REPUBLIC OF TURKEY

ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF INFORMATICS

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TRANSMITTING VITAL HEALTH DATA WITH COAP OBSERVE

GÖKÇE MANAP

MASTER OF SCIENCE

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ASST. PROF. DR. ALPER KAMİL DEMİR

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Submitted by **Gökçe MANAP** in partial fulfillment of the requirements for the degree of **Master of Science in Department of Information Technologies, Adana Alparslan Türkeş Science and Technology University** by,

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28/06/2021

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Gökçe MANAP

ABSTRACT

TRANSMITTING VITAL HEALTH DATA WITH COAP OBSERVE

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Internet of Things (IoT) is one of the most preferred technologies of recent times. Today, the use of IoT in daily life is increasing and it is expected to increase further over time. IoT devices can communicate automatically without the need for any user. It can receive data from other devices or generate data through the sensors on them. IoT can be used in smart city systems, home automation systems, traffic, and many other areas. One of the areas where the IoT system is used is the health sector. In healthcare technology, IoT systems play an important role in the automatic acquisition, monitoring, and processing of patients' health data. Elderly patients who do not want to be in a crowded environment or who need compulsory home care can expect to be monitored and treated remotely. As a solution to these situations, IoT systems can be considered to collect the health data of individuals and transmit them to a health institution. In this case, it is necessary to analyze the performance of network protocol stacks that can work with IoT systems in order to transmit this health data quickly and reliably. In this study, the health data of the patients were updated every second using the CoAP Observe method. The standard IoT protocol stack is used. 4 different metrics (latency, energy efficiency, reliability, and throughput) were determined and performance evaluation was made. A total of 12 scenarios were evaluated with 4 different scenarios and 3 different PDR (Packet Delivery Ratio) values (100, 95, 90) using MAC (CSMA, nullMAC) and RDC (contikiMAC, nullRDC) protocols.

Keywords: Internet of Things, Medium Access Control, Radio Duty Cycle, CoAP, CoAP - Observe, Remote Healthcare

ÖZET

HAYATİ SAĞLIK VERİLERİNİN COAP OBSERVE YÖNTEMİ İLE İLETİLMESİ

Gökçe MANAP
Bilişim Teknolojileri Anabilim Dalı
Danışman: Asst. Prof. Dr. Alper Kamil DEMİR
Haziran 2021, 35 sayfa

Nesnelerin İnterneti (IoT), son zamanların en çok tercih edilen teknolojilerinden biridir. Günümüzde IoT'nin günlük hayatta kullanımı artıyor ve zamanla daha da artması bekleniyor. IoT cihazları, herhangi bir kullanıcıya ihtiyaç duymadan otomatik olarak iletişim kurabilir. Diğer cihazlardan veri alabilir veya üzerlerindeki sensörler aracılığıyla veri üretebilir. IoT, akıllı şehir sistemlerinde, ev otomasyon sistemlerinde, trafikte ve diğer birçok alanda kullanılabilir. IoT sisteminin kullanıldığı alanlardan biri de sağlık sektörüdür. Sağlık teknolojisinde IoT sistemleri, hastaların sağlık verilerinin otomatik olarak alınmasında, izlenmesinde ve işlenmesinde önemli bir rol oynar. Kalabalık bir ortamda olmak istemeyen veya zorunlu evde bakıma ihtiyaç duyan yaşlı hastalar, uzaktan izlenip tedavi edilmeyi bekleyebilirler. Bu durumlara çözüm olarak IoT sistemlerinin, bireylerin sağlık verilerini toplayıp bir sağlık kuruluşuna iletmesi düşünülebilir. Bu durumda, bu sağlık verilerini hızlı ve güvenilir bir şekilde iletmek için IoT sistemleriyle çalışabilen ağ protokol yığınlarının performansını analiz etmek gerekir. Bu çalışmada, CoAP Observe yöntemi kullanılarak hastaların sağlık verisi her saniyede güncellenmiştir. Standart IoT protokol yığını kullanılmıştır. 4 farklı metrik (gecikme, enerji verimliliği, güvenilirlik ve işlem hacmi) belirlenmiştir ve performans değerlendirmesi yapılmıştır. MAC (CSMA, nullMAC) ve RDC (contikiMAC, nullRDC) protokolleri kullanılarak 4 farklı senaryo ve 3 farklı PDR (Packet Delivery Ratio) değerleri (100, 95, 90) ile toplam 12 senaryo değerlendirmesi yapılmıştır.

Anahtar Kelimeler: Nesnelerin İnterneti, Ortama Erişim Kontrolü, Radyo Görev Döngüsü, CoAP, CoAP-Observe, Uzaktan Sağlık Hizmetleri

dedication

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NOMENCLATURE

IoT	: Internet of Things
COAP	: Constrained Application Protocol
UDP	: User Datagram Protocol
TCP	: Transmission Control Protocol
HTTP	: Hyper-Text Transfer Protocol
IETF	: Internet Engineering Task Force
IEEE	: Institute of Electrical and Electronics Engineers
OSI	: Open Systems Interconnection
IP	: Internet Protocol
IPv6	: Internet Protocol version 6
LLN	: Low-Power and Lossy Network
RPL	: Routing Protocol for Low-Power and Lossy Networks
DODAG	: Destination Oriented Directed Acyclic Graph
DIO	: DODAG Information Object
RDC	: Radio Duty Cycle
MAC	: Medium Access Control
CSMA	: Carrier Sense Multiple Access
RTS	: Request to Send
CTS	: Clear to Send
PDR	: Packet Delivery Ratio
AED	: Adaptive Energy Efficiency Data Transfer
LoRaWAN	: Long Range Wide Area Network
GPRS	: General Packet Radio Service
3G	: 3rd Generation
4G	: 4rd Generation
GHz	: Gigahertz
mA	: Miliamper
ISM	: International Safety Management Code
EMG	: Electromyography

ECG	: Electrocardiogram
SPo2	: Oxygen saturation

1. INTRODUCTION

The advancement of Internet of Things (IoT) technology, has made it possible to connect millions of devices and the Internet. (Atzori et al., 2010). IoT, enriches our lives and provides an easy platform. This technology helps us in many computing-based applications. It provides an integrated environment with many applications such as smart homes, smart cities, various automation and smart wearable devices. So much so that modern health services are thought to be designed with promising technological, economic and social expectations.

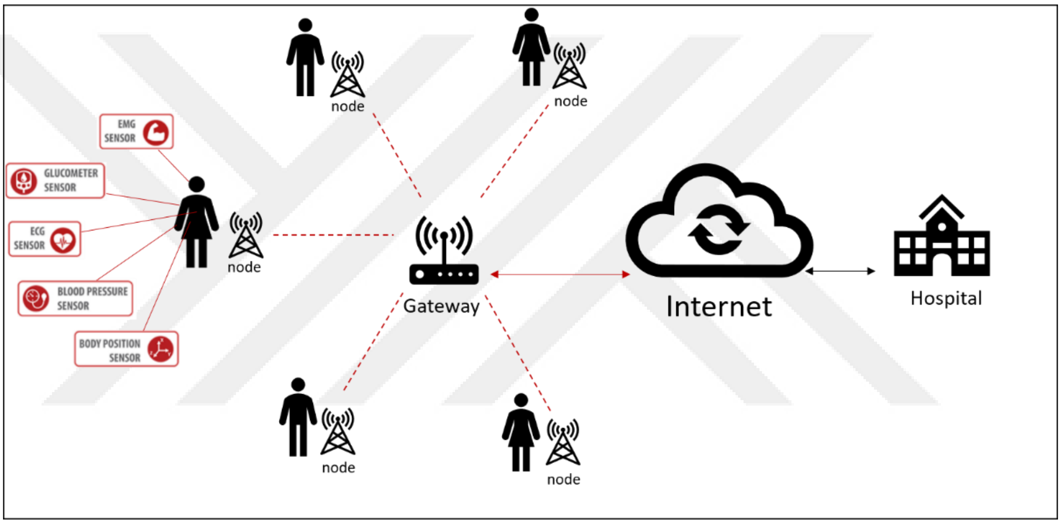

Figure 1. 1 Remote Health Services

Home care services are increasing due to reasons such as transportation difficulties, adverse hospital conditions, transportation of elderly and disabled patients. Home care is an easy and practical method for many people. Healthcare professionals are interested in IoT technology for diagnosis and treatment. Thus, the interest in wearable devices is also increasing. Healthcare professionals can monitor patients remotely with this technology. In this study, it is aimed to transmit vital data such as heart rate, glucose level, blood pressure, electronic heart graphy (ECG) of the patients. Health data of the person can be monitored full time without going to the hospital.

Wearable devices are designed by integrating small sensors into the devices. Today, these devices are low-power and low-loss sensors. Health sensors should also work full time with low memory and low power. At the same time, these devices must have lightweight equipment. Protocols running on these devices should also be lightweight. Accordingly, we preferred the CoAP Observe method (CoRE Working Group, 2014), for these restricted devices to transmit health data. In this study, performance was evaluated using CoAP Observe along with various other protocol stacks.

Observe method, CoAP / UDP / IPv6 / 6LowPAN / 802.15.4 protocol stack given in Figure 1.2 has been studied. A patient monitoring platform has been developed with the protocol stack provided in this study. It is aimed to transmit the vital signs of individuals to health institutions/employees as soon as possible. Performance metrics (energy consumption, latency, reliability, and throughput) were analyzed by the CoAP Observe method. The equipment and methods used are detailed in the sections below.

Figure 1. 2 IoT Layers

2. LITERATURE REVIEW

Studies in the field of IoT health are new and up-to-date. Some of the research and studies in this field are mentioned below. The novelty of this study is the transmission of health data by the CoAP Observe method. It also presents the performance effects of different scenarios of MAC and RDC layer protocols. As far as we know, the transmission of health data with CoAP Observe is not available in the literature.

(Islam et al., 2015) includes a comprehensive review of healthcare services in IoT technology. The authors have provided improvements in the transmission of health data and solutions in health services. At the same time, security requirements and privacy classifications in different IoT networks were evaluated in terms of health services. A security model has also been presented to reduce the vulnerability of individuals. How to benefit from innovations such as wearable devices within the scope of healthcare services was discussed.

In (BİLGİLİ & DEMİR, 2020), It is intended to transmit e-Health data with standard CoAP. Performance effects of MAC and RDC protocols such as CSMA and contikiMAC were investigated. Real-time network simulation (Cooja) has been used with various hardware. Vital health data was transmitted over the 6LoWPAN IoT network. Network topology and various patient (client) numbers are used with E-Health sensors.

Group communication and group description for CoAP is presented in (Ishaq et al., 2016). The CoAP specification treats several CoAP resources as a group, rather than processing one resource separately. According to the identified need, the CoAP group is based on multicast IP for group communication. CoAP requests are available to all group members. At the same time, CoAP is an alternative interface for group management and multicast messages. CoAP Observe relieves Internet users from continuity by observing their resources once clients have subscribed.

Another work in (Christian et al., 2018) is an improvement study on personalized healthcare technology. As a contribution to wearable health technology, a technology that can detect critical events such as heart attacks has been introduced. Adaptive Energy-Efficient Data

Transfer (AED) scheme has been developed that minimizes data transfer from devices. When the simulation results are examined, it shows that AED reduces the transfer percentage by 71.35% for stable data transfer. It is showed that it reduces 30.33% for bulk data transfer.

The use of LoRaWAN technology is suggested in (Mdhaffar et al., 2017). Medical data collected with LoRaWAN low-power network was sent to a test unit with low-power network connections. This test unit has been tested in rural areas where there is no network coverage or data transfer is difficult. It has been applied to chronic patients living in these areas. Glucose, body temperature, and blood pressure values were collected and followed in these patients. It has been examined to see the power consumption of LoRaWAN. Studies have shown that its power consumption is lower than other long-range solutions such as GPRS, 3G, 4G.

2.1. Iot Healthcare Related Works

In (Singh Rajput & Gour, 2016), measurements such as heart rate measurement for heart and diabetic patients were taken as a daily activity through sensors. This data was then saved in cloud technology and shared with others. Shared health data can be accessed via the mobile application. The system architecture is in a layered form: Medical sensors (Physical layer), Gateway layer, IoT Service Platform layer, Mobile-based applications.

In another study (Nguyen et al., 2017), Suggests an IoT Layered Architecture (IoTTA) approach to transform medical health data of IoT-based applications into real-time clinical feedback. This approach includes a 5 layer architecture. These layers are; detection, sending, processing, storage, and data mining. This study aims to develop systems and also helped to develop useful and effective solutions.

In the study in (Filho et al., 2021), The contagion caused by the Covid 19 outbreak highlights the importance of remote healthcare. A platform called IoT-based PAR has been introduced to prevent healthcare professionals from staying under difficult conditions and increasing contagion. This article proposes an alternative method for low-cost components such as Raspberry pi. Simplified cloud infrastructure is presented that provides the services required to implement this method. The data collected, processed, and analyzed is from the intensive care unit of a hospital in Brazil.

3. MATERIALS AND METHODS

3.1. Simulation Environment

In our study, the Cooja simulation environment was preferred due to its ease of use in tests. This environment supports restricted IoT devices. There are many IoT node devices that we want in the Cooja environment. The WisMote device was chosen among these devices. At the same time, Contiki operating system, which can operate in both hardware and software environments, was chosen. Californium COAP application is used to get our data from the IoT environment. The simulation environment has been prepared in a prototype that can be encountered in real life.

3.1.1. Cooja Network Simulator

Building large networks on physical nodes are difficult. Simulators can run faster than real-time speeds while allowing rapid prototyping and testing on large networks (Sehgal, 2013). The Cooja network simulator (Figure 3.1) is a network simulator running the Contiki operating system on the Java platform. This tool can simulate many IoT devices and their wireless communication. It supports multiple node types. The activities of these nodes can be monitored. Also, the serial interface of a node can be displayed. Thanks to all these features and hardware, the Cooja network simulator provides a suitable environment for us to work. In this simulator, 29 nodes and 1 gateway node were studied (Figure 3.7).

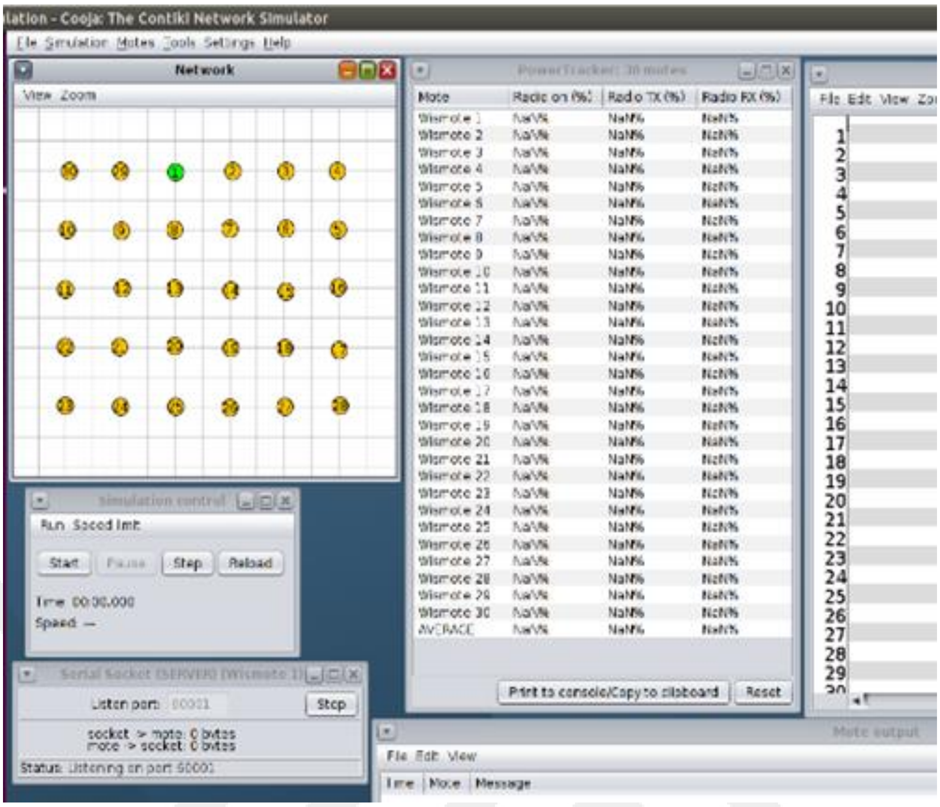

Figure 3. 1 Cooja Network Simulation Environment

3.1.2. ContikiOS

There are many operating systems for constrained IoT devices. Of these systems, ContikiOS runs on the Cooja simulator (Figure 3.1). ContikiOS system is an open-source operating system. It has many network protocol drivers developed under IETF. Allows us to easily change configuration files, MAC, RDC layer protocols. Compatible with a wide variety of IoT devices both in a simulation environment and real hardware. It is a very efficient and comfortable environment for us to work with a complete IP network, memory allocation, 6LoWPaN, RPL, CoAP protocol support.

3.1.3. WisMote

WisMote is a sensor module adapted for IoT applications (Figure 3.1). It works with a wireless connection and 2.4 GHz ISM frequency band. WisMote has a wide variety of built-in sensors. Therefore, it can be used for any physical measurements such as environment, healthcare, home automation, or various applications. WisMote includes an IEEE 802.15.4 protocol stack. It supports the Contiki OS operating system developed for restricted devices and is compatible with Zigbee and 6LoWPAN (IPv6) protocols.

3.1.4. Californium CoAP

Californium is developed in Java. It supports multi-threading. It can run multiple clients independently of each other. It can send and receive CoAP messages. It supports different protocols and is a lightweight application. A border router is used between the Californium CoAP client and the server within the IoT environment. It can also be called a gateway. This is a link between the internet and the IoT. With this gateway, the Californium application can send and receive message packets from a node within the IoT network (Figure 1.2).

3.1.5. Health Sensors And Arduino

The health sensor set from which we received health data was selected as MySignals (Figure 3.2). This set contains many of the sensors we need. It is very practical hardware set due to its ease of use. Ancillary equipment is needed to process the data read from these health sensors. This hardware is usually Arduino (Figure 3.3). The data read in the health kit is processed and sent over the Arduino's serial port.

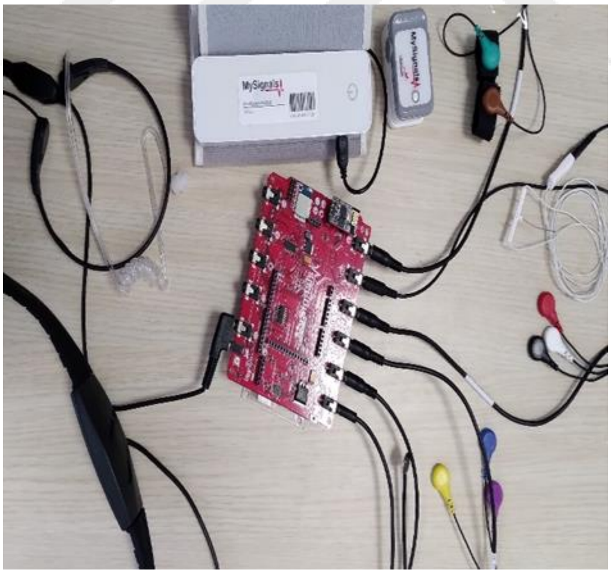

Figure 3. 2 MySignals Health Sensor Kit

Figure 3. 3 Arduino Uno Microcontroller

3.2. Network Stack

The IoT Network stack has a similar structure to the OSI model. In Figure 3.4, the stack on the left shows the LLN (Low-Power and Lossy Network) Internet Stack and the right stack shows the standard traditional Internet stack model. The network stack layers are detailed in the subheadings below.

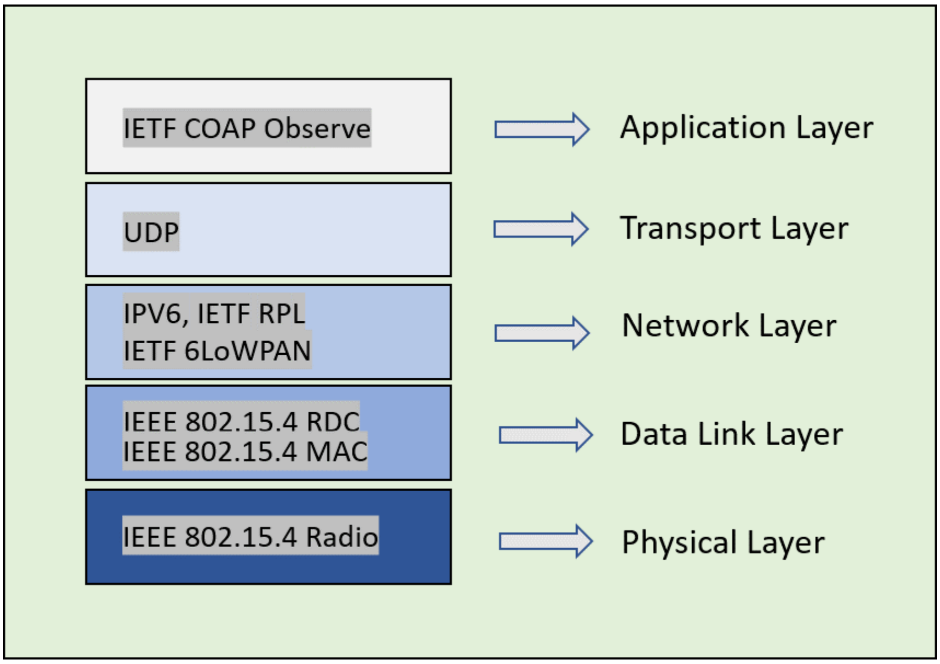

Figure 3. 4 Left side IoT Network Stack, right side OSI Model

3.2.1. Physical Layer: 802.15.4 Radio

IoT devices communicate with each other over the wireless network. Applications can run embedded or external. The IEEE standard 802.15.4 is the physical layer that focuses on low-cost, low-speed, and ubiquitous communication between devices (*IEEE 802.15.4*, n.d.). It offers low-cost communication of peripheral devices with little or no infrastructure or aims to reduce power consumption. IEEE 802.15.4 is a low data rate wireless personal area network and is the PHY and MAC layer used by many IoT protocols such as ZigBee and WirelessHART (*IEEE 802.15.4*, n.d.). This physical layer aims at flexibility and applicability. It is based on low production and usage costs with the integration of typical basic transceivers.

3.2.2. Link Layer: Radio Duty Cycle

There are Radio Duty Cycle protocols for 802.15.4 based applications. There are 2 available RDCs within the Contiki OS operating system used in this study; these are ContikiMAC and nullRDC. Changing batteries is undesirable. Accordingly, although the power consumption of 802.15.4 radios is low, it can still be reduced. Nodes turn on their radios to communicate, and packet exchange remains fairly open, otherwise, it will shut down. We can call this low power listening.

ConitikiMAC is an RDC protocol that sleeps nodes when there is no packet exchange. In this way, the nodes consume less energy. Radio Duty Cycle approaches aim to turn the radio off as much as possible. Always on status of the radio can be possible with nullRDC.

3.2.3 Link Layer: Medium Access Control (MAC)

Contiki operating system includes CSMA / CA (Carrier Detection Multiple Access with Collision Avoidance) and nullMAC. The MAC layer aims to use the same radio environment without collision. When there is traffic, it retracts to avoid collisions. A node first listens for the environment. If there is a transmission in the environment, it waits for a while. When the traffic is detected to be empty, operations such as sending a request (RTS) or sending cancellation (CTS) are performed. If there is no transaction in the environment, the node sends the entire frame. The sending node waits for a confirmation message from the receiver for the correctness of the frame. If there is no confirmation message, collision is assumed. In this case, it waits for a while before retransmitting.

It changes the performance according to the number of nodes in the networks where NullMAC is used. It can be adversely affected in networks with a large number of nodes.

3.2.4. Network Layer: 6LoWPAN

The maximum packet size that the IEEE 802.15.4 physical layer can send is 127 Bytes and the packet length that the IPv6 protocol should send without fragmentation is 1280 Bytes, resulting in an adaptation layer requirement. The 6LoWPAN protocol has been developed to meet these requirements (Palattella et al., 2013). This layer breaks down IP packets into smaller components and compresses packet header portions to fit IPv6 packets into much smaller 802.15.4 chunks (Figure 3.5). The IoT protocol stack, network layer 6LoWPAN, is an acronym for IPv6 over a low-power wireless personal area network.

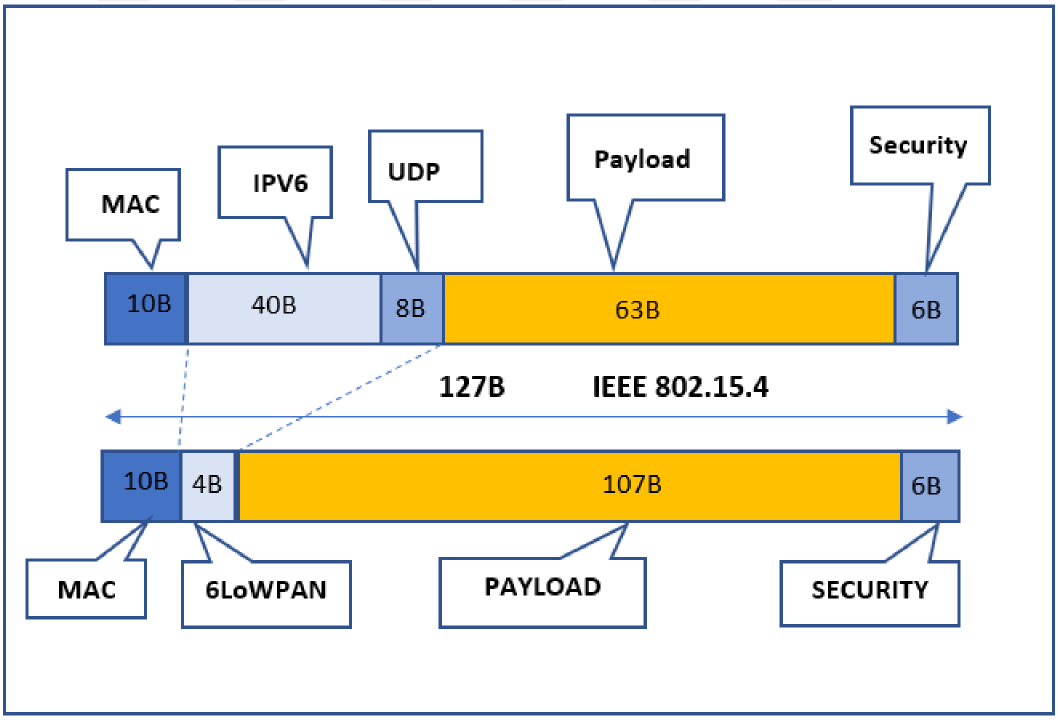

Figure 3. 5 6LoWPAN

3.2.5. Network Layer: Routing Protocol for Low-Power and Lossy Networks

RPL creates a tree-based topology using local links generated by IPv6. In this topology, data flow is from a rooted device to an end device and vice versa. In order to determine the most suitable data flow path, a parameter called rank is used to indicate the location of the devices in the network. In the calculation of rank, algorithms called the objective function and calculate the quality of the road according to a selected parameter are used. For example, Rank can be calculated with the help of a metric that shows the probability of the line to drop packets. The RPL protocol starts with the node designated as the root node spreading the control packets called DODAG (Destination Oriented Directed Acyclic Graph) Information Object (DIO) to the network. The nodes (child nodes) that receive the DIO message compute their rank information using an objective function. Here, the objective function adds a value (link metric) expressing the quality of the channel to the rank value of the node from which the DIO message comes (ancestor node), and this calculated value is determined as the rank value of the child node. The child node adds the calculated rank value to the DIO messages it will broadcast. DIO messages are sent at variable periods using an algorithm called Trickle. When the network is stable, the Trickle algorithm pulls the DIO broadcast period to the maximum value. DIO broadcast period retreats to its minimum value when network configuration starts or when there is a change in network topology. Thus, as long as there is no change in the network, the control traffic is reduced. This characteristic makes RPL a suitable routing protocol for low power networks. With these features, RPL offers an ideal routing protocol for low-power and lossy networks (Almusaylim et al., 2020). In addition, its compatibility with IPv6 reduces the memory needs of the nodes to a certain extent. This makes it the default routing protocol for many Internet of Things applications.

3.2.6. Transport Layer: UDP

UDP (User Datagram Protocol) is the protocol used to transport message packets. Data is sent without establishing a connection between the two nodes. There is no prior agreement for the packages to be sent. In this way, it is aimed to minimize the problem of delivering packages. There is no handshake for the data to be sent in UDP, so transmission is not guaranteed. The main purpose of UDP protocol is minimum network load and minimum protocol weight.

3.2.7. Application Layer: COAP Observe

CoAP has been proposed by the IETF as an alternative to HTTP for restricted devices at the application layer. CoAP is a lightweight basic protocol that can be extended with alternative features. Allows message exchange. Built for application-level resource-constrained networks (IoT networks). Resource-constrained devices are small mechanisms with low processing power. These mechanisms are normally general purpose and low-cost 8 and 32-bit microcontrollers. In addition, they are configurations with TCP / IP stack capabilities and more limited throughput.

CoAP does not work over TCP, it works over UDP. 6LoWPAN is an example of such a constrained network configuration setup. CoAP provides a similar structure to the request and response mechanism of HTTP. Similar to Web, messages are addressed using a port number and IP address.

In the CoAP Observe method, an observation is made between clients and a resource, and the resource status is reported to the client. This is the declared response to the Get request. Then there is no need to send Get requests again. Such notification response should reflect the key (token) specified in the request, and the notification period should also be specified (ie how long the notification will be renewed.). (Figure 3.6). In this study, the notification time was taken as 1000 milliseconds (1 second).

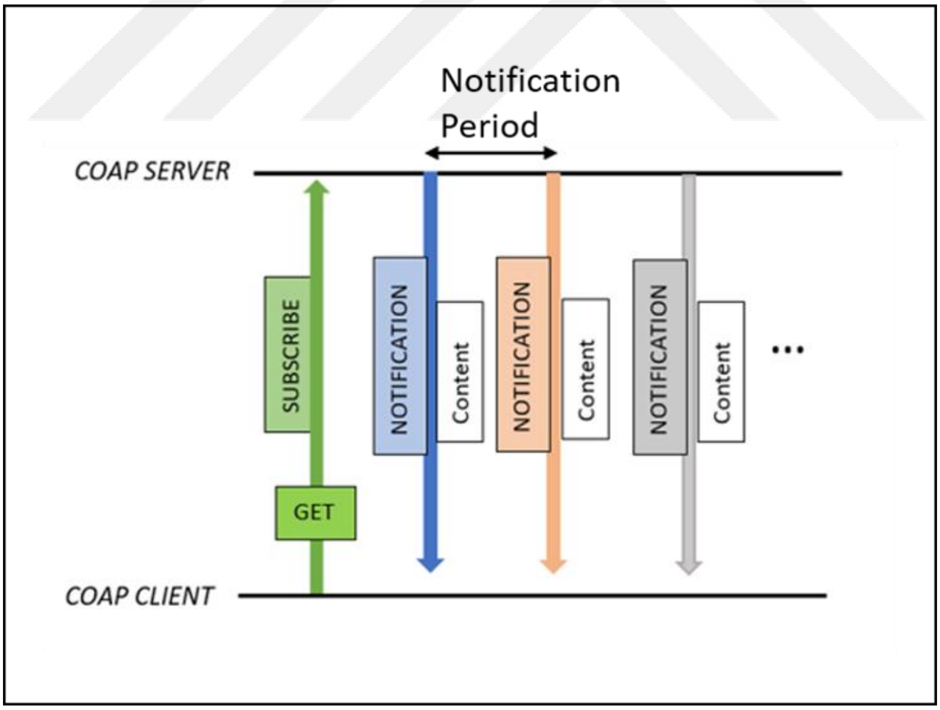

Figure 3. 6 COAP Observe

3.3. Performance Metrics

In the IoT network, four different metrics are chosen to transmit vital data. These four metrics are the most important metrics for remote health monitoring. The definition of these metrics is detailed below.

3.3.1. Latency

One of the important metrics for communicating patient health data is latency. This metric represents the maximum delay in the transmission of packets. In this study, the time between two successful packs was calculated. Delay is very important for critically ill patients. For example, in a person with heart disease, the ECG signal should be received with the least delay. Different scenarios are performed for different patient groups according to the specified delay. Evaluations are given in the Results and Discussion section.

3.3.2. Energy Efficiency

Battery life and energy efficiency are also important criteria in the transmission of health data. Since health data is vital, the transmission will stop in the event of a battery shortage. Since the battery cannot be changed every time, energy must be used efficiently. By calculating the energy consumption, we can reach the information for how long a node can be used.

3.3.3. Reliability

The success rate in packet transmission is defined as reliability. In data transmission, increased reliability is aimed at the number of successful packets. Health data must be submitted accurately and completely. Missing data may cause an important problem in patient follow-up. Packages should be delivered without loss, especially for critically ill patients. In the results section, the number of successful packages and performance analysis according to the clients are shown in the tables.

3.3.4. Throughput

This metric deals with successful packets received from a node over the network. However, the health information given is not to receive data from a single patient. Rather, health information must be sent from multiple nodes at the same time. This is the same in real life. More patients are followed up and more successful packages are expected. This also increases productivity. With this metric, transmission success per node is analyzed.

3.4. System Requirements

4 different scenarios were realized with MAC (CSMA, NullMac) and RDC (ContikiMAC, NullRDC) protocol layers. At the same time, PDR values were tested separately as 100, 95, 90 in the Cooja simulation environment. Performance effects of a total of 12 scenarios according to different client numbers were examined with 4 different scenarios and 3 different PDR values. As seen in the table, in Cooja, the Simulation Speed Limit was chosen as 100%. This is because nodes are close to the real environment value at this value.

Table 3. 1 Simulation Variables

Simulation Variables	**Values**
Simulation Speed Limit	%100
NETSTACK_CONF_MAC	CSMA, NullMAC
NETSTACK_CONF_RDC	ContikiMAC, NullRDC
Packet Delivery Rate	100, 95, 90
Periodic Handler (Notification-period)	1.0*clock second (1000 MS)

We have a data packet of health data obtained from the sensors of the MySignals healthcare kit. The sensors and data lengths (bytes) used are given in Table 3.2. The content of each health data is determined as 64-Byte in total. Each patient has 44-Byte health information consisting of these sensors. 20-Byte is reserved for information such as credentials. These data packets are automatically updated every 1000 milliseconds.

Table 3. 2 Content of Health Data Packets

Sensors	**Bytes**
Body Position	6
Body Temperature	2
Snore Sensor	3
Galvanic Skin Response	8
Airflow Sensor	2
EMG Sensor	2
ECG Sensor	2
SPo2	4

Blood Pressure Sensor	6
Body Scale	2
Glucometer	6
Total of Sensor's Byte	44
Free Space	20
Total of Data Packet	64

3.5. Network Topology

In the Cooja network simulator topology, the gateway node is in the center. As shown in Figure 3.7, a 6x5 matrix is designed for nodes. 29 clients and 1 gateway are positioned as shown. The performance evaluation has been tested in increments from 1 to 29 nodes. This topology is suitable for about 20 meters between them. This topology is thought of as a nursing home or hospital environment.

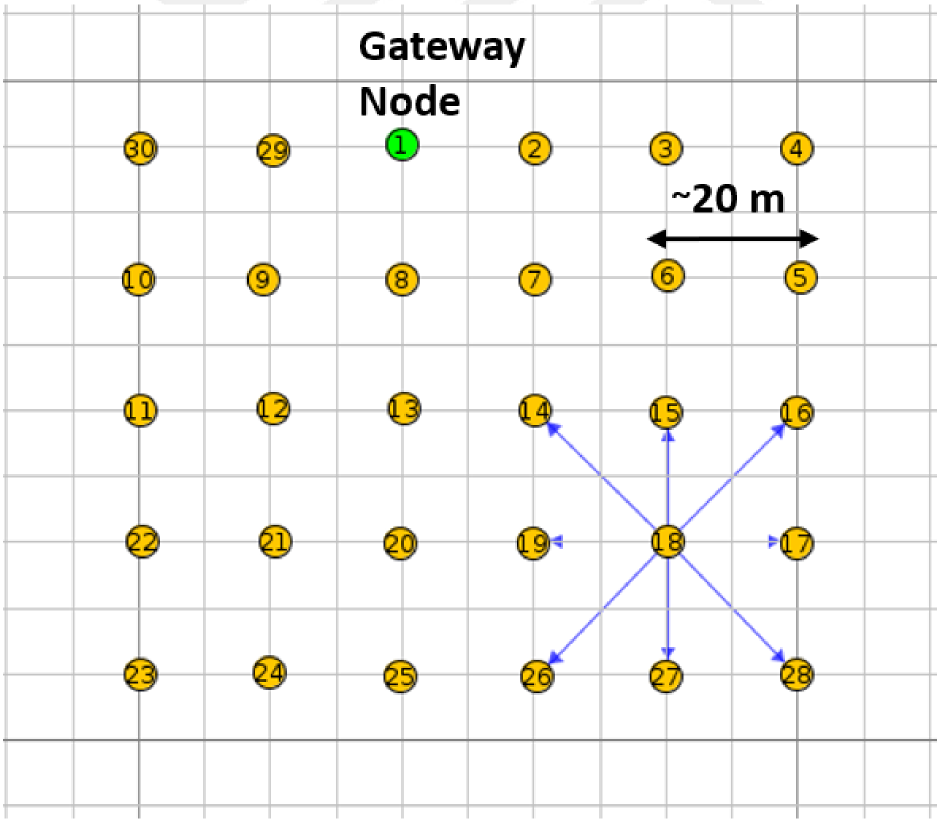

Figure 3. 7 Network Topology

4. RESULTS AND DISCUSSIONS

According to the metrics given in section 3.3. performance results for different scenarios are given.

4.1. Latency

The latency in transmitting health data is very important. Packages need to be renewed within a certain period time, as health data is vital. In this study, when different patient categories were examined, it was stated that the delay between two successful packages was minimal.

The renewal rates indicated in Table 4.1 are information obtained from healthcare professionals (BİLGİLİ & DEMİR, 2020). The areas highlighted in red are the information that should be renewed in 1 minute at the latest. It is the information that needs to be renewed in 15 minutes at the latest, shown in orange, in 30 minutes at the latest in yellow, and in 1 hour shown with a green area. When we compare the results of our study, health information for almost all sensors is provided with minimal delay.

Table 4. 1 Health Sensor Data Collection Interval Threshold Values (in minutes) by Patient Categories

Sensor	Patient Category		
	Critical	Non-Critical	Follow-up
Body Position	30	30	15
Body Temperature	15	30	60
Snore Sensor	30	60	60
Galvanic Skin Response	60	60	60
Airflow Sensor	30	30	60
EMG Sensor	1	60	60
ECG Sensor	1	60	60
SPo2	1	60	60
Blood Pressure Sensor	30	60	60
Body Scale	60	60	60
Glucometer	60	60	60
Patient ID	-	-	-

Thresold 1: 1 minute
Thresold 2: 15 minutes
Thresold 3: 30 minutes
Thresold 4: 60 minutes

Different scenarios according to the data obtained from the simulation are presented in Table 4.2. Four different scenarios were determined with PDR (Packet Delivery Rate). The delay results of implementing by increasing the number of clients (from 1 to 29) are given in Table 4.2.

Table 4. 2 Maximum Delay Between Two Successful Packets (in Seconds)

MAXIMUM DELAY BETWEEN 2 PACKETS												
	nullMAC/ nullRDC			CSMA/ nullRDC			nullMAC/ contikiMAC			CSMA/ contikiMAC		
PDR/ Clients	**100**	**95**	**90**	**100**	**95**	**90**	**100**	**95**	**90**	**100**	**95**	**90**
1	2,04	3,07	2,01	1,56	1,06	1,04	2,01	2,28	21,56	1,48	11,22	16,84
3	2,06	24,97	39,1	2,02	1,08	1,2	2,46	28,7	43,04	52,11	21,63	68,74
5	4,22	51,29	6,4	1,17	3,33	4,16	42,29	35,36	5	50,91	82,32	58,94
7	4,12	67,24	22,01	3,31	3,25	3,13	39,21	6,25	28,95	57,16	59,65	71,38
9	34,32	49,49	25,47	22,07	20,43	17,54	25,21	32,15	4,98	66,79	63,45	70,05
11	66,89	46,34	7,97	32,41	65,24	69,32	67,93	43,85	11,45	54,1	60,64	59,24
13	28,5	14,15	27,02	15,35	31,01	70,82	59,67	27,47	14,61	65,5	79,82	80,06
15	44,05	30,76	11,78	76,33	40,3	78,41	41,97	43,35	44,2	63,49	55,98	63,46
17	55,7	24,14	80,97	72,27	57,4	61,96	60,88	54,05	7,35	33,29	81,04	77,43
19	55	53,8	8,97	70,19	72,45	82,65	73,81	58,46	4,971	66,06	77,35	71,08
21	74,7	51,46	2,32	76,37	66,14	67,75	64,45	33,07	9,76	70,33	72,23	92,85
23	64,62	13,67	3,05	90,32	63,7	75,56	70,69	35,91	57,8	63,94	66,98	70,84
25	93,15	51,32	5,79	80,85	84,6	80,93	66,34	25,94	9,68	64,71	44,15	44,15
27	76,98	32,14	25,68	74,2	141,83	82,63	62,63	39,14	50,8	66,3	59,12	42,43
29	69,85	49,02	3,04	67,04	147,99	77,65	34,35	81,83	38,79	59,89	50,25	60,99

Threshold 1: Under 1 Minute
Threshold 2: Under 3 Minute

As shown in Table 4.2, the results are given using different scenarios at the MAC and RDC layers. According to Table 4.2, the maximum delay between two successful packets is minimum (seconds) in all scenarios. Minimum delay is provided for all sensors, taking into account the emergency and critical condition of the patients. Figure 4.1 shows the resulting graph of the scenario using nullMac and nullRDC. The resulting graph of the scenario using CSMA and nullRDC is shown in Figure 4.2. The resulting graph of the scenario using nullMAC and contikiMAC is shown in Figure 4.3. The resulting graph of CSMA and contikiMAC protocols is shown in Figure 4.4.

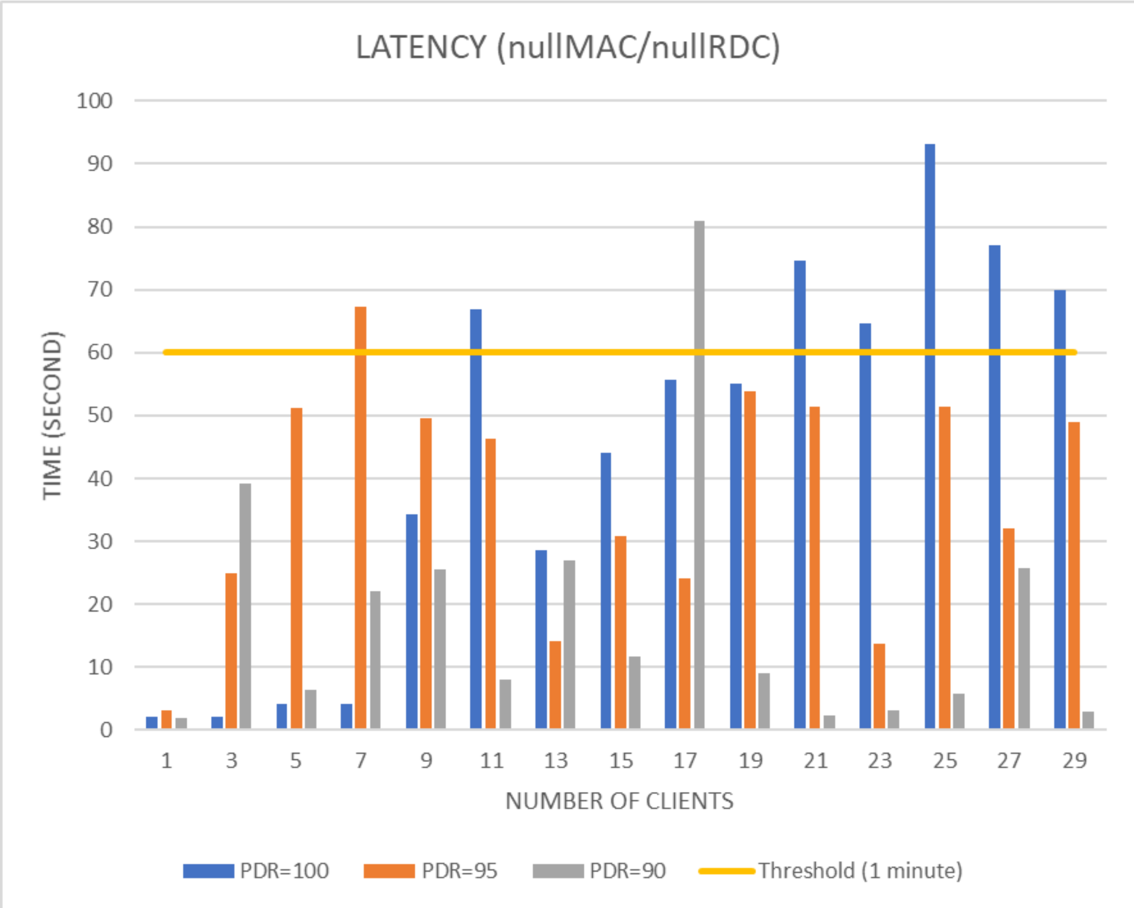

Figure 4. 1 Maximum Delay Between Two Successful Packets nullMAC and nullRDC Protocols

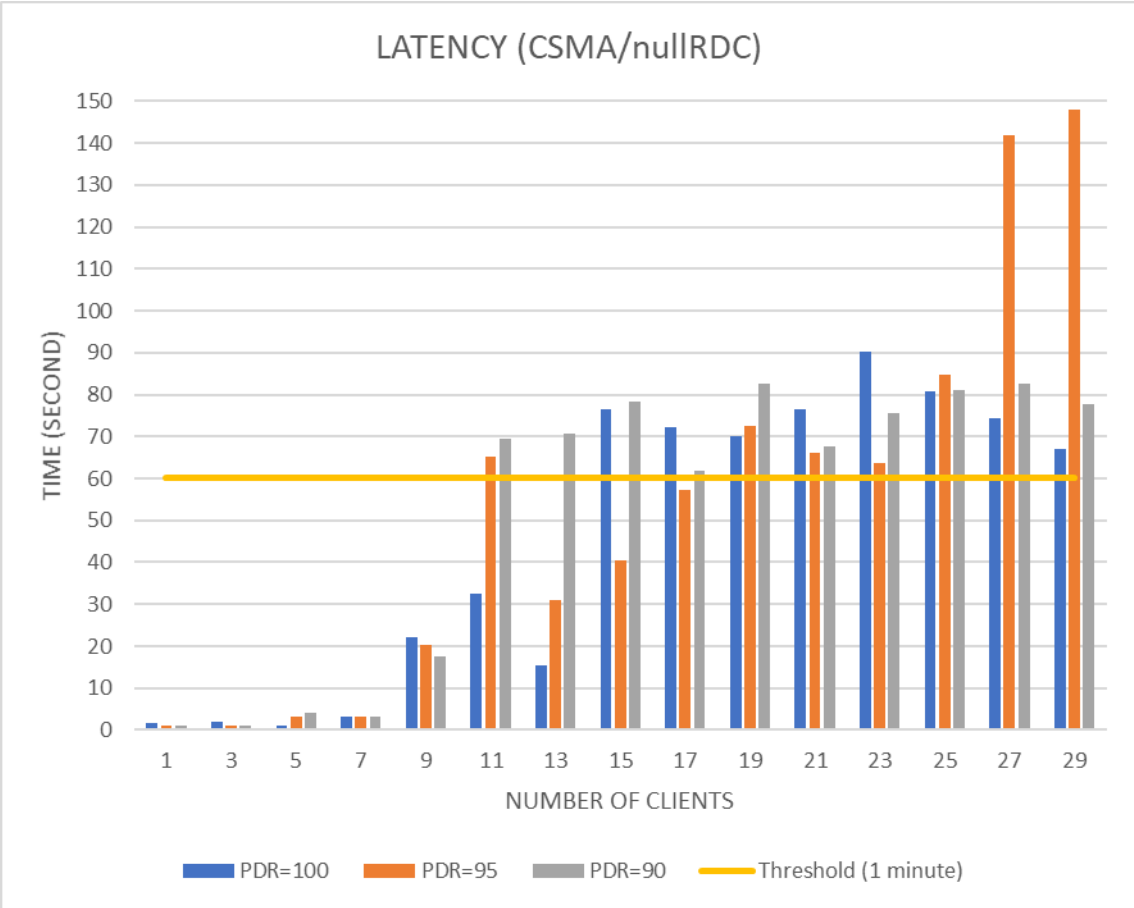

Figure 4. 2 Maximum Delay Between Two Successful Packets CSMA and nullRDC Protocols

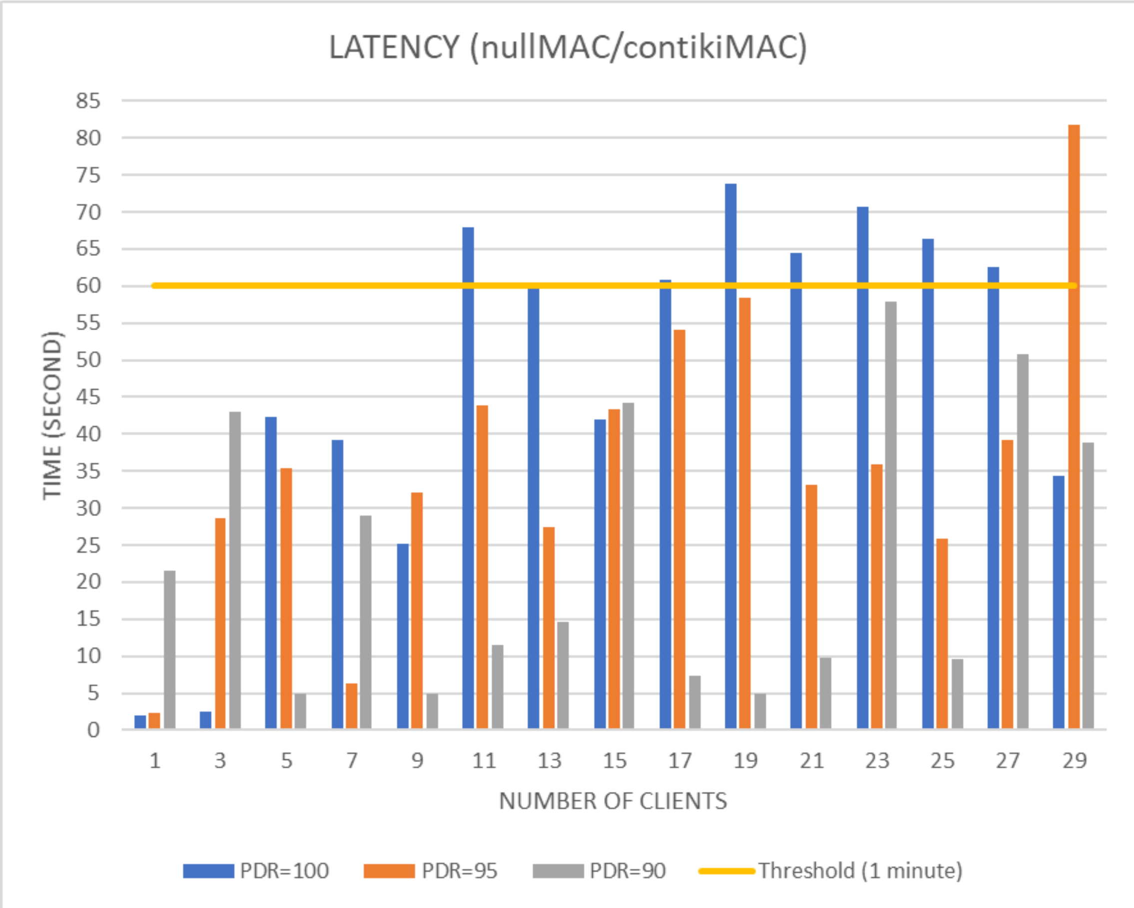

Figure 4. 3 Maximum Delay Between Two Successful Packets nullMAC and contikiMAC Protocols

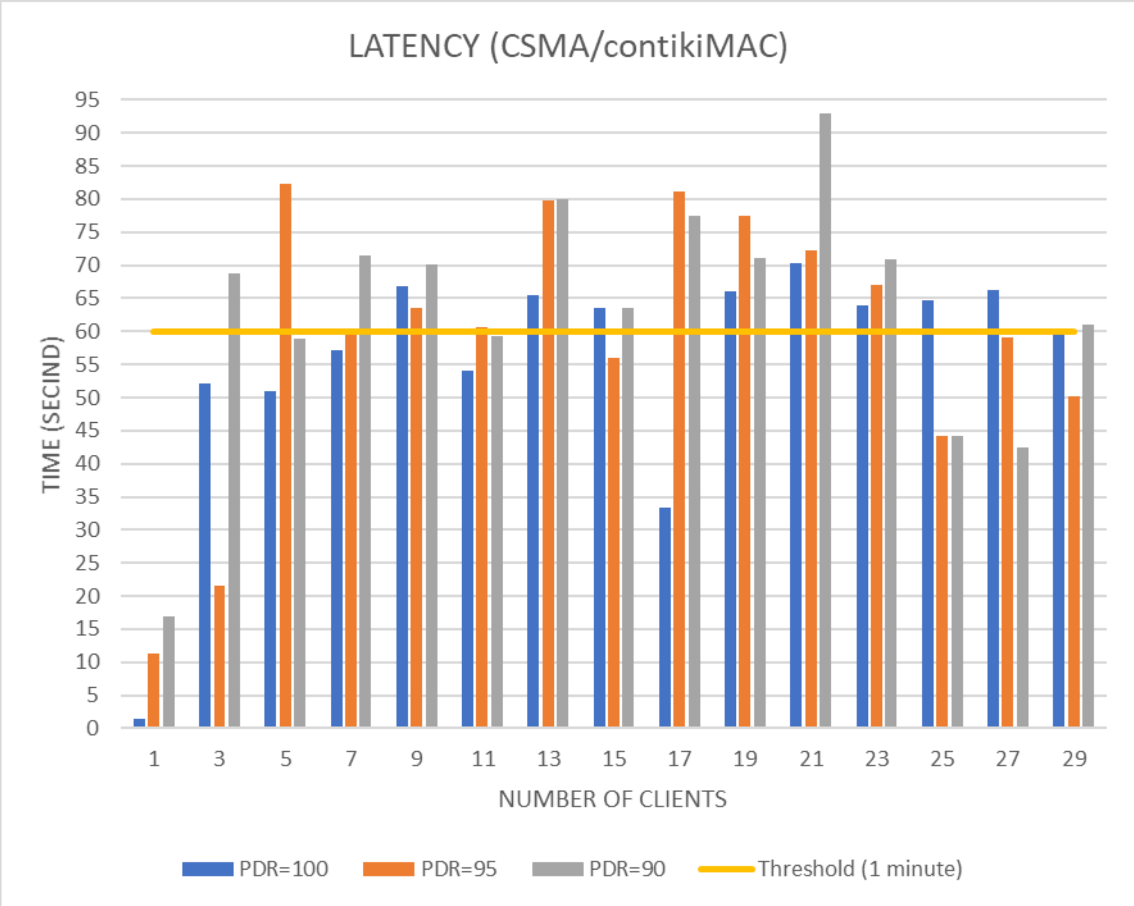

Figure 4. 4 Maximum Delay Between Two Successful Packets CSMA and contikiMAC Protocols

One min threshold was determined for critically ill patients. It was observed that there was an average of one minute delay in all scenarios. As the number of clients increases, it is seen that the latency increases. This is due to increased network traffic.

4.2. Energy Efficiency

The simulation environment has been prepared in the closest way to real life. It uses the WisMote TI CC2520 radio integrated circuit used in the simulation environment. The values given in Table 4.3 are obtained from the datasheet of the relevant radio integrated circuit. The Power Consumption chart gives energy expended per hour (mA). It can be estimated approximately how long the 802.15.4 radio will operate on a single battery.

Table 4. 3 Power Consumption (per hour)

Power Consumption	
Mode	**Radio IC TI CC2520**
Active RX	22,3
Active TX	25,8
Sleep Mode	0,03

Our battery is assumed to be a low-capacity battery. The result given is valid only for data exchange in nodes. Energy consumption of auxiliary devices and equipment have been ignored.

Table 4. 4 Average Energy Consumption (per hour)

	ENERGY CONSUMPTION (mA per hour)											
	nullMAC/ nullRDC			**CSMA/ nullRDC**			**nullMAC/ contikiMAC**			**CSMA/ contikiMAC**		
PDR/ Clients	**100**	**95**	**90**	**100**	**95**	**90**	**100**	**95**	**90**	**100**	**95**	**90**
1	1,32	1,98	3,3	0,66	0,66	0,66	0,06	0,08	0,08	0,07	0,08	0,08
3	3,96	5,94	7,92	1,98	1,98	2,31	0,06	0,07	0,11	0,33	0,31	0,45
5	7,92	9,9	12,5	3,63	3,96	4,95	0,41	0,48	0,6	0,47	0,49	0,58
7	11,9	13,2	21,1	4,95	5,61	6,6	0,68	0,62	0,74	0,82	1,01	1,21
9	13,2	23,8	25,1	6,93	7,92	8,91	0,67	0,79	1,8	1,2	1,05	1,31
11	18,5	23,8	26,4	9,9	12,9	15,5	0,92	1,06	2,2	1,31	2,09	2,26
13	25,7	27,1	29,7	13,2	15,2	17,2	1,21	2,18	4,45	1,31	2,3	2,51
15	27,7	31,7	37	19,9	21,1	23,8	2,92	2,24	4,45	2,96	3,52	3,69
17	33,7	36,3	39,6	23,8	25,1	28,4	4,55	2,74	4,87	3,06	4,21	4,8
19	37,6	39,6	47,5	25,1	27,7	29,7	4,89	3,62	5,2	3,26	5,11	5,32
21	39,6	49,5	52,8	29,7	32,3	36,3	4,91	4,45	5,39	4,49	5,74	5,8
23	39,6	49,5	56,1	36	39,9	46,2	4,82	4,75	5,39	4,58	5,26	5,4
25	39,6	49,5	56,1	39,6	47,5	49,5	4,82	5,82	5,4	5,12	5,6	5,51
27	39,6	49,5	59,4	47,5	49,5	52,8	4,82	5,2	4,6	5,12	5,6	5,71
29	39,6	49,5	59,4	47,5	49,5	59,4	4,95	5,41	4,8	5,14	5,2	5,8
AVG	25,3	30,7	35,6	20,7	22,7	25,5	2,71	2,63	3,34	2,62	3,17	3,36

In the evaluation given in Table 4.4, when the number of nodes increased, energy consumption increased. Moreover, energy usage is high when the RDC protocol is not used. Because when RDC is not used, the radio always stays on and listens. The power consumption of the NullRDC protocol is high. Change in PDR values is also a factor that changes the average. It has been observed that as the PDR value decreases, the energy consumption increases.

4.3. Reliability

It is aimed to transfer health data without loss. According to different PDR criteria (100, 95, 90), four different tables are given according to the successful packages in Table 4.5. According to Table 4.5, successful packages may be less, but when the number of clients is low, full efficiency is achieved.

Table 4. 5 Average Successful Packets

	nullMAC/nullRDC			**CSMA/nullRDC**			**nullMAC/contikiMAC**			**CSMA/contikiMAC**		
PDR/ Clients	**100**	**95**	**90**	**100**	**95**	**90**	**100**	**95**	**90**	**100**	**95**	**90**
1	100	84	22	100	100	100	99	91	95	100	99	80
3	99,66	65,33	15	100	100	100	97,33	90,66	32,33	80,66	76,3	63,33
5	97,4	55	7,4	100	97,4	99	71	59,4	17,6	53,2	51,6	31,8
7	97,85	26,42	4,71	100	99,71	100	45,45	52,84	10,42	46,8	33,2	11,42
9	80,55	28,44	10,44	87,3	89,22	90,66	65,55	34,55	29,22	24,88	10,88	8,66
11	53,09	12,45	7,23	85,9	88,45	87,36	19,36	19,36	14,36	19,81	8,09	8,09
13	45	7,38	5,96	91,38	80	77,2	22,15	13,84	16,3	5,76	5,37	7,3
15	56,86	3,06	2,73	53,13	60,53	37,66	20,53	13,66	18,13	5,66	6	4,73
17	48,05	8,05	2,11	55,35	48,23	40,17	21,64	8,64	15,11	2,05	7	8,29
19	46,89	9,47	2,91	45,42	51,84	51,31	14,1	10,52	9,47	3,21	4,78	9,42
21	40	5,52	3,12	44,9	49,19	31,38	13,14	8,95	15,47	2,57	4,19	6,04
23	38,34	3,04	2,95	39,82	28,78	37,39	6,04	6,86	14,17	3,4	2,17	3,6
25	38,76	7,08	2,91	33,48	30,76	31,04	5,44	7,88	6,72	4,84	3,12	2,84
27	38,7	4,33	2,25	33,1	34,11	28,37	6,7	7,62	6,29	3,92	1,66	3,14
29	24,96	9,55	3,57	34,2	29,65	26,75	8,51	9,86	9,24	4,48	1,5	3,1

According to the results given below, when the PDR is 100 (Figure 4.5), 95 (Figure 4.6) and 90 (Figure 4.7), four scenario results are given. Results can be analyzed easily.

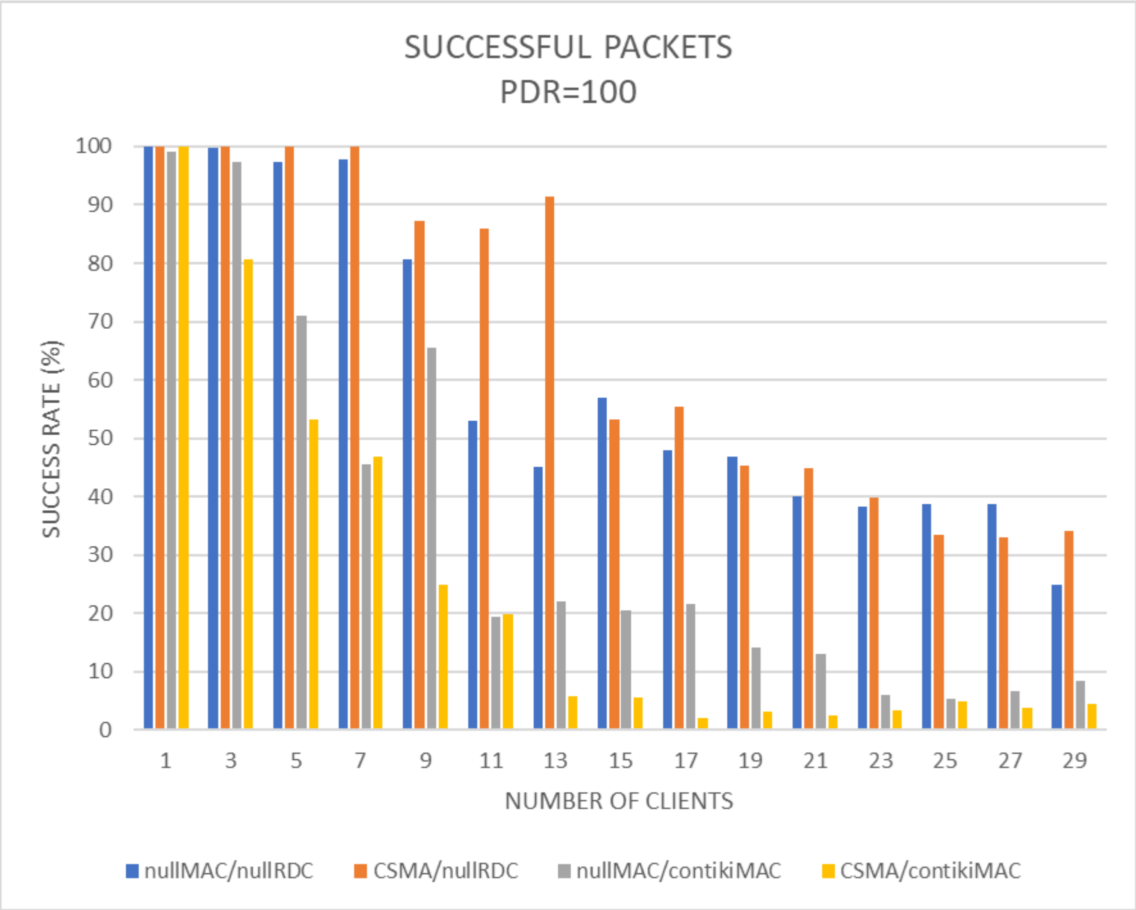

Figure 4. 5 Successful Packets Ratio for PDR 100

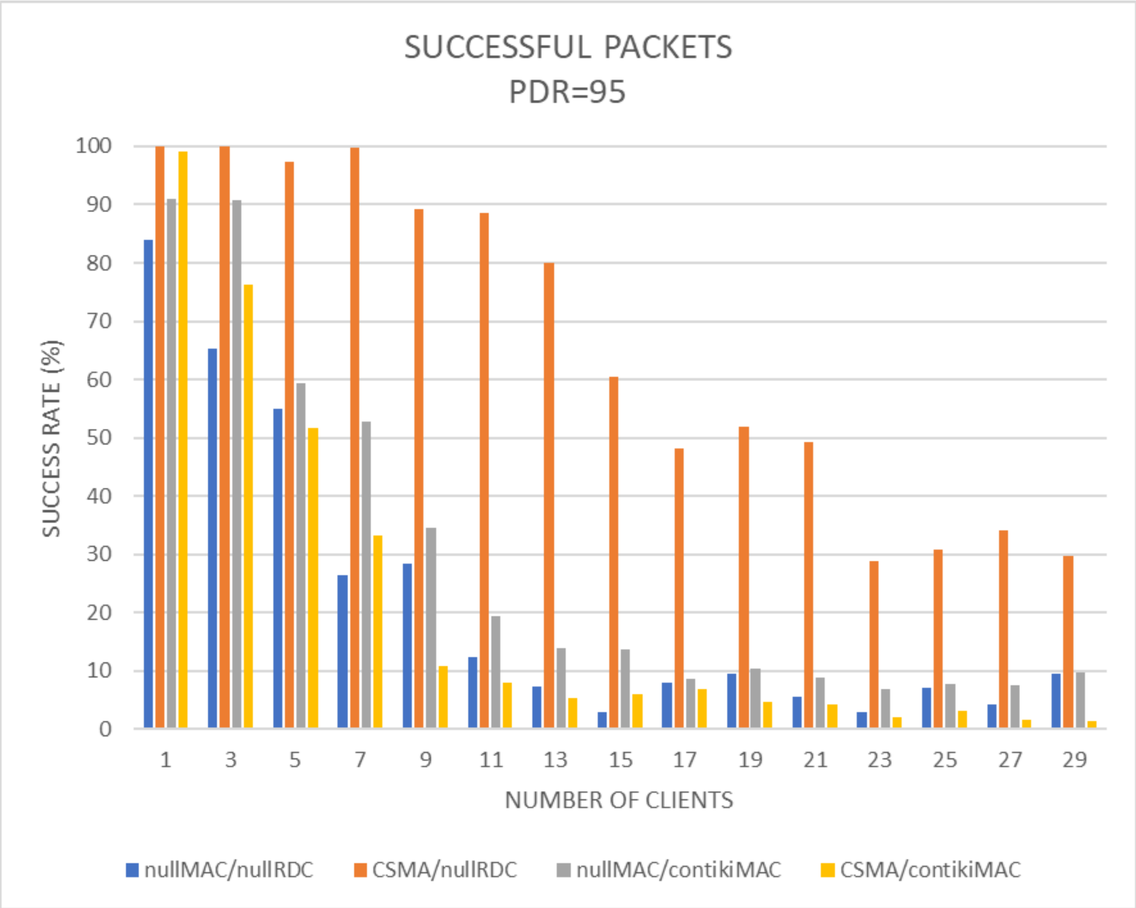

Figure 4. 6 Successful Packets Ratio for PDR 95

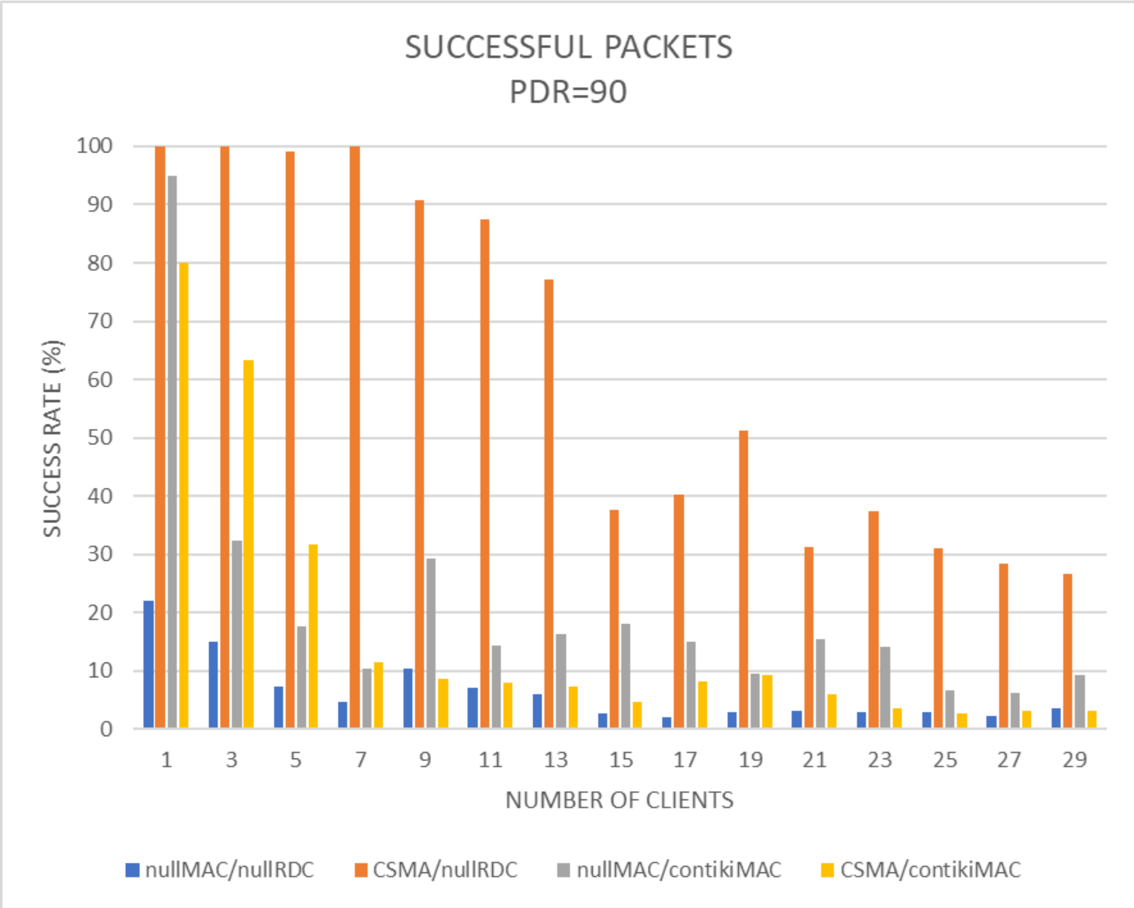

Figure 4. 7 Successful Packets Ratio for PDR 90

As can be seen from the figures, the packets were all transmitted at maximum speed. Transmitted with minimum latency at different PDR values. As the PDR value decreased, the number of transmitted packets decreased.

When the number of clients is at most 5, the number of successful packages is 100% or close to 100% (when PDR is 100). As the number of clients increased, network traffic increased, so lost packets also increased. On the other hand, as can be seen from the table, the highest success rate was obtained in CSMA and nullRDC scenario. This scenario gave the highest performance on all evaluated PDR values. In this metric, the minimum time was targeted and the target was achieved.

4.4. Throughput

Below are different protocol charts of different PDR values (Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11). These values show the number of successful packets reached per minute. When the results are analyzed, as the number of nodes increased, the number of successful packets decreased. When the graphs are examined, the CSMA-nullRDC scenario has shown the best performance. 60 successful packages were reached per minute, and one package was reached every second (Figure 4.9). Efficiency is high when the number of nodes is kept to a minimum in all four scenarios. Since we receive one packet every second, the average number of packets reached per minute has decreased as the number of nodes increases.

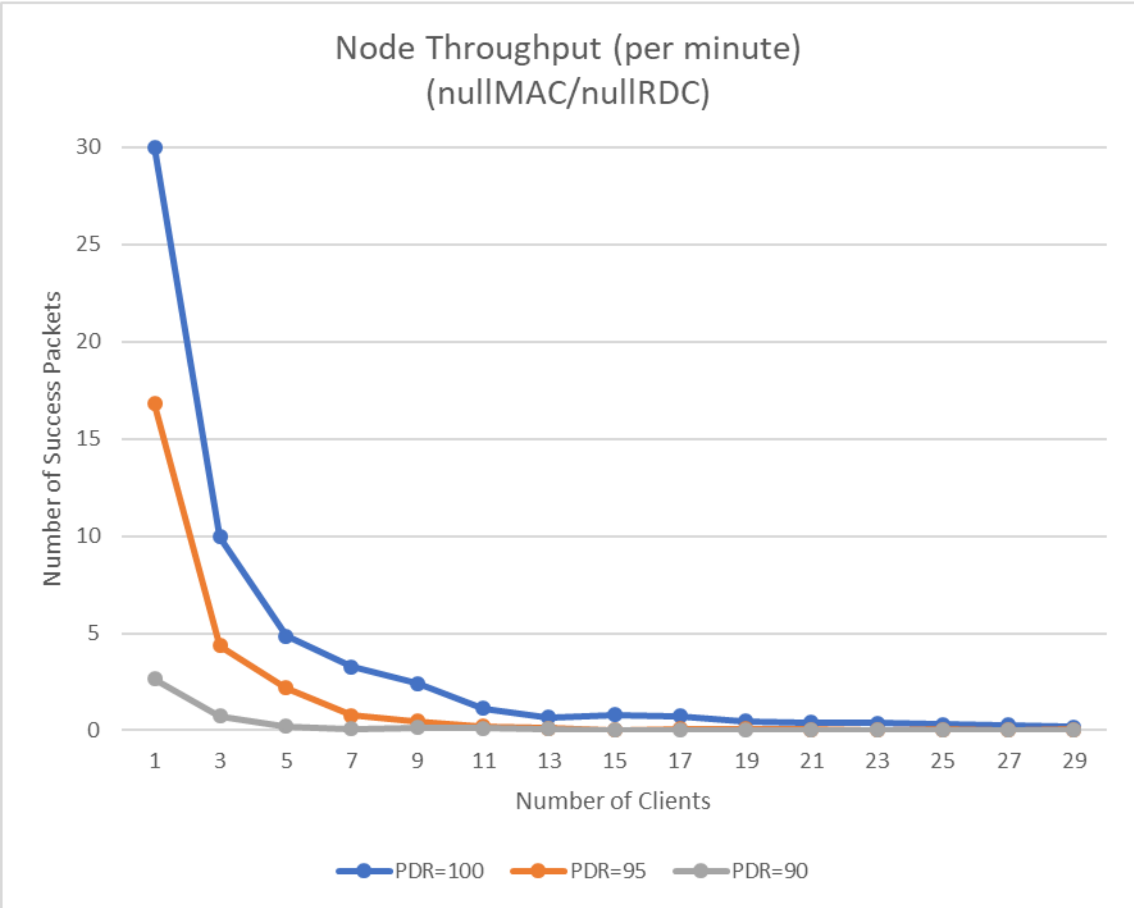

Figure 4. 8 Node Throughput per minute for nullMAC/nullRDC protocols

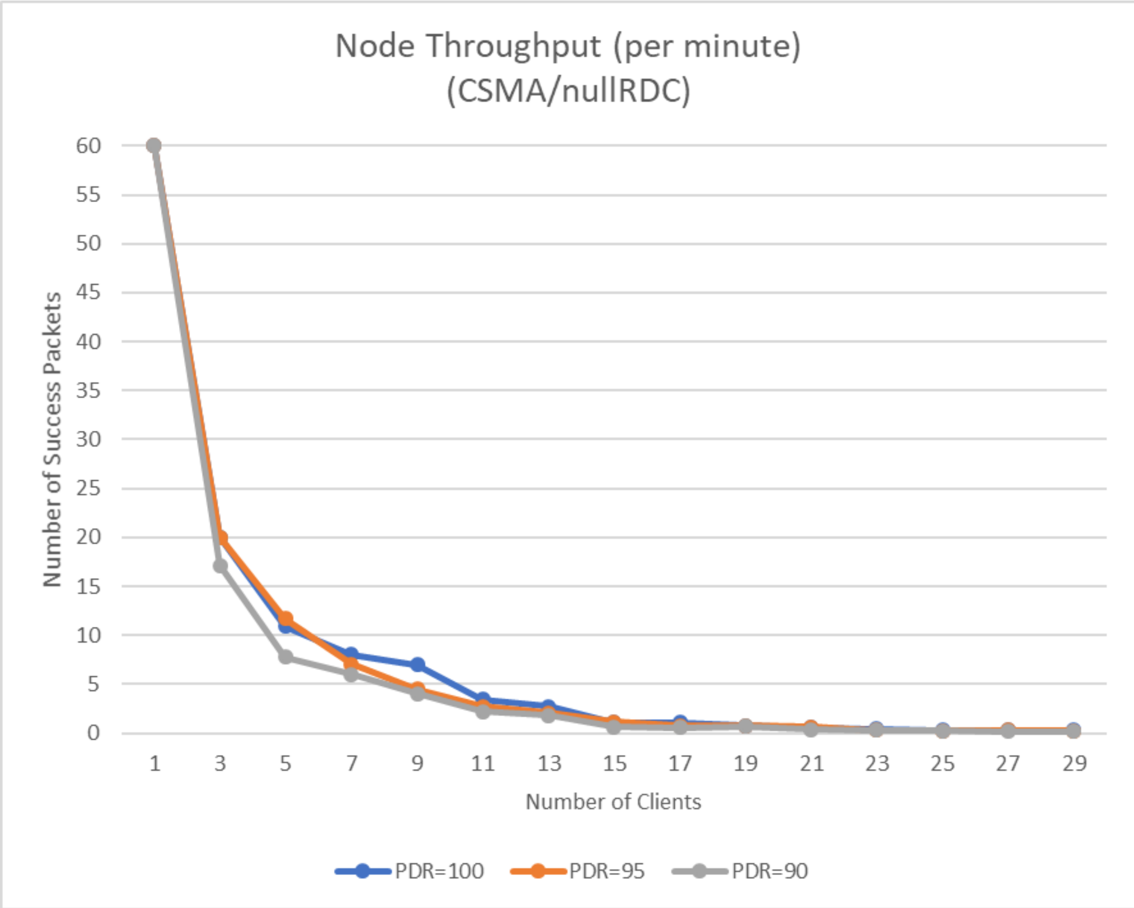

Figure 4. 9 Node Throughput per minute for CSMA/nullRDC protocols

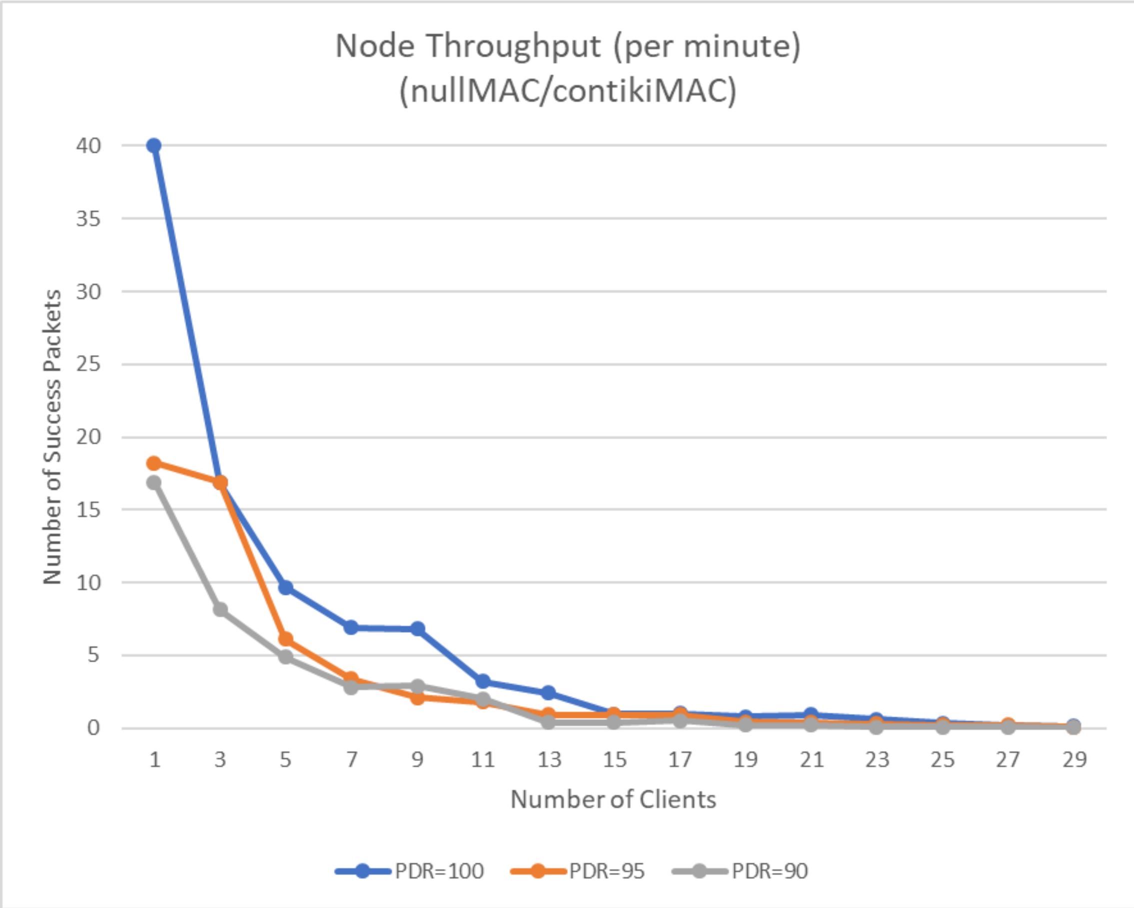

Figure 4. 10 Node Throughput per minute for nullMAC/contikiMAC protocols

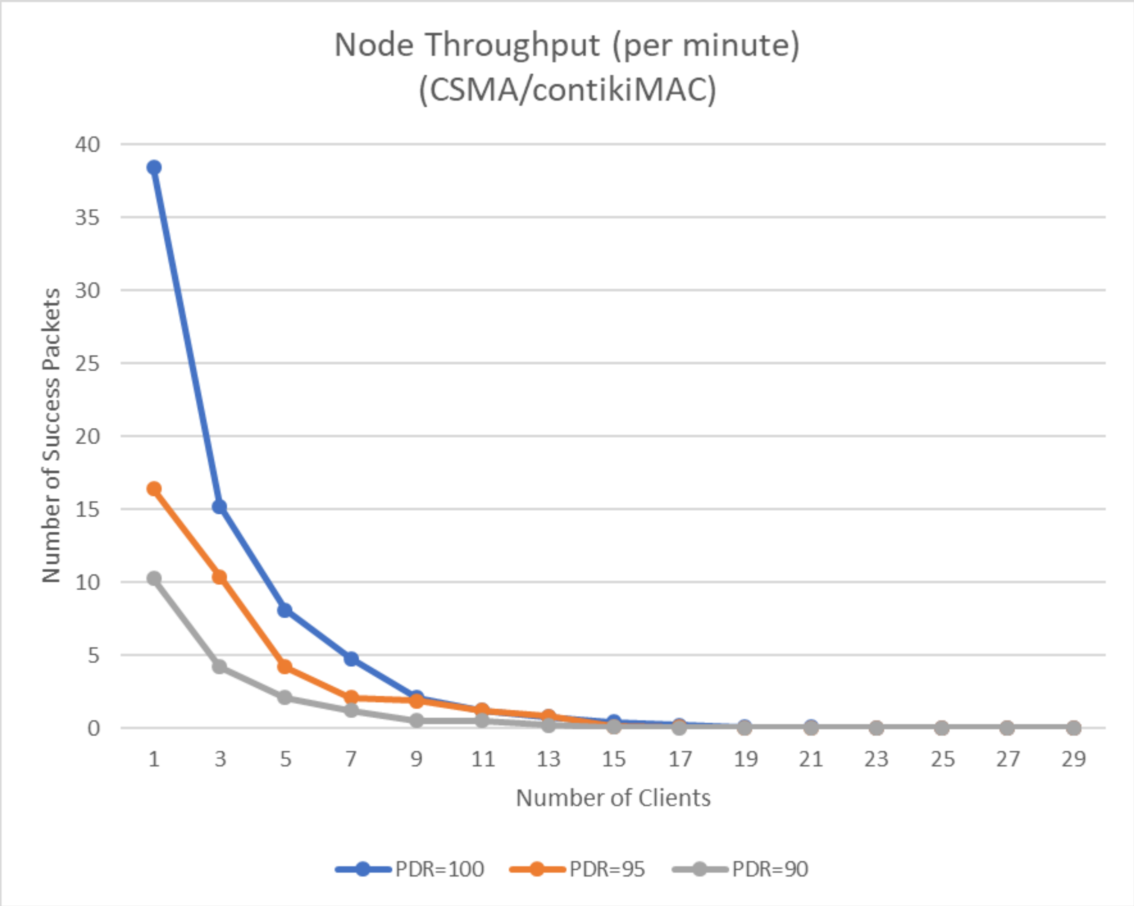

Figure 4. 11 Node Throughput per minute for CSMA/contikiMAC protocols

5. CONCLUSION

In this IoT study, the transfer of health data was made using the CoAP Observe method. Studies in the literature have been reviewed and there has been no study on the CoAP Observe method. With the Observe method, clients subscribe to a resource once and periodically retrieve health information. We have determined this information period of 1 second. Each patient's health data is updated independently of each other every second.

The standard IoT protocol stack is used. Performance evaluations were analyzed in the Cooja simulation environment. The system requirements closest to the real environment are selected. In the Cooja Network simulator, the nodes are designed to be located in the patient care environment. The network topology is designed as rooms that are 20 meters apart. It is designed to have 29 different clients and 1 gateway. Performances are tested increasing from 1 to 29 nodes.

Performance metrics were investigated and the four most important metrics for communicating patients' health information were examined. These are latency, energy efficiency, reliability and throughput. The performance results of these metrics are presented in detail. Among the metrics, the delay yielded the most successful results. According to other studies, minimum delay was achieved in the transmission of health packages. A successful evaluation with an average delay of 1 minute and a maximum of 3 minutes.

When the number of nodes is kept low, success has been achieved in all 4 metrics. This means that the number of nodes can be kept to a minimum when examining critically ill patients. Thus, network traffic is reduced and may be more suitable for critically ill patients. When the performance results are examined, it can be decided which scenario and number of nodes will be used according to the patient category (critical or non-critical).

The CSMA and nullRDC scenario were the most successful among the different scenarios. In this scenario, transmission efficiency is higher for 3 different PDR values (100, 95, 90). While this scenario increased the packet transmission success, it also increased energy consumption. When the RDC protocol is not used, the radio stays on and listening. This means energy consumption. In scenarios where the RDC protocol is not used, the energy consumed per hour (mA) is higher than the scenarios using RDC. As a result, battery life is shortened.

6. FUTURE RESEARCH

We aim to increase successful packages according to the performance results evaluated above. At the same time, we aim to improve other metrics with higher performance. The Congestion Control Mechanism of the CoAP Observe method can be examined. The RPL protocol can be examined in detail. We also aim to examine the performance of this study in the real environment. OpenMote (Figure 6.1) nodes can be used instead of simulation nodes in this target.

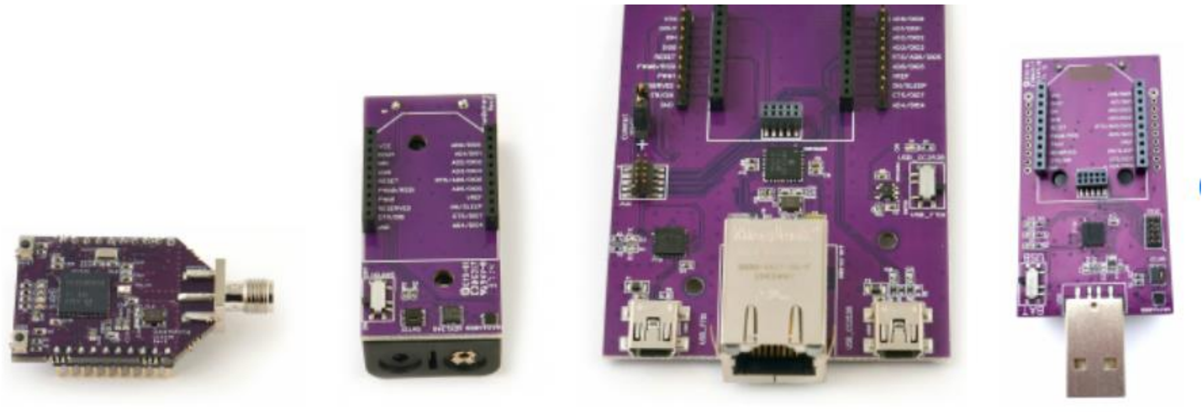

Figure 6. 1 OpenMote Devices

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