purpose. The patient can follow those data locally on RPI 4 and the cloud.

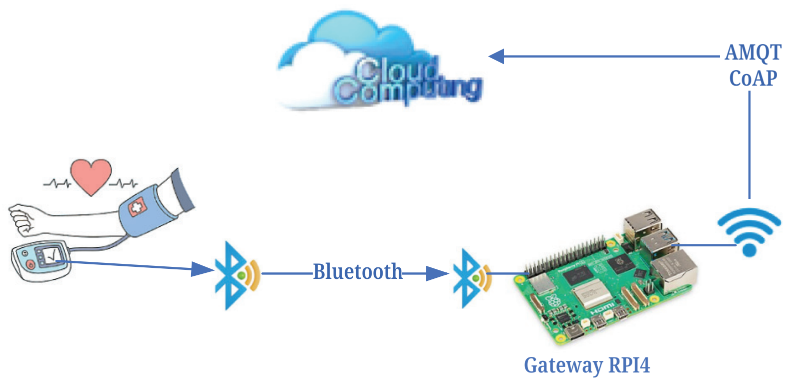

Fig. 1. Experimental design for the implementation of the research

3.2 Algorithm for conducting the experiment

First, we are creating an RPM remote patient monitoring system hardware platform. The system is built from a digital blood pressure device with built-in Bluetooth modules and an RPI 4 as a gateway. The gateway enables the integration between the device and the ThingsBoard cloud, real-time remote monitoring and predictive maintenance. Data is transmitted to the gateway from an OMRON X4-like intelligent automatic blood pressure monitor that is clinically validated via Bluetooth. The model RPI4-A used has a CPU with core type quad-core 1.5GHz and Cortex-A72 (ARM v8) 64-bit, RAM 4 GB, four USB Ports, and communication via Ethernet, WiFi, and Bluetooth. Gateway communication with the cloud is implemented with different protocols to communicate with the ThingsBoard cloud, as shown in Figure 1.

We choose to communicate between the gateway and the cloud using two different protocols, AMQP and CoAP. To experiment, we chose CoAP because it is designed for resource-constrained devices, which makes it suitable for communicating with IoT devices commonly used in RPM systems (e.g., wearables, sensors). AMQP provides reliable and asynchronous communication between the various components of the RPM system. AMQP supports a scalable and distributed architecture, allowing the RPM system to handle many patients and devices. However, it is critical for the secure and efficient transmission of patient data.

Second, we developed the Python software application to collect, process, and integrate the data in the cloud through the AMQP and CoAP protocols. The developed code includes different scenarios for experimenting. We create different scenarios to investigate the data transmission delay for each protocol and the gateway's CPU load. Each scenario comprises measurable parameters such as transmitted data packet number, packet topic number, and topic byte value. When developing the code, we use information from Table 1, regarding the amount of data the digital blood pressure monitor generates. The data size of 1 Kb is equal to the standardised data volume for this device. Table 3 shows the protocol characteristics of the study relevant to the code's development.

Third: Register an account to work in the ThingsBoard cloud. Several setups and configurations are done to integrate the cloud and the Raspberry P device. The ThingsBoard platform supports various integration protocols such as HTTP, CoAP, MQTT, AMQP, OPC-UA and databases to store the data [33].

Fourth, the created code is executed to transmit, process, and store data in the cloud database. The scenarios for experimenting include the measurement of data packet delay and CPU load at different values of the measurable parameters. The delay function measures the data delay of the different protocols. This function measures the time from sending the packets to receiving a message confirming the received data in the cloud.

4 RESULTS AND DISCUSSION

4.1 Investigation of data transmission delay in CoAP and AMQP protocols

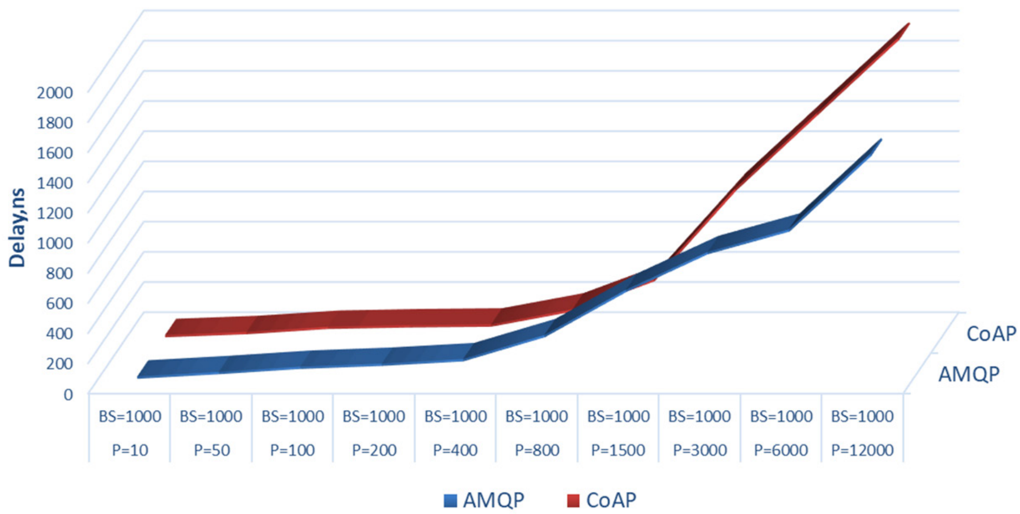

Fig. 2. Delay of protocols AMQP and CoAP at Byte Size – 1000

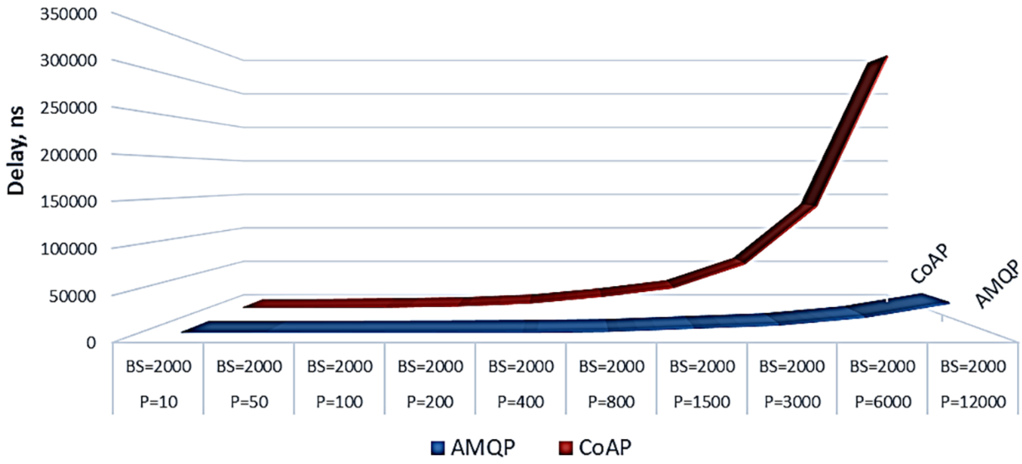

Fig. 3. Delay of protocols AMQP and CoAP at Byte Size – 2000

With a smooth increase in the packet numbers, CoAP and AMQP decrease their performance, Figure 2. With fewer packets, CoAP performs better than AMQP. As the packet numbers increase, above 3000 in the case with 1000 Byte Size (in this particular study), the CoAP performance drops sharply, while the AMQP performance decreases more smoothly. Accordingly, AMQP outperforms CoAP at higher packet numbers. Figure 3 delivers the results of a study of the delay of the transmitted data for packets with 2000 Byte Size. As the number of packets increases, above 100–200, the performance of CoAP drops sharply, while the performance of AMQP decreases more smoothly. Accordingly, AMQP outperforms CoAP at a higher number of packets. The comparative analysis between Figures 2 and 3 regarding the size of the delay proves that the delay, when simultaneously increasing the size of the packets and their number, increases up to seven times the delay with the CoAP protocol.

4.2 Investigation of the processor load during data transmission using CoAP and AMQP protocols

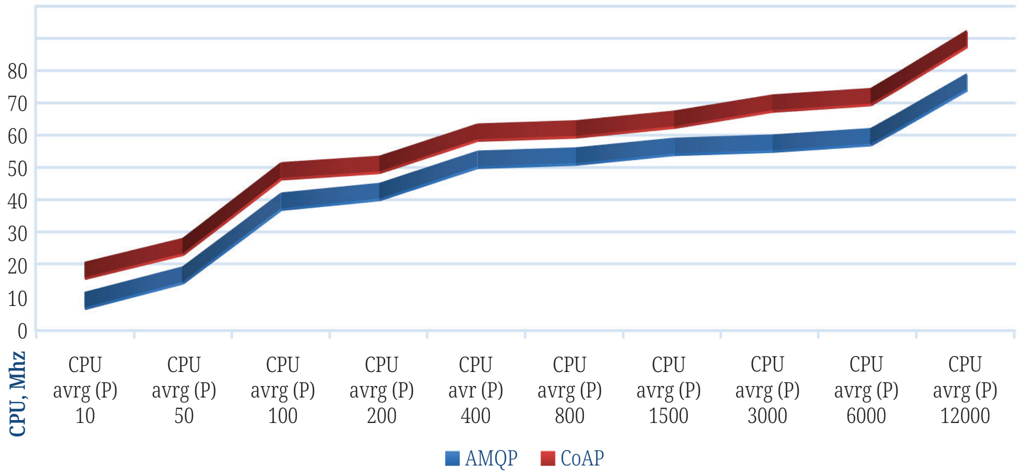

Fig. 4. CPU-Average at load for 1000 Byte Size

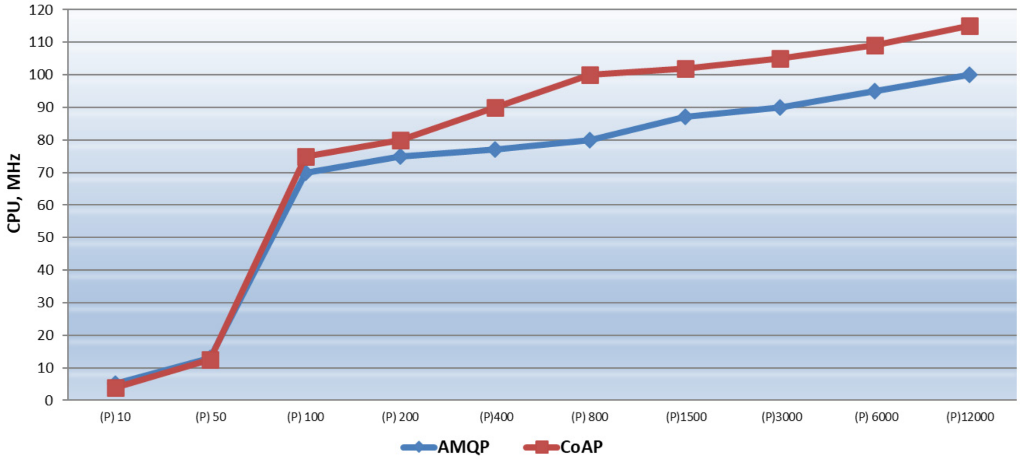

Fig. 5. CPU-Average at load for 2000 Byte Size

With a smooth increase in the packet numbers, CoAP and AMQP CPU usage increase in Figures 4 and 5. In the case of fewer packets, CoAP consumes less CPU energy than AMQP. As the packet numbers increase above 3000 (in this particular study), in the case with 1000 Byte Size (Figure 4), CoAP consumes more CPU energy than AMQP. In the 2000 Byte Size (Figure 5), as the packet numbers increase above 100–200 (in this particular study), CoAP consumes more CPU energy than AMQP. Of course, any experimental result depends on hardware, firmware and software configurations. The comparative analysis of the load on the microprocessor of the gateway when increasing the number and size of the transmitted data packets shows that with the CoAP protocol, the CPU load is approximately 30% higher.

What will happen if the CPU load is high?

When the CPU load on the RPI 4 increases, it can affect system performance and responsiveness. As a result, this can result in slower response times for user interactions and processing delays.

A higher CPU load usually leads to increased heat generation. The Raspberry Pi 4 has a built-in heatsink. However, constant high temperatures may require additional cooling solutions to prevent thermal throttling, which is a mechanism that reduces CPU speed to avoid overheating.

The Raspberry Pi 4 is designed to adjust its processor's speed to manage temperature dynamically. If the CPU temperature rises to a certain threshold, the system may engage in thermal throttling, reducing the CPU frequency to prevent overheating, resulting in lag. Higher CPU load often corresponds to increased power consumption. It is important to remember this, especially in scenarios where energy efficiency is critical, such as in battery-powered applications like ours. Prolonged high CPU load can lead to reduced system stability. This can lead to issues like app crashes, unresponsiveness, or even system crashes if the load is not managed effectively.

Bearing in mind the set of requirements placed on RPM and especially the requirement for timely transmission of data in emergency patients, during surgery, as well as the risk of a sudden increase in blood pressure leading to severe consequences such as stroke and heart attack, we may recommend the transmission of data from blood pressure measuring devices to be performed using the AMQP protocol.

5 CONCLUSIONS

The number of patients with cardiovascular diseases is constantly increasing. Current evidence suggests that digital hypertension management and blood pressure monitoring technology are a realistic possibility to reduce or even eliminate the occurrence of cardiovascular events in hypertensive patients. Most research on the state of the circulatory system, such as the state of blood pressure and heart rate, mainly focuses on automating data analysis and does not consider the problem of effectively transmitting the collected health data in sufficient depth. This work reviews the key communication technologies and research challenges in the real-time transmission of measured blood pressure data. Although online blood pressure monitoring offers many advantages, this approach has potential challenges and problems. One such challenge is the delay in transmission of measured data, which is not tolerated in RPM systems, as it affects human lives, and feedback must be given immediately. To conduct the experimental studies, a prototype of the RPM system for blood pressure monitoring was built, which allows the processing of the received data at a higher level. In this experiment, all sensors are wirelessly connected to the RPI 4 via Bluetooth protocol, which transmits the received data to the ThingsBoard cloud for real-time storage, processing, and monitoring via the AMQP and CoAP protocols. The paper investigates the impact of the data integration protocol from the gateway to the cloud on the delay in transmission of the measured blood pressure values. The analysis of the obtained experimental results gives reason to conclude that:

- As the number of packets increases smoothly, both CoAP and AMQP protocols decrease performance;
- CoAP works better than AMQP with less packets;
- When the number of packets increases beyond 3000 in the 1000 Byte Size case, the CoAP performance drops sharply and the delay increases. AMQP degrades more smoothly, and accordingly, AMQP outperforms CoAP in performance at higher packet counts and has less latency;
- When increasing the size of one packet to 2000 Byte Size and the number of packets above 100–200, the performance of CoAP drops sharply, while the performance of AMQP decreases more smoothly and accordingly, AMQP outperforms CoAP at a higher number of packets;
- The comparative analysis regarding the size of the delay clearly shows that the delay when simultaneously increasing the size of the packets and their number of AMQP increases up to seven times compared to the delay of the CoAP protocol;
- Under the same experimental conditions and transmitted packets up to 3000, the CoAP protocol consumes less CPU power than AMQP, but increasing the packets above 3000 gives an advantage to AMQP, as CoAP starts to consume more CPU power. The lightweight nature of CoAP minimises communication overhead, making it well-suited for transmitting small and frequent updates from remote patient monitoring devices;
- For larger packets up to 2000 Byte Size and increasing them above 100–200, CoAP starts consuming more CPU power than AMQP;
- Comparative analysis of the load on the microprocessor of the gateway when increasing the number and size of transmission data packets shows that with the CoAP protocol, the load on the processor is approximately 30% greater.

The results obtained from the experiment are particularly useful for RPM system designers as they facilitate informed design decision-making. Of course, any experimental result depends on the requirements of the particular patient monitoring system and hardware, firmware and software configurations.

In conclusion, numerous requirements must be considered when implementing a remote patient monitoring system. These requirements may include the type of sensor device used and its applications or the deployment location and surrounding environment. The requirements are important in determining the data quality, routing protocols, transmission delay, and communication networks to be deployed. However, the end-to-end delivery of patient vital signs data depends on the characteristics of the communication network.

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7 AUTHORS

Filip Tsvetanov, PhD, University lecturer, researcher and expert in ICT and security of computer and sensor networks, in Department of Communication and Computer Engineering and Technologies in Faculty of Engineering – South-West University “Neofit Rilski” Blagoevgrad, Bulgaria. Scientific research in the field includes telecommunication, computer and sensor networks, and security of transmitted data and networks—author of more than 60 publications and four books (E-mail: ftsvetaniv@swu.bg, ftsvetanov@gmail.com; ORCID: https://orcid.org/0000-0002-2653-812X; Scopus Author ID: 55602176500).

Martin Pandurski, PhD, scientific research in the field includes problems of sensor data integration to cloud structures, patient monitoring systems, medical sensors, neural networks, artificial intelligence in healthcare, medical prostheses (E-mail: tom1000@abv.bg).